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The Light Stability of Silk Adhered to Sheer Silk and Polyester Backing Fabrics with Poly(vinyl acetate) Copolymer Adhesives

by

Irene Frances Karsten ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science

in

Textiles and Clothing

Department of Human Ecology

Edmonton, Alberta

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ABSTRACT

Adhesive backing treatments for the conservation of silk artifacts were evaluated by examining (i) the relative light stability of silk laminates and their components and (ii) the effects of backing materials on laminate properties. Samples were prepared from silk habutae and silk or polyester crepeline adhered with Appretan MB Extra or Lascaux Hot-seal Adhesive 371, both poly(vinyl acetate) copolymer adhesives. Laminates and unlaminated components were exposed to xenon arc radiation and subsequently characterized by measuring colour change, stiffness, tensile properties, and peel strength, and through scanning electron microscopy. Laminates lost tensile properties due to light exposure at the same rate as unlaminated habutae but at different rates than their corresponding backing fabrics. Increases in stiffness of laminates and both components were distinct. Polyester crepeline produced stiffer, stronger, and tougher laminates than silk crepeline. Adhesive type affected the stiffness and peel strength of the laminates, but not their tensile properties.

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CHAPTER I INTRODUCTION

Background

Textile artifacts are a significant part of our cultural heritage. People have used objects and clothing made from interlaced or interconnected textile fibres since prehistoric times. Studying these textiles is essential to fully understanding cultures, past or present. Aspects of technology, aesthetics, dress, and social life can be deciphered from textile artifacts. Although written and pictorial sources can inform us about the role of textiles in a society and about the nature of those textiles and their manufacture, nothing can replace actual textiles as sources of information. Textiles are, furthermore, a source of aesthetic pleasure. Preservation of these artifacts is, therefore, important.

The role of the textile conservator is to care for and treat these artifacts in ways that preserve as much of their physical information and beauty as possible. As they degrade, information from textiles is gradually lost. Fibres become brittle and break apart. Fabrics develop holes or tears; pieces are lost. If the damage is severe enough, the object is no longer understandable as a material culture artifact. The conservator uses proper techniques of display, storage and handling in order to prevent or reduce the rate of further deterioration. When an object is already degraded, however, treatment may be necessary before it can be displayed or handled safely.

Many of the most severely damaged and most highly valued textiles are wholly or partly made of silk. Silk has been prized by numerous cultures for its beautiful lustre and drape, and for the brilliant colours that it can be dyed. But historic silks are often fine fabrics that are susceptible to embrittlement, splitting, fragmentation, and disintegration into dust. The nineteenth and early twentieth century practice of weighting silk with the salts of metals such as tin and iron has resulted in accelerated deterioration of many artifacts. Light is a major cause of the deterioration of both unweighted and weighted silks (Egerton, 1948b).

Justification

The treatment of very brittle silk artifacts is problematic for the textile conservator. Traditional stitching techniques used to support fragile textiles onto new fabric backings cannot be used since stitches cut through the brittle yarns. Stitching is also physically and aesthetically inappropriate for the painted decoration found frequently on brittle silks. Without support, however, brittle artifacts, such as flags and banners, are often confined to storage. Handling or display inevitably causes further damage. As a result, conservators have turned to adhesives in order to attach such artifacts to a support fabric. In most cases the artifact is heat-sealed to a sheer fabric backing of silk crepeline, polyester crepeline or nylon net coated with a thermoplastic adhesive.

Nevertheless, the use of adhesives poses an ethical dilemma. Conservators strive to use only stable techniques and materials that can be reversed or removed completely at any time (International Institute for Conservation-Canadian Group & Canadian Association of Professional Conservators [IIC-CG & CAPC], 1989). Even conservators in favour of adhesive treatments agree that they are never totally reversible in practice (Keyserlingk, 1992; Landi, 1992). Separating a weakened, porous, and fibrous surface from the adhesive polymer in which it is embedded is next to impossible even when a suitable, safe solvent is available. Adhesive treatment may be justified for an artifact that will disintegrate otherwise, but only if the adhesive meets certain criteria. The adhesive must remain stable over time. For conservators this means a product that retains appropriate properties for at least twenty, but preferably one hundred years under museum conditions (Feller, 1994). During this time the adhesive must continue to provide support without substantially altering the visual or mechanical properties of the artifact. It must also not increase the rate of deterioration of the artifact.

The ageing properties of adhesives and their effects on artifacts are only partially understood. Most of the adhesives used in conservation today are synthetic polymers. They have not been in use long enough to provide a clear indication of their long-term stability. Although thorough research has been conducted on the ageing of adhesive films (see for example Down, MacDonald, Tétreault, & Williams, 1992, 1996), very little work has considered the ageing of adhesives in situ on treated artifacts. No studies have focussed on the effect of light degradation on textiles backed with adhesives, although objects prepared for display in this way are exposed to light. Few studies have, like Pretzel (1993, 1997a, 1997b), systematically compared adhesives and backing fabrics as they are used to support artifacts in order to help conservators make informed treatment decisions. Since most historic artifacts are irreplaceable and adhesive treatments are not completely reversible, further research is necessary to ensure that such techniques meet the rigorous expectations of textile conservators.

Research Purpose

The purpose of this study is twofold: (i) to determine whether silk backed with sheer, adhesive-coated fabrics deteriorates in the same manner when exposed to light as its components, plain silk and coated backing fabrics; and (ii) to investigate whether the type of adhesive and backing fabric affect the properties of silk laminates.

Objectives

1. To prepare adhesive-coated backing fabrics and heat-sealed silk-adhesive-backing fabric laminates from the following backing fabrics and adhesives:
    i) silk and polyester crepeline, and
    ii) Appretan MB Extra and Lascaux Hot-seal Adhesive 371.

2. To compare the colour, stiffness and tensile properties of the laminates, plain silk, and coated and uncoated backing fabrics as well as the peel strength of the laminates before and after 86 and 172 hours of exposure to light.

3. To determine whether the type of adhesive and backing fabric affects the properties of the laminates before and after light exposure.

4. To observe and compare laminate and component surfaces before and after light exposure by optical and scanning electron microscopy.

Hypotheses

Part I: Comparison of the Properties of Laminates and their Components

Plain silk versus silk-adhesive-backing fabric laminates. The colour change, stiffness, tensile strength, extension at break, and energy to rupture of plain silk and of silk-adhesive-backing fabric laminates are expected to differ significantly before and after exposure to light. Furthermore, the rate at which changes in these properties occur due to light exposure will differ significantly for plain silk and silk-adhesive-backing fabric laminates. Thus, the interaction of the factors *sample type* and *exposure* will be significant.

Null Hypotheses

1. There is no significant difference between the colour change, stiffness, tensile strength, extension at break, and energy to rupture of plain silk versus silk-adhesive-backing fabric laminates before and after exposure to light ($p \leq .05$).
2. There is no significant interaction between the factors *sample type* and *exposure* ($p \leq .05$).

Silk-adhesive-backing fabric laminates versus their corresponding coated backing fabrics. The rate at which changes in colour, stiffness, tensile strength, extension at break, and energy to rupture occur due to light exposure will differ significantly for silk-adhesive-backing fabric laminates and their corresponding unlaminated backing fabrics. Thus the factors *lamination* (laminated/unlaminated) and *exposure* will interact significantly.

Null Hypothesis

3. There is no significant interaction between the factors *lamination* and *exposure* ($p \leq .05$).

Part II: Effects of Adhesive and Backing Fabric Type on Laminate Properties

Laminates. The type of adhesive or backing fabric is expected to affect the colour change, stiffness, tensile strength, extension at break, energy to rupture, and peel strength of the laminates. Differences before and after light exposure will be significant ($p \leq .05$).

Null Hypothesis

4. There is no significant difference ($p \leq .05$) between the colour change, stiffness, tensile strength, extension at break, energy to rupture, and peel strength before and after exposure to light for laminates having
    i) silk versus polyester crepeline backing fabrics, or
    ii) Appretan MB extra versus Lascaux Hot-seal Adhesive 371 adhesives.

Coated versus uncoated backing fabrics. The effects of the materials observed on the laminates will be compared to the effects recorded for various coated and uncoated backing fabrics. The changes in colour change, stiffness, tensile strength, extension at break, and energy to rupture will differ significantly for samples having different adhesives or backing fabrics ($p \leq .05$). The rates at which these properties change should also differ significantly for the various sample types: the interactions between *adhesive* and *exposure* and between *backing fabric* and *exposure* will be significant.

Null Hypotheses

5. There is no significant difference ($p \leq .05$) between the colour change, stiffness, tensile strength, extension at break, and energy to rupture before and after exposure to light of coated and uncoated backing fabrics having
    i) silk versus polyester crepeline backing fabrics, and
    ii) Appretan MB extra versus Lascaux Hot-seal Adhesive 371 versus no adhesive.
6. The interaction of the factor *exposure* with the factors *adhesive* or *backing fabric* is not significant ($p \leq .05$).

Delimitations and Limitations

Although this study purports to reveal the effects of light exposure on silk treated with adhesive-coated backings, its results may not pertain directly to treated artifacts for several reasons. First, the laminated specimens differ from actual treated artifacts in several ways. The silk habutae is unlike the brittle silk that would be given an adhesive backing treatment since it is new, undegraded fabric. Using new silk circumvented the difficulty in locating and the ethical problems raised by using six metres of naturally embrittled, historic silk fabric. More important, new silk provides a more homogeneous fabric than would a historic silk which has aged under unknown conditions, as is usually the case. Halvorson (1991) found that the physical properties of specimens drawn from historic silks varied so widely that statistically significant effects were difficult to discern. Although accelerated light ageing could have provided a more uniformly embrittled fabric (Halvorson), the time and expense required were too great for this project. Furthermore, since the rate of change of properties diminishes as silk ages (Hersh, Tucker, & Becker, 1989; Lemiski, 1996), changes in new silk due to light exposure would be more dramatic and, as a result, more likely to expose significant differences. Nevertheless, the properties of laminates made up of silk "artifacts" that are less brittle than their backing fabrics may not change in the same manner as those of treated historic silks.

Silk habutae also represents only one type and colour of silk fabric that may require adhesive backing treatment. Since surface profile is an important factor in adhesion (Allen, 1984; Newey, Boff, Daniels, Pascoe & Tennant, 1992), the relatively smooth, flat surface of the plain-woven habutae may give results that are not representative of fabrics with more textured surfaces. The effect of adhesive backing and subsequent ageing on dyes will also not be addressed. Maintaining the colour of a historic artifact is a critical part of that artifact's preservation. However, the degradation of dyes and the role played by dyes in the degradation of fibres is very complex. Individual dyes are affected by factors such as light and pH in different ways. Furthermore, they affect the ageing of fibres--through photosensitization, for example--in individual ways. In order to accurately assess the role played by dyes in the degradation of laminated structures, a large number of dyes would have to be considered. This was not possible in this study. Such research would be more appropriate once the roles of fibre, adhesive, and light are better understood.

Not every adhesive and support fabric used in textile conservation will be tested. Neither will the results of this study be used to rank the chosen materials according to suitability for conservation use. Adhesives and support materials are chosen to meet the requirements of a particular artifact. Availability and the skills and resources of the conservator involved also influence decisions. The materials chosen for this study are those that have been widely employed in the field due to their relatively good working qualities and stability. The adhesives, in particular, have both been included in some form in research studies of adhesive ageing (Down, et al., 1992, 1996) and adhesive testing for textile backing treatments (Pretzel, 1993, 1997a, 1997b).

Due to time constraints and the availability of accelerated ageing instruments, the model "artifact" will not be aged in a manner that closely parallels the type of lighting treated artifacts would be exposed to in a museum setting. Few historic textiles in museum collections are exposed to natural light, the type of radiation that xenon arc radiation most closely matches (Atlas Electric Devices, 1986). More important, ultraviolet radiation is always excluded in museums. Its inclusion in this study breaks with the trend towards filtering all or most UV radiation when testing products for conservation purposes. However, accelerated ageing using UV-filtered xenon arc radiation produces almost no change in the physical properties of plain silk in the time available (Halvorson, 1991; Lemiski, 1996). Given the known stability of the backing fabrics and adhesives on their own, ageing silk laminates for relatively short periods of time under mild conditions would not be expected to produce any major differences. More severe ageing conditions will result in a clear pattern of silk degradation against which the degradation of adhesive-backed silk laminates can be more reliably compared. If these conditions produce no significant differences between the ageing characteristics of plain and backed silk habutae, less severe conditions would be expected to do the same.

Definition of Key Terms

Accelerated ageing denotes any technique used to increase a material's rate of deterioration above that encountered under normal conditions through the manipulation of environmental factors such as temperature, relative humidity, and electromagnetic radiation.

Adherend is the body attached to another body by an adhesive (Shields, 1984, p. 342).

Adhesion is "the attachment of two surfaces by interfacial forces consisting of molecular forces, chemical bonding forces, interlocking action, or combinations of these" (Shields, 1984, pp. 342-343).

Adhesive refers to a material that binds other materials together through surface attachment (Shields, 1984, p. 343).

Backing is a type of textile *support* treatment wherein a fabric is reinforced by the application of a new fabric to one side using stitching or an adhesive.

Bond strength is the force required to break an adhered assembly at or near the adhesive-substrate interface (Shields, 1984, p. 344).

Cohesion refers to the ability of bulk material to resist rupture due to intermolecular forces (Shields, 1984, p. 344).

Colour change or *colour difference* refers to the difference between the colour of a sample and that of a standard as calculated from measured tristimulus values. Three potential causes of colour change are of interest in this study: light exposure, the addition of an adhesive backing to silk habutae, and adhesive coating.

Conservation encompasses "all actions aimed at the safeguarding of cultural property for the future. The purpose of conservation is to study, record, retain and restore the culturally significant qualities of the object with the least possible intervention. Conservation includes...examination, documentation, preventive conservation, preservation, restoration and reconstruction" (IIC-CG & CAPC, 1989, p. 18).

Consolidation is a conservation treatment in which materials, including textile fibres, are impregnated with a natural or synthetic polymer in order to improve structural strength and prevent complete disintegration (Newey, et al., 1992, p. 123).

Crepeline is an exceptionally sheer, plain weave fabric (Tortora & Merkel, 1996, p. 149).

Degradation refers to the loss of desirable fibre properties by such means as heat (*thermal degradation*), ultraviolet or visible light (*photodegradation*), chemicals (*chemical degradation*) and stress (*mechanical degradation*), singly or in combination (Schnabel, 1981, p. 14; Tortora & Merkel, 1996, p. 166).

Delustrant is a pigment (usually titanium dioxide) or chemical used to dull the lustre of manufactured fibres (Tortora & Merkel, 1996, p. 167).

Dispersion refers to a two-phase system wherein one phase is suspended in the other (Shields, 1984, p. 345). The former is called the *disperse phase* and the latter the *continuous phase* (Oil and Colour Chemists' Association, Australia [OCCAA], 1983, p. 158). Adhesive dispersions are often called *emulsions* due to the emulsion polymerisation process by which they are produced. Technically, an emulsion is a dispersion made up of mutually insoluble liquids. Since adhesives of this type usually consist of a solid resin dispersed in water, the term *dispersion* is more accurate. *Latex* is even more precise since it refers to dispersions having water as its continuous phase (OCCAA, p. 158).

Energy to rupture or *work of rupture* is the total amount of energy required to break a specimen (Tortora & Merkel, 1996, p. 637). A measure of a material's toughness, it is calculated by determining the area under a load-elongation curve.

Extension at break is the increase in length of a specimen at the point of failure expressed as a percentage of the original length (Tortora & Merkel, 1996, p. 198).

Facing refers to a conservation *support* attached to the front of an artifact.

Flexibility is the property of textiles of being able to be bent or folded without rupture (Tortora & Merkel, 1996, p. 225).

Flexural rigidity is "a measure of stiffness, where two equal and opposite forces are acting along parallel lines on either end of a strip of unit width bent into unit curvature in the absence of any tension" (ASTM test method D 1388-96, American Society for Testing and Materials [ASTM], 1996, p. 361).

Habutae is a soft, light, plain weave silk fabric (Tortora & Merkel, 1996, p. 260).

Hand refers to the tactile qualities of fabrics including softness, firmness, drapeability, fineness, and resilience (Tortora & Merkel, 1996, pp. 262-263).

Heat-sealing is a method of bonding materials using heat reactivation of a thermoplastic adhesive present on one of the adherends combined with pressure (Shields, 1984, p. 347).

Interface denotes the "contact area between adherend and adhesive surfaces" (Shields, 1984, p. 347).

Laminate refers to the product formed when two or more layers of material (identical or diverse) are bonded together (Shields, 1984, p. 347). In conservation backing treatments, this structure consists of the artifact and the support fabric joined by an adhesive. As a verb, it also refers to the process by which the layers are adhered together.

Lining, as used in this paper, refers to a technique used in paintings conservation wherein a canvas is reinforced on the reverse with a new fabric support applied with an adhesive or resin.

Natural ageing refers to the deterioration of materials resulting from the continuous action of environmental conditions (light, relative humidity, temperature, oxygen or moisture levels, and pollutants) or inherent vice under conditions of normal use.

Peel strength is the tensile force per unit width required to separate the layers of a laminate structure under peel stress (Shields, 1984, p. 350).

Polyester, for the purposes of this paper, is used, as it is commonly used, to refer to *poly(ethylene terephthalate)* fibres, fabrics, and films, rather than as the generic name for polymers containing ester links in the main polymer chain.

Shear deformation or *distortion* is the movement of yarns from a normal 90° interlacement to one at a lower angle. A fabric that has been deformed in this way is skewed (Tortora & Merkel, 1996, pp. 510, 524).

Silk refers to the degummed fibroin fibres procured from the cocoons of the *Bombyx mori* moth larvae and, by extension, to the fabrics made from such fibres.

Stability refers to "the resistance to change in terms of physical or chemical properties" (Feller & Wilt, 1990, p. 37).

Stiffness is resistance to bending (ASTM test method D 1388-96, ASTM, 1996, p. 361).

Support refers to the addition of new material to a generally weak textile artifact (usually to the reverse side), either completely or in patches for reinforcement or protection (Landi, 1992, p. 40). It is also used to indicate the layer of added material itself. *Backing* and *facing* are two forms of support (see *backing* and *facing*). *Encapsulation*, in which a textile is stitched between two layers of sheer fabric, is another. A support technique for display, in which the artifact is attached to a rigid fabric-covered board or frame, usually by stitching or pressure, is called *mounting*. *Lining*, which in paintings conservation refers to a support technique (see *lining*), is not a support treatment in textile conservation. It refers to the insertion of a new layer of material to the reverse side of a textile artifact in order to allow a textile to hang properly, to protect the textile from dust or wear, or to give a tidy finish to the artifact (Landi, p.149).

Tensile or *breaking strength* is the maximum tensile force observed when a specimen is stretched until it breaks (CAN/CGSB-4.2 No.9.1-M90, Canadian General Standards Board [CGSB], 1997a, p. 2).

Wetting refers to the spreading of a liquid over a solid surface.

CHAPTER II REVIEW OF THE LITERATURE

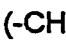
Photochemical Degradation of Silk and Polyester

An investigation into the light stability of textiles treated with adhesive-coated backings requires an understanding of the effects of light on all of the fibres present. This includes the fibres that make up the artifact and those in the backing fabric. A knowledge of the photochemical properties of two fibres is required for the purposes of this study: silk, as artifact and backing fabric, and polyester, as backing fabric. A review of the literature concerning the photodegradation of these fibres follows a brief introduction on their structure and properties.

Fibre Structure

Silk

Raw silk strands from *Bombyx mori* larvae are composed of two filaments of fibroin held together by a sericin gum that is removed during processing. The filaments are smooth-surfaced and translucent with a fluctuating diameter that averages 12 to 30 μm (Hatch, 1993). In cross section they are roughly triangular. Many studies have revealed evidence of a fibrillar structure (Becker, 1993; Lucas, Shaw, & Smith, 1958; Miller, 1986; Miller & Reagan, 1989).

Silk filaments consist of the protein fibroin. Analysis of the amino acid content of fibroin shows that of approximately sixteen amino acids present, glycine, alanine, and serine comprise about 80 to 85% of the total (Robson, 1985). Since these amino acids have small side chains (-H, $-CH_3$, and $-CH_2OH$ respectively), fibroin molecules can pack closely together and form hydrogen bonds between >CO and >NH groups. Studies have suggested that the polypeptide chains of glycine alternating with alanine and occasionally serine are arranged antiparallel in pleated sheets (Figure 1). In crystalline regions, the sheets are layered on top of one another and held together by van der Waal's forces (Robson). Amino acids with bulky side chains, such as tyrosine ($-CH_2$$-OH$), are concentrated in the amorphous regions of the molecules (Lucas, et al., 1958; Robson), although experimental evidence does not preclude their presence in crystalline regions (Lucas, et al.). Overall, fibroin molecules are highly crystalline (about 60%) and highly oriented along the fibre axis (Cook, 1984a; Robson).

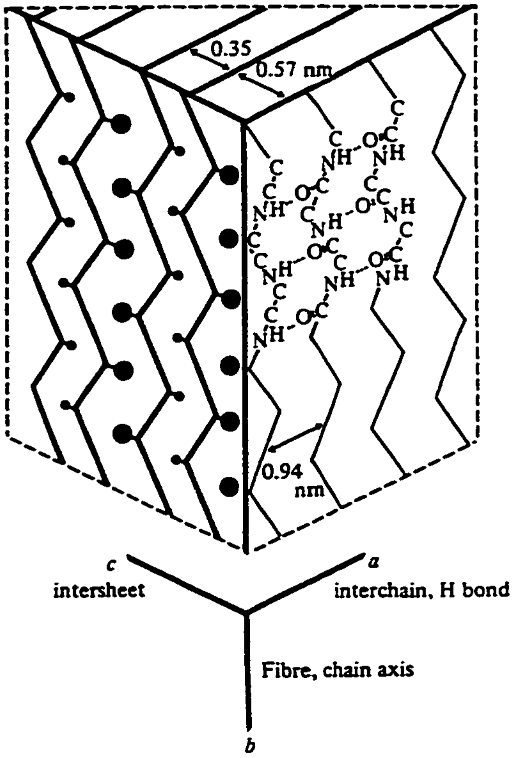
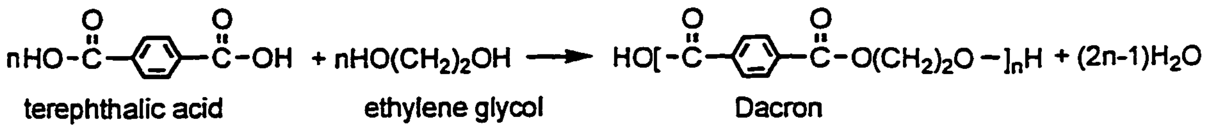


Figure 1. The parallel β-pleated sheet configuration of *Bombyx mori* silk fibroin.
Note. From "Silks--Their properties and functions," by M. W. Denny, 1980. In *The mechanical properties of biological materials. Symposia of the Society for Experimental Biology, Vol. 34*, p. 258. Copyright 1980 by the Society for Experimental Biology. Reprinted with permission.

Polyester

Poly(ethylene terephthalate) (PET), which, as a fibre is commonly known as polyester, is produced from the reaction of either terephthalic acid or the dimethyl ester of terephthalic acid with ethylene glycol (Moncrieff, 1975):



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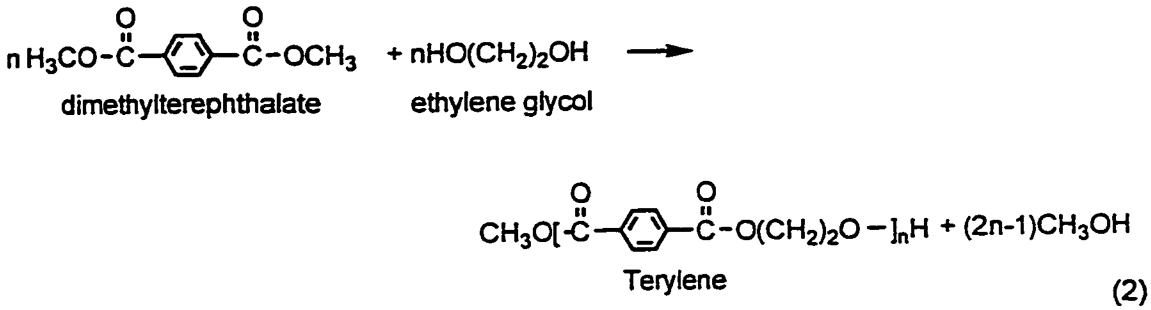


(2)

The polymer, composed of 115 to 140 monomer units, is linear (Hatch, 1993). The polymer chains are nearly planar, and thus can pack closely, held together by van der Waal's forces (Peters, 1963). Fibres are approximately 35% crystalline and 65% amorphous (Hatch). The molecules are generally highly oriented to the fibre axis, even in the amorphous regions (Hatch; McIntyre, 1985). The degree of orientation is dependent upon the amount that fibres are drawn after spinning (McIntyre). Polyester fibres are smooth-surfaced, partially transparent, and usually of a circular cross section, 12 to 25 µm in diameter (Hatch).

Properties

Physical Properties

Both filament fibres, silk and polyester (PET) are similar in tensile properties but distinct in their reaction to moisture (Table 1). Compared to a medium tenacity PET, silk has slightly lower values for tenacity and initial modulus, but its extension at break, yield strain, and toughness are similar. With appropriate methods of spinning and drawing, polyester can be significantly stronger and tougher. In their reaction to moisture, however, the two fibres are very different. Silk fibroin is sufficiently polar to result in water absorption into amorphous regions under humid conditions. Fibres swell (Cook, 1984a) and their mechanical properties change correspondingly (Robson, 1985). In contrast, polyester picks up almost no atmospheric moisture even at very high relative humidities. The moisture regain at 100% RH is only 0.6 to 0.8% (Moncrieff, 1975), compared to 35% for silk (Cook). Polyester is thus more prone to problems related to static electricity.

Table 1. Properties of Silk and Polyester Fibres

Property	Typical Characteristics		
	Silk	Polyester (PET)[a]	Source
Physical			
specific gravity	1.32-1.34	1.38	Hatch, 1993
refractive index	$n_{\parallel} = 1.591$	$n_{\parallel} = 1.72$	Robson, 1985/Cook, 1984b
	$n_{\perp} = 1.538$	$n_{\perp} = 1.54$	Robson, 1985/Cook, 1984b
birefringence	$\Delta n = 0.053$	$\Delta n = 0.18$	
Mechanical[b]			
tenacity	0.38 N/tex	0.47 N/tex	Morton & Hearle, 1993
% loss when wet	8%	0%	Morton & Hearle, 1993
initial modulus	7.3 N/tex	10.6 N/tex	Morton & Hearle, 1993
breaking extension	23.4%	15%	Morton & Hearle, 1993
energy to rupture	59.7 mN/tex	53 mN/tex	Morton & Hearle, 1993
yield strain	3.3%	3%	Robson, 1985/McIntyre, 1985
elastic recovery	medium	high	Hatch, 1993
Sorptive			
moisture regain	9.9-11.1%	0.4%	Robson, 1985/McIntyre, 1985
effect on mechanical properties	high	low	Hatch, 1993
Thermal			
glass transition (T_g) of amorphous polymer	175°C	69°C	Magoshi & Nakamura, 1975/McIntyre, 1985
melting point	175°C(decomposes)	256°C	Cook, 1984a/McIntyre, 1985
thermoplasticity	no	yes	Kroschwitz, 1990
flammability	burns slowly, self-extinguishing, leaves crushable black bead	burns slowly, melts, drips, self-extinguishing, leaves hard grey or tawny bead	Hudson, Clapp, & Kness, 1993
Chemical			
resistance to:			
alkali			
dilute	low	high	Cook, 1984a, 1984b; Hatch, 1993; Harris,1954
concentrated	low	low, if hot	
acid			
dilute	moderate	high	
concentrated	low	moderate	
organic solvent	high	high	
oxidizing agent	low	high	
Other			
sunlight resistance	low	high	Cook, 1984a; Hatch, 1993
biological resistance	moderate	low	Hatch, 1993
electrical resistivity	moderate	high (static is a problem)	Hatch, 1993

[a] medium tenacity [b]at 20°C, 65% RH

Thermal Properties

Silk and polyester (PET) behave differently in response to heat (Table 1). Silk scorches at temperatures above 150°C (Hudson, Clapp, & Kness, 1993) and begins to decompose rapidly above 175°C (Cook, 1984a). Prolonged exposure to heat at elevated temperatures (125-150°C) results in loss of strength and elongation, and intense, rapid yellowing (Hersh, et al., 1989; Kuruppillai, Hersh, & Tucker, 1986; Miller, 1986). The physical changes are accompanied by an increase in the concentration of amino groups and ammonia (Hersh, et al.; Kuruppillai, et al.), and significant losses of the amino acids proline, methionine, and phenylalanine (Miller). Miller observed less severe changes when silk was heated in a vacuum. These results suggest that both chain scission and oxidation are involved in the thermal degradation of silk (Harris, 1934; Hersh, et al.; Kuruppillai, et al.; Miller).

A thermoplastic fibre, polyester (PET) gradually loses strength above 150°C (Hudson, et al., 1993), sticks at 230-240°C (Cook, 1984b), and begins to degrade slowly at temperatures near its melting point of 256°C (McIntyre, 1985). Loss of strength due to prolonged exposure to elevated temperatures is much slower than that of silk. Polyester retains 85% of its strength after 1 month at 150°C (Cook), whereas silk can lose up to 90% after 4 days at the same temperature (Kuruppillai, et al., 1986). Changes in viscosity can indicate degradation at lower temperatures (Mohammadian, Allen, & Edge, 1991). Losses of intrinsic viscosity of up to 80% were measured for PET films at 90°C and 100% RH. Losses decreased significantly at temperatures below the glass transition temperature and in less humid environments. Nevertheless, thermal degradation is most problematic in polymer melts, where even small amounts of oxygen or water can result in chain scission and secondary reactions producing acetaldehyde with deleterious effects on the properties of the final product (Zimmermann, 1984).

Chemical Properties

Polyester (PET) is much more stable to degradation by chemical agents than silk (Table 1). Both acids and alkalies affect silk more severely. Silk dissolves in concentrated acids and alkalies, but resists weak alkalies and organic acids, which are often used for particular effects (Cook, 1984a). It is especially affected by solutions of pH lower than 4 and higher than 8 (Lucas, et al., 1958; Robson, 1985). Polyester is in general more resistant to acids and alkalies although it is degraded by concentrated inorganic acids, and is particularly susceptible to strong alkalies (Harris, 1954; McIntyre, 1985; Moncrieff, 1975). Both fibres are hydrolysed by acids and alkalies, and by each in a different manner (Lucas, et al.; McIntyre, 1985). Acidic hydrolysis is more rapid than alkaline hydrolysis for silk (Lucas, et al.; Otterburn, 1977; Peters, 1963; Robson, 1985) but slower for polyester (Cook, 1984b; McIntyre). Acids attack fibroin molecules randomly along the whole chain, whereas alkalies appear to affect the ends of the chains (Lucas, et al.; Otterburn; Peters). Sulphuric and nitric acids also cause sulfonation and nitration of protein residues (Lucas, et al.; Otterburn; Peters; Robson). Alkalies tends to attack the surface of polyester fibres, resulting in a decrease in diameter or pitting of the surface but in minimal loss in molecular weight of the polymer molecules; whereas acids cause chain scission throughout the molecules, thus lowering the molecular weight (McIntyre).

Polyester is highly resistant to oxidizing agents, while silk is not (Cook, 1984a; Moncrieff, 1975). Reactions in silk are believed to involve oxidation of the side chains or of the amino-terminal residues and breakage of the peptide bonds (Sitch & Smith, 1957; Robson, 1985). Certain oxidizing agents render silk less soluble, an effect due probably to the formation of cross-links (Earland & Stell, 1957; Earland, Stell, & Wiseman, 1960; Lucas, et al., 1958). The same effect is also produced by other chemicals such as formaldehyde (Lucas, et al.; Otterburn, 1977; Peters, 1963; Robson) and alkalies (Robson & Zaida, 1967; Robson). Lucas, et al. noted that the insolubility of fibroin may also be due to the substitution of hydrophobic for hydrophilic groups.

Photochemical Degradation

Silk

Silk is one of the textile fibres most highly degraded by light. Exposure results in loss of mechanical properties such as tensile strength, extension at break, and work of rupture (Becker, 1993; Egerton, 1948a, 1948b; Halvorson, 1991; Harris, 1934; Hersh, et al., 1989; Kuruppillai, et al., 1986; Lemiski, 1996; Miller, 1986; Tsukada & Hirabayashi, 1980). Undyed silk also yellows (Becker; Becker & Tuross, 1994; Halvorson; Hersh, et al.; Lemiski).

Influence of oxygen. Although the mechanism of light degradation is not fully understood, the process appears to involve oxidation. Harris (1934) reported that silk skeins exposed to sunlight for four months in a vacuum or in hydrogen lost no strength, while those exposed in oxygen did. Egerton (1948a) confirmed the importance of oxygen by comparing degradation due to exposure to mercury lamps in atmospheres of carbon dioxide, nitrogen, oxygen, and air. Loss of strength was greatest in oxygen and similarly high in air. Almost no strength was lost in the carbon dioxide and nitrogen environments. Further study revealed higher strength losses for tin-weighted silk exposed to sunlight at higher partial pressures of oxygen (Egerton, 1948b). Indirect evidence of oxidation comes from the production of ammonia nitrogen as a result of photochemical degradation. Several studies report increases in the amount of ammonia nitrogen in silk upon exposure to light (Becker, 1993; Becker & Tuross, 1994; Harris, Hersh, et al., 1989; Kuruppillai, et al., 1986; Miller, 1986). Harris has argued that the rate of ammonia production from the degradation of proteinaceous materials is accelerated by oxygen.

Oxidation of polymers is usually initiated by the formation of free radicals that are capable of reacting with oxygen (Schnabel, 1981). In photolysis, light energy is sufficient to induce an excited state in a polymer molecule or side group which can either dissociate or react with another species to form free radicals.

$$R_1\text{-}R_2 + h\nu \rightarrow R_1\cdot + R_2\cdot \tag{3}$$

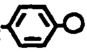
The free radicals then react with oxygen to form peroxy free radicals. Also formed are hydroperoxides, which decompose in light of wavelengths under 300 nm to form yet more free radicals (Schnabel, p. 114):

$$R\cdot + O_2 \rightarrow ROO\cdot \tag{4}$$

$$ROO\cdot + RH \rightarrow ROOH + R\cdot \tag{5}$$

$$ROOH + h\nu \rightarrow RO\cdot + \cdot OH \tag{6}$$

The presence of free radicals can lead to chain reactions on the polymer molecule that may result in the alteration of side groups or chain scission. Although many polymer molecules absorb only light of short wavelengths, impurities in the polymer can initiate the autoxidation cycle by absorbing near UV or visible light and forming free radicals (Schnabel).

Importance of tyrosine. One of the major sites for the oxidation of fibroin is the tyrosine side group (-CH_2--OH). Oxidation alters the structure of the residue, introducing acidic groups so that tyrosine is no longer detected in amino acid analysis (Sitch & Smith, 1957). Rutherford and Harris (1941) showed that losses in tensile strength of silk corresponded to decreases in tyrosine content. Altering the hydroxyl groups on the tyrosine residues through methylation or by reaction with bases reduced the rate of loss of breaking strength, by preventing oxidation. Okamoto (in Lucas, et al., 1958) studied the light degradation of fibroin amino acids separated by chromatography and found that tyrosine was one of three most highly affected, the other two being threonine and leucine. More recent research (Becker, 1993; Becker & Tuross, 1994) has confirmed the importance of tyrosine. Of all the amino acids in fibroin, tyrosine was lost most rapidly from undyed silk habutae exposed to three levels of xenon arc radiation: through quartz-quartz, borosilicate-borosilicate, and borosilicate-soda lime filter combinations with lower wavelength cut-offs of 230, 285, and 300 nm respectively. Samples were exposed for 100, 250, 500, and 1000 kJ/m^2 of irradiation. The loss of tyrosine was linear with increasing exposure for the two milder filter combinations. Light containing the shortest wavelengths resulted in an exponential loss of tyrosine, suggesting a threshold effect related to either wavelength or energy dose. A slight loss of tyrosine due to exposure to 80 AATCC fading units (AFUs, approximately equivalent to 340 kJ/m^2) of xenon arc radiation through borosilicate-soda lime filters was also noted by Miller (1986). The loss was not significant, but the total exposure was much less than that in the work by Becker. The pattern of loss due to radiation of the same wavelength is similar, however, in the two studies. The relative amount of tyrosine rises after short exposures (100 kJ/m^2 for Becker and 40 AFUs or 170 kJ/m^2 for Miller) before beginning to fall.

Although tyrosine is thought to play an important role in the photodegradation of silk, other amino acids are also affected by light. Becker (1993) found that lysine, arginine, threonine, aspartic acid, serine, and glutamic acid suffered appreciable losses, with the rate dependent on the level of UV radiation in the light source. Valine, leucine, isoleucine, glycine and alanine were comparatively stable, though they were also affected by exposure to low-wavelength UV light. Miller (1986) reported significant losses in methionine, proline, valine, isoleucine, leucine, lysine, and phenylalanine. Glycine, alanine, and serine remained stable. Differences in these results may reflect differences in ageing protocol and analytical technique. Miller employed shorter, milder exposures of xenon arc radiation than Becker. In addition, the system of ion-exchange chromatography used by Becker was unable to detect proline and methionine.

Factors affecting the rate of degradation. The rate of light degradation is affected by the total amount of radiation and by the energy level of the dose, which depends on the wavelengths of the radiation emitted by the light source. Changes in physical properties of silk due to light degradation appear to follow first-order kinetics; that is, the rate of change is proportional to the amount of material present (Hansen & Ginell, 1989; Hersh, et al., 1989; Kuruppillai, et al., 1986). Several studies have reported a decreased rate of change in yellowing and tensile properties with increased exposure time (Hansen & Ginell; Hersh, et al., 1989; Horswill, 1992; Kuruppillai, et al., 1986; Lemiski, 1996). This pattern is most visible when exposure is to radiation of shorter wavelengths (Lemiski). In general, faster rates of degradation are related to exposure to radiation of higher energy and shorter wavelengths. Both Halvorson (1991) and Lemiski showed that, for exposures of equal length, the change in colour, stiffness, and tensile properties of silk exposed to xenon arc radiation with no ultraviolet component (lower cut-off at 400 nm) is almost imperceptible while that of silk exposed to radiation through borosilicate-soda lime filters (lower cut-off of 300 nm) is clearly significant. Becker's work with three levels of filtration (1993, Becker & Tuross, 1994) indicated a similar effect with respect to changes in amino acid content and percent solubility of silk. Exposure to ultraviolet radiation is clearly more destructive.

The rate of silk degradation is also influenced by other treatments. Silk treated with acidic solutions loses strength much more rapidly than untreated or alkali-treated silk (Harris, 1934). Rutherford and Harris (1941) attributed this difference to the stripping of cations from hydroxyl side groups on the amino acid residues. As support for this theory, strength loss almost identical to that of the acid-treated silk occurred when cations were removed using electrodialysis. Furthermore, acid-treated silk rinsed thoroughly in distilled water lost as much strength as unrinsed samples, showing that degradation was not due to free acid. When acid-treated or electrodialyzed samples were subsequently treated with bases in order to replace the cations, strength loss was reduced to levels above that of untreated silk. Acid treatments, especially sulphuric acid treatments used to maintain the pH of dye baths and as final clearing rinses, have been suggested as possible factors in the severe degradation of silk flags (Ballard, Koestler, Blair, & Indictor, 1989).

Dyes may increase or retard the rate of photochemical degradation of silk. Egerton (1948a, 1948b) found that dyed silk exposed to sunlight often lost strength to a much greater degree than undyed silk. The effect was especially pronounced in very moist environments. Furthermore, at 100% RH, undyed yarns set within 2 mm of dyed yarns also lost strength more rapidly than isolated undyed yarns. Egerton attributed this effect to a volatile oxidizing agent or peroxide. Some dyes, however, did not affect the strength loss of silk.

Weighting with metal salts also increases the rate at which silk degrades in light. Horswill (1992) and Lemiski (1996) exposed weighted and unweighted silk to xenon arc radiation for up to 720 or 160 hours respectively. Both found that the weighted samples yellowed and lost tensile strength faster than unweighted silk when exposed to light with an ultraviolet component. Lemiski also reported more rapid changes in extension at break, energy to rupture and stiffness of weighted silk. Filtration of ultraviolet light reduced the rate of change of colour and stiffness to the levels of unweighted silk. However, weighted silk exposed to filtered light still showed a significant decrease in tensile properties by the end of the full ageing period (Lemiski).

Metal salts are thought to act as catalysts of photochemical reactions (Robson, 1985). Certain metal ions speed up the process of autoxidation by inducing the decomposition of hydroperoxides to form free radicals through redox reactions (Schnabel, 1981, p. 194):

$$\mathrm{ROOH} + \mathrm{Me}^{n(+)} \rightarrow \mathrm{RO}\cdot + \mathrm{Me}^{(n+1)(+)} + \cdot\mathrm{OH}^{(-)} \tag{7}$$

or

$$\mathrm{ROOH} + \mathrm{Me}^{(n+1)(+)} \rightarrow \mathrm{ROO}\cdot + \mathrm{Me}^{n(+)} + \mathrm{H}^{(+)} \tag{8}$$

The effect may depend on particular metals. Robson noted that copper and nickel nitrate, for example, inhibit photodegradation. As long as hydroperoxides are present, metal ions may catalyze the oxidation of fibroin in the absence of light. Weighted silks are known to degrade in the dark (D'Olier & Mack, cited in Halvorson, 1991). Egerton (1948b) has questioned the role of peroxides in the photodegradation of tin-weighted silk, however. Weighted silk yarns did not produce the degradative effect on adjacent, unweighted yarns at short distances that dyed yarns could in humid environments. If the effect of metal salts is only to speed up oxidation reactions that also occur in their absence, then unweighted silk should degrade to the same degree given sufficient exposure. Lemiski's observation that the total loss of tensile properties of unweighted silk approached that of weighted silk with increased exposure (1996) supports the idea of a catalytic role. Indeed, the degree of degradation of an artifact is not an infallible indicator of the presence of metal salts. Many highly deteriorated silk fabrics, especially those used for flags, are not weighted (Ballard, et al., 1989; Lemiski). Since the degradative effect of weighting on silk is not limited to the effects of light, however, the deterioration mechanisms may involve a complex interplay among several factors. Van Oosten (1994) has suggested other factors that may contribute to the low strength of weighted silk. Weighting minerals may prevent the reestablishment of hydrogen bonds between fibroin molecules that have been broken by the acidic and alkaline baths used in the weighting process. The minerals may also occupy spaces in the amorphous regions of silk fibres and impede fibre extension. The transformation of the weighting agents from gel-like compounds into crystalline ones may also cause mechanical damage to the fibres.

Other silk finishing techniques may influence the rate of photodegradation. Becker (1993; Becker, Willman, &Tuross, 1995) detected unusually high levels of serine in the amino acid profiles and the soluble extracts of samples from naturally aged silk gowns. She attributed this to the presence of sericin on the yarns. Serine is the major constituent of sericin, the protein that holds the fibroin filaments together when extruded by the silkworm (Robson, 1985). Fabrics with high serine levels also had high tyrosine levels and appeared to be in better physical condition. Thus, residual sericin was considered to play a protective role (Becker, et al.). Brooks and O'Connor (1997) reported historical evidence that degumming techniques were controlled to produce silks of differing sericin levels, and that sericin-rich silks produced more brilliant effects with certain dyes. According to Otterburn (1977), the "boiled-off liquor" from degumming, which holds sericin in suspension, was widely used as a retarding agent that promoted levelling when silks were dyed. Certain silk fabrics, such as georgette, chiffon, and crepe de chine, are woven in the gum (Cook, 1984a). Nevertheless, silks that are not degummed tend to be stiff, dull and somewhat yellowed (Cook; Hudson, et al., 1993; Humphries, 1996). Degumming is, therefore, a standard treatment for bringing out the softness and lustre of silk (Cook; Humphries), and to facilitate final finishing (Hudson, et al.). Fabrics that have not been degummed are considered less durable (Hudson, et al.). Thus, the interpretation that high serine levels are due to residual sericin should be examined more closely.

Research on potential treatments for brittle silk has found that many materials may not inhibit degradation due to light and may even accelerate it. Horswill (1992) found that many commercial antioxidants may retard the rate of strength loss somewhat, but increase the rate of colour change. Similarly, Becker, Hersh, and Tucker (1989) found that few commercial stabilizers reduced the degradative effects of light on the colour, strength, and ammonia content of silk. Silk consolidated with Paralene C (polychloro-*p*-xylylene) yellows more severely and loses strength at the same rate as plain silk when exposed to UV-containing light (Halvorson, 1991; Hansen & Ginell, 1989).

Polyester

Although more resistant than silk, polyester is embrittled by exposure to light. The tensile strength and extension at break of fibres or films decreases (Day & Wiles, 1972a; Horsfall, 1982; Tweedie, Mitton, & Sturgeon, 1971; Wall & Frank, 1971). The effect can be superficial and result in surface cracking of exposed films (Blais, Day, & Wiles, 1973). Unlike silk, yellowing is not usually associated with the photodegradation of polyester (Day & Wiles, 1972b). The exposed polymer does exhibit loss in intrinsic viscosity, which is interpreted as loss in molecular weight (Day & Wiles, 1972a; Mohammadian, et al., 1991).

Factors affecting the rate of degradation. The rate of polyester degradation in light is affected by the nature of the light source. Studies have shown that minor differences in the emission spectra of light sources, especially in the UV range, can result in different rates of strength loss (Tweedie, et al.,1971; Wall & Frank, 1971; Wall, Frank, & Stevens, 1971). The level of short-wavelength UV radiation is also a factor. Using cut-off filters, Day & Wiles (1972b) showed that little loss of tensile properties or molecular weight occured in light of wavelengths above 315 nm. This is consistent with the theory that light is absorbed primarily by the ester carbonyl groups on the polymer chain (Day & Wiles, 1972a). Carbonyl groups have absorption maxima between 200 and 300 nm (Grattan, 1978; Schnabel, 1981). Thus polyester is stable to exposure to sunlight through window glass, which filters out wavelengths below 310 nm (Horsfall, 1982).

The nature of polyester photodegradation is also dependent on whether oxygen is present. Day and Wiles (1972b) exposed samples of polyester film to mercury arc lamps in air, oxygen, nitrogen, and a vacuum. Those exposed in air and oxygen exhibited loss in viscosity and the production of a fluorescent material. Those without oxygen became insoluble and yellowed. Increases in the concentration of -COOH end groups, a molecular change that parallels changes in physical properties due to light exposure (Day & Wiles, 1972a), occurred in all groups. Further research (Day & Wiles, 1972c) showed that higher levels of carbon dioxide were released from films exposed in air. The authors explained these differences by postulating two levels of reaction. The first, photolytic cleavage, results in the formation of a gel in the absence of oxygen as the radicals produced recombine to form cross-links. The cross-linking of phenyl groups to form a conjugated double bond system may explain the yellowing of these films. When oxygen is present, the radicals react with it instead, preventing the formation of cross-links. Oxidative reactions also result in the formation of hydroxyl radicals from the decomposition of hydroperoxides, as has already been shown (Equation 6). The substitution of these radicals on the phenylene rings to form monohydroxy species can account for fluorescent emissions. The authors have also proposed a reaction sequence that can explain the formation of CO_2 (Day & Wiles, 1972c).

The rate of photodegradation of polyester is also dependent on the presence of a delustering pigment, such as titanium dioxide, in the fibres. Dull polyester fibres degrade more rapidly than bright fibres (fibres without delustrant) (Horsfall, 1982; Wall & Frank, 1971). The effect is increased in humid environments (Horsfall). The pigment acts as a photosensitizing agent, which, in the presence of oxygen and water vapour, gives rise to peroxides or hydroxyl and perhydroxyl radicals which cause oxidative degradation of the surface of the fibres (Allen & McKellar, 1980; Egerton & Shah, 1968). Since the pigments can absorb radiation in the near ultraviolet and visible range, delustred fibres are less stable to sunlight through window glass (Allen & McKellar; Wall & Frank, 1971, Wall, et al., 1971).

Adhesives

The success of a backing treatment depends on the properties of the adhesive that holds the silk artifact to the support fabric. The following section considers theoretical aspects of how polymers function as adhesives. It describes the nature of adhesive polymers in general and of the class of poly(vinyl acetate) adhesives in particular. Finally it examines the results of adhesive testing projects that relate to the concerns of conservation practice.

Adhesion

Adhesion of two dissimilar bodies occurs if they interact when brought into contact (Gent & Hamed, 1990). Interaction strong enough to produce a bond that requires a reasonable degree of force to break it is rare between two solid surfaces (Allen, 1984; Wake, 1982, p. 31). The surfaces of solids are irregular at the microscopic level and even more so at the molecular level. When brought together, the number of points at which molecules from each surface are close enough to allow the formation of bonds at the interface is very small. Applying force may increase the area of interaction but the resulting adhesion will rarely be sufficient to adhere the surfaces together (Allen). Furthermore, some of the applied energy, stored as elastic energy, will break the bonds formed as soon as the load is removed (Wake, p. 31). A material which fills the gaps between the surfaces, interacts with both surfaces and achieves a sufficiently strong and rigid interface between them is required. Such a material is called an adhesive (Newey, et al., 1992; Wake).

Wetting

An adhesive must first wet or flow over the surfaces to be joined in order to interact with them. Wetting occurs while the adhesive is in a liquid state. The adhesive is thus able to conform to the irregular surface of the solid, filling pores and crevices. The extent to which a liquid adhesive flows over a surface depends largely on the interfacial tension, the viscosity of the adhesive, and the nature of the surface.

Relative surface tensions, or the interfacial tension of a system, largely determine the degree to which a liquid wets a solid surface (Jaycock & Parfitt, 1981; Newey, et al., 1992). The forces of attraction between the molecules of the liquid and solid (adhesive forces) must be greater than those between the molecules of the liquid (cohesive forces) in order for the liquid to spread out over the solid surface. In other words, the liquid must have a lower surface tension than the solid. The surface tension is characterized by the angle between the solid and liquid surfaces at the point of contact (Figure 2). A contact angle of 0° occurs with complete wetting while one of 180° indicates no wetting.

The relationship between the free energies of the surfaces in a liquid-solid system at equilibrium have been described by Young and Dupré (in Allen, 1984; Wake, 1982). According to Young's equation,

$$\gamma_{sv} = \gamma_{sl} + \gamma_{lv} \cos\theta \tag{1}$$

wherein γ_{sv}, γ_{sl}, and γ_{lv} are the free surface energies of the solid-vapour, solid-liquid, and liquid-vapour interfaces respectively and θ is the contact angle (Figure 2). The work required to separate the liquid from the solid, the work of adhesion, W_A, is given by the Dupré equation:

$$W_A = \gamma_s + \gamma_{lv} - \gamma_{sl} \,. \tag{2}$$

A layer of vapour coating the surface of a solid results in a reduction of free surface energy called the spreading pressure, π:

$$\pi = \gamma_s - \gamma_{sv} \tag{3}$$

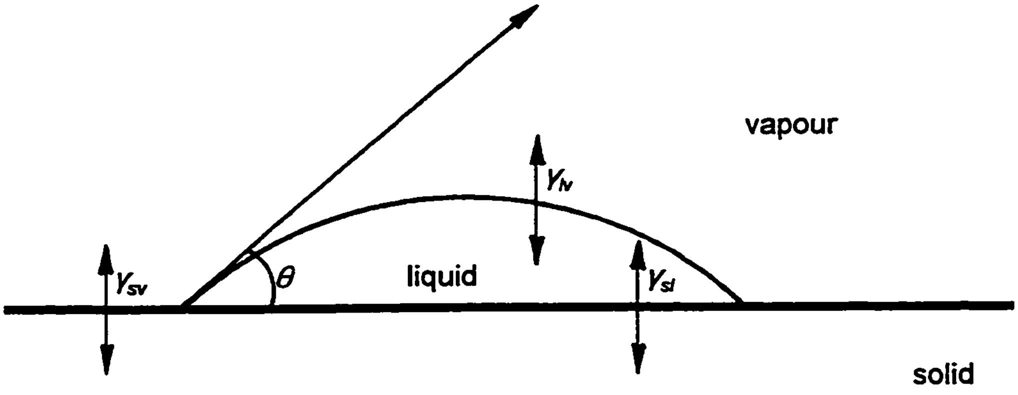


Figure 2. Contact angle, θ, and the forces between a drop of liquid and a solid surface at the solid-vapour (γ_{sv}), solid-liquid (γ_{sl}), and liquid-vapour (γ_{lv}) interfaces.
Note. Adapted from Allen, 1984, p. 7; Wake, 1982, p. 52.

Thus, from equations 2 and 3,

$$W_A = \pi + \gamma_{sv} + \gamma_{lv} - \gamma_{sl} \tag{4}$$

Combining equations 1 and 4 yields the Young-Dupré equation:

$$W_A = \gamma_{lv} (1 + \cos\theta) + \pi \tag{5}$$

The conditions necessary for wetting to occur can be derived from the Young and Dupré equations. Jaycock and Parfitt (1981) considered the reverse of the work of adhesion; that is, the work required to form a solid-liquid interface by bringing a plane solid surface and a plane liquid surface into contact. They called this the work of adhesional wetting:

$$W_A = -\gamma_{lv} (\cos\theta + 1). \tag{6}$$

They distinguished this from the work required for a liquid to spread over a solid surface, that of spreading wetting, W_S:

$$W_S = -\gamma_{lv} (\cos\theta - 1). \tag{7}$$

For these processes to be spontaneous, the values of W_A and W_S must be negative. This occurs for adhesional wetting when the contact angle is less than 180 degrees, a condition that is relatively easy to achieve in most liquid-solid systems. However, a real liquid and solid are not brought into contact as two planar surfaces. Some spreading must take place for the liquid to fully contact the solid. Spreading wetting occurs spontaneously only when the contact angle is 0 degrees. This condition is more difficult to achieve. Surfactants may have to be used to ensure that the contact angle is sufficiently low (Jaycock & Parfitt; Weidener, 1969). Alternatively, energy must be added to the system for wetting to occur.

In real systems of adhesive application, wetting rarely takes place only under equilibrium conditions. The liquid adhesive is initially propelled over the surface by applied pressure. The rate at which this movement occurs determines the contact angle of the liquid (Wake, 1982). This will be an advancing contact angle which is always greater than the angle at equilibrium. Once the applied pressure has passed, equilibrium is established (Wake).

The viscosity of the liquid also affects the degree of wetting (Allen, 1984; Newey, et al., 1992). Less viscous solutions penetrate the irregularities of surfaces with greater ease than thicker solutions. The viscosity of adhesives in solution depends largely on the proportion of adhesive solids (material that remains once the adhesive has set) to solvent, which in turn is affected by the nature of the polymer molecules. Polar liquids tend to be more viscous than nonpolar liquids due to the greater attraction of polar molecules to each other (Moncrieff & Weaver, 1992). Viscosity also tends to vary directly with the cross-link density and molecular-weight range of the liquid (Allen). Other factors being equal, the larger or more cross-linked the molecules, the greater the viscosity (Moncrieff & Weaver). A high concentration of solids in a solution of low viscosity is thus often achieved at the expense of molecular weight, affecting the strength of the resulting adhesive films (Skeist & Miron, 1990). Emulsion polymerization circumvents this limitation since the liquid phase in which the polymer molecules are dispersed determines the viscosity of the adhesive (Jaffe, Rosenblum, & Daniels, 1990; Skeist & Miron). Viscosity also decreases with increase in temperature (Allen). Like surface tension, the viscosity of an adhesive formulation can be adjusted through judicious choice of solvent and additives.

The physical nature of the solid surface influences the degree of wetting as well. Although surface roughness can improve bonding by increasing the area over which adhesion occurs, it can also impede wetting if the adhesive is unable to flow into the irregularities or sets before penetration is complete (Gent & Hamed, 1990; Wake, 1982). On the other hand, the porosity of materials such as yarns and fabrics can promote wetting through capillary action (Garbassi, Morra, & Occhiello, 1994; Jaycock & Parfitt, 1981; Newey, et al., 1992). Due to the small diameter of the pores and the low contact angles of the curved liquid-solid interface, liquid adhesive in pores is at a lower pressure than the bulk adhesive on the surface. The pressure differential drives the liquid into the pores (Garbassi, et al.). Gases trapped in micropockets or compounds adsorbed on the solid surface prior to bonding reduce wetting unless they are readily dissolved by the adhesive. Slowing the rate at which the adhesive solidifies may counteract these problems by allowing the liquid more time to spread into surface irregularities. Applied pressure also helps (Gent & Hamed). Horie (1987) has summarized visually how these various factors affect the wetting of textile substrates (Figure 3).

Setting Mechanisms

Once the surface is wetted, the polymer must undergo a phase change from a liquid to a solid state if it is to have sufficient strength to resist external stresses and form a functioning bond (Allen, 1984; Newey, et al., 1992). Three mechanisms account for the setting of most adhesives: chemical reaction, freezing, and solvent evaporation (Allen; Skeist & Miron, 1990). In reaction adhesives, polymerization of the adhesive occurs *in situ*. The reaction is initiated by the addition of a catalyst, by heat or by light. Epoxies

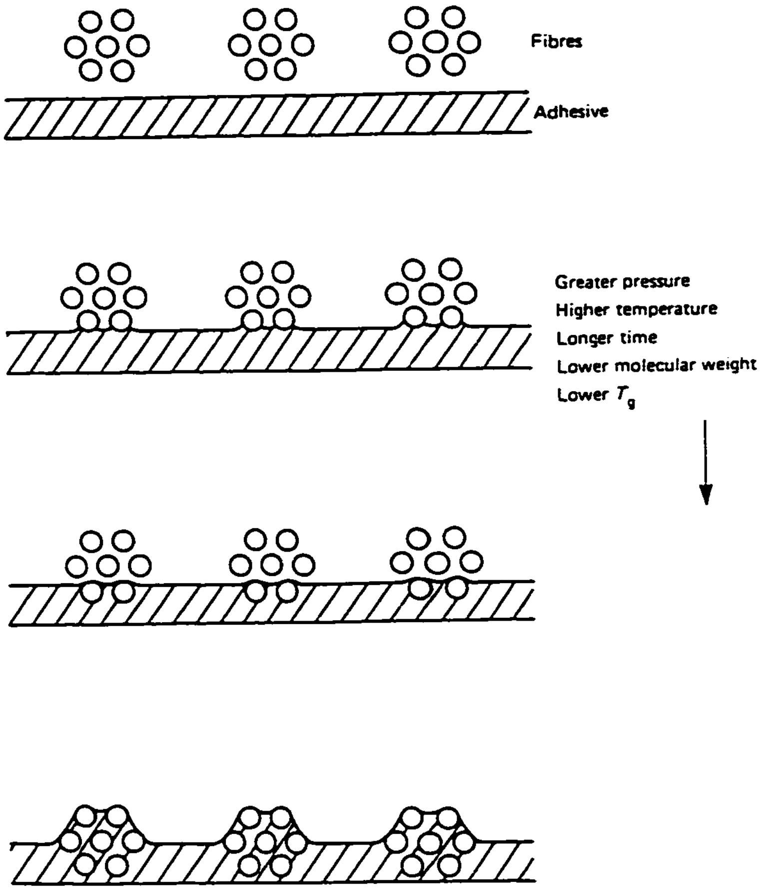


Figure 3. Development of an adhesive bond between a textile substrate and a high viscosity liquid adhesive.
Note. From *Materials for conservation* (p. 79), by C. V. Horie, 1987, Oxford: Butterworth-Heinemann. Copyright 1987 Butterworth-Heinemann. Reprinted with permission.

and cyanoacrylates function in this manner. Because the reaction is exothermic, these adhesives are also known as thermosetting adhesives.

Melt-freeze adhesives, such as waxes or hot melt adhesives, are transformed from liquid to solid states by the application and removal of heat (Newey, et.al., 1992; Skeist & Miron, 1990). Bonding may occur immediately after the application of the liquid adhesive to a substrate, or later when the dried adhesive is reactivated with heat and bonded under pressure. This latter process is known as heat-sealing (Shields, 1984). Adhesives can be applied in powder form or as an extruded film for heat-sealing. Alternatively, thermoplastic adhesives can be applied to one substrate from solution, dried, and then reactivated with heat. Bonding occurs relatively quickly compared to other adhesive types. Since the adhesive material is one hundred percent solids when bonding takes place, shrinkage upon setting is usually not a problem.

Solution adhesives, such as starch pastes or poly(vinyl acetate) dispersions, solidify through the evaporation of the aqueous or organic solvent in which the polymer was dissolved or dispersed (Newey, et al., 1992; Skeist & Miron, 1990). The manner in which the adhesive dries to a film depends on how it is applied. Polymer molecules, extended by dissolution in a solvent, gradually become entangled and join through secondary bonding as the solvent evaporates (Wake, 1982). If the solution is applied by spraying, that is in droplet form, the solvent may have time to partially evaporate before reaching the substrate and be deposited as particles or filaments to produce what paintings conservators call "flocked" coats for heat-sealing (Daly Hartin, Michalski, & Paquet, 1993). The size and shape of the dried particles depends on the method of atomization, the porosity of the solid phase that forms first on the outside of the droplet, and on the conditions during drying (Masters, 1985). Particles can produce agglomerates by coalescing when solvent concentration is still high, or through adhesion of sticky surfaces when partially dried (Masters).

Solution adhesives in which the polymer is dispersed in the solvent form films through coalescence of the polymer particles. The process consists of several stages (Eckersley & Rudin, 1996; Elliot, Wetzel, Xing, & Glass, 1997; Feller, 1971; Gauthier, Guyot, Perez, & Sindt, 1996). During the first stage, water evaporates until the particles become closely packed. The particles at this stage are stabilized by electrostatic or steric forces, or by surfactant molecules on the surface. In the second stage, the particles are deformed and begin to coalesce. Capillary forces due to water evaporating from interstitial voids, and interfacial forces strong enough to overcome the stabilizing forces are thought to cause this deformation. The third stage occurs once the film is dry and may continue over several months (Feller). Polymer molecules diffuse across the particle boundaries. Eventually, a homogeneous film may form (Figure 4).

The degree of coalescence is affected by the size and nature of the polymer particles, by components in the water phase, and by conditions during drying. Smaller particles pack more closely and produce more integrated films (Eckersley & Rudin, 1996; OCCAA, 1983). Molecular structure influences coalescence indirectly through the glass transition temperature, T_g, of the polymer. Below T_g, the polymer is in a glassy state; above T_g, it is more rubbery. Below T_g, the polymer molecules are relatively immobile and less able to diffuse across particle boundaries. Above T_g, molecular segments move sufficiently to permit diffusion. Several factors affect T_g: the size and type of side groups

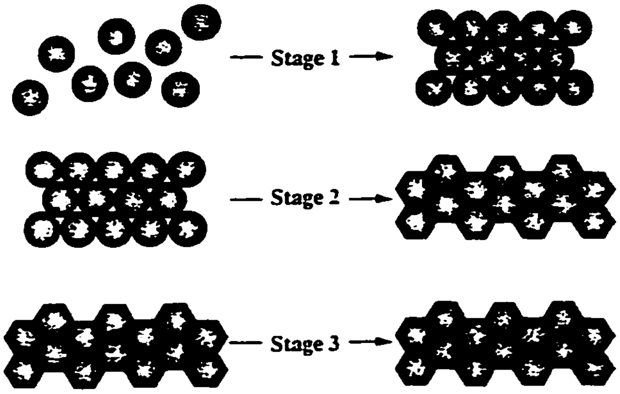


Figure 4. Stages of film formation for an aqueous polymer dispersion.
Note. From "Film formation of acrylic copolymer latices: A model of stage II film formation" by S. T. Eckersley and A. Rudin, 1996, in T. Provder, M. A. Winnik and M. W. Urban (Eds.), *Film formation in waterborne coatings*, p. 4. Copyright 1996 American Chemical Society. Reprinted with permission.

and chains, copolymerization, secondary bonding, and molecular weight (Jaffe, et al., 1990; Schilling, 1989). In practice, polymers often coalesce at temperatures slightly below T_g. However, below a certain temperature, the minimum film forming temperature (MFFT) of each polymer, coalescence does not occur (Feller, 1971; OCCAA). Drying produces a powder instead of a film. At temperatures close to T_g, an intermediate stage occurs in the coalescence process where all interstitial water has evaporated but particles are not well deformed. Even so, the film is transparent (Keddie, Meredith, Jones, & Donald, 1996). Both T_g and MFFT are lowered through plasticisation of the polymer by water or other chemicals (Feller; Newey, et.al., 1992; OCCAA). Heating dried polymer powder above its MFFT (annealing) can result in coalescence in the absence of water (Sperry, Snyder, O'Dowd, & Lesko, 1994).

The type of stabilizing system also affects the manner in which coalescence occurs. Stabilisers are usually either surfactants or colloids. Both inhibit coalescence by coating the surface of the polymer particles. Surfactants, however, may dissolve into the polymer film or accumulate in voids between the particles, thus hindering but not preventing eventual film integration (OCCAA, 1983). In contrast, colloids remain attached to the particle surface, preventing coalescence; but they may act as an interparticle cement (OCCAA). Thus dispersions protected by surfactants produce relatively clearer but more slowly setting films than dispersions protected by colloids (Jaffe, et al., 1990).

Environmental conditions during setting also affect the nature of particle coalescence. Temperature, humidity, and air velocity all affect the rate of water evaporation and thus of the first stage of coalescence. Increases in temperature and air velocity increase the evaporation rate, while increases in relative humidity slow it down (Gauthier, et al., 1996; Gutoff, 1997). Increasing the water evaporation rate can result in the formation of a skin at the adhesive surface, through which the remaining water must diffuse in order to evaporate (Gutoff, OCCAA, 1983). If the skin becomes thick enough, diffusion occurs so slowly that adhesive below the skin remains unset. At temperatures above 100°C, the softened surface film can burst due to increased vapour pressure below it (OCCAA). Differences in the rate at which stage one occurs, however, may not always affect the final properties of the adhesive film (Gauthier, et al.).

Bonding Mechanisms

The interaction between adhesive and substrate has been explained in a number of ways. Allen (1984) and Wake (1982) have summarized the major theories of adhesion as follows: (a) mechanical, (b) diffusion, (c) electrostatic, and (d) physico-chemical (physical and chemical adsorption). Mechanical adhesion is achieved by simple interlocking of two materials. Roughening of substrate surfaces is commonly understood to increase adhesion due to mechanical interlocking. In reality, the scale of the roughness is critical. For example, metals roughened through grit blasting adhere more poorly when grit of large particle size is used because the irregularities produced have smooth walls (Wake, p. 35). Similarly, the penetration of fibre ends from spun staple yarns into the adhesive is more important than the penetration of the adhesive into the fabric structure. Thus bonds formed with fabrics made from staple yarns are higher than those with fabrics made from filament yarns (Wake, p. 283).

Bonding through diffusion usually occurs between two very similar materials such as two adhesives, two surfaces of the same adhesive or two metals rather than between distinct materials such as fibres and adhesives. In this mechanism, molecules diffuse from one surface into the other, tying the two surfaces together. If the surfaces are very alike, the interface disappears entirely. The electrostatic explanation for adhesion, which is not widely accepted (Wake, 1982), proposes that the surfaces of adhesive and adherend are charged and held together by forces of electrostatic attraction.

Theories considered to have the greatest importance in explaining adhesion are those of physical and chemical adsorption (Allen, 1984). In physical adsorption, molecules of the two substances come close enough to allow van der Waal's forces, or the attraction between momentary dipole forces, to operate. The phenomena involves low energy levels and is relatively easy to reverse. Chemical adsorption, on the other hand, is limited to the interaction of specific molecular groups, involves greater amounts of energy and is less easy to reverse. Covalent and hydrogen bonds are usually involved. Polymer composition or substrate surfaces are often modified to increase chemical adsorption for particular applications that require high strength bonds (Wake, 1982).

Bond Failure

Two types of bond failure occur: cohesive and adhesive. Cohesive failure occurs within bulk material, usually the adhesive but sometimes the adherend. The forces of attraction between the molecules within the adhesive or substrate are weaker than those between adhesive and substrate molecules (DeLollis, 1973). Adhesive failure, on the other hand, occurs when conditions are the opposite: attraction between molecules is weakest at the interface. The Young and Dupré equations predict where adhesion should fail in an ideal system (Allen, 1984; Wake, 1982). From equation 2,

$$W_A = \gamma_s + \gamma_{lv} - \gamma_{sl}, \qquad (2)$$

the work required to break apart a liquid to form two new surfaces, the work of cohesion, W_C, is

$$W_C = 2\gamma_{lv}. \qquad (8)$$

When complete wetting occurs ($\theta = 0$), Equation 5,

$$W_A = \gamma_{lv}(1 + \cos\theta) + \pi, \qquad (5)$$

gives

$$W_A = 2\gamma_{lv} + \pi. \qquad (9)$$

Thus, $W_A = W_C + \pi$, (10)

and the work of adhesion is always greater than the work of cohesion as long as there is some spreading pressure, π. Both Allen and Wake have suggested that this equation pertains to the adhesive-solid system once the adhesive has solidified, barring any stresses due to shrinkage. Failure should, therefore, be cohesive (within the adhesive), rather than adhesive.

Real systems are more complicated. First, wetting may not be complete ($\theta > 0$), especially on low energy solids such as organic fibres and polymers. Moreover, the spreading pressure of such solids is usually small. Thus, adhesive failure may be a likely possibility (Miller & Neogi, 1985). Indeed, a polymer coating can be peeled cleanly from a filament textile as long as no filaments or yarns are completely embedded in it (Wake, 1982). If the textile is woven from staple yarns, fibre ends will probably penetrate the coating. These fibre ends will break off when the coating is peeled away, but only if the they are embedded deeply enough that the shear force required to pull them out exceeds their tensile strength (Wake, p. 286).

Failure that appears to occur at the interface may be due to a weak boundary layer between adhesive and adherend (Wake, 1982, pp. 168 -169). This layer must be thick enough to be a duplex layer; that is, to possess two molecularly independent surfaces. Cohesive failure then occurs within this boundary layer. Weak boundary layers can be formed from contaminants or components of the polymer which migrate to the interface, or from the products of reactions between materials in the substrate and those in the adhesive which form at the interface (Wake). Surfactant stabilizers in polymer dispersions are thought likely to migrate to the interface and interfere with adhesion, especially wet adhesion (OCCAA, 1983). Contamination of the substrate surface by products, such as oils and greases, that are not soluble in or displaced by the adhesive polymer, also contribute to adhesive failure (DeLollis, 1973).

Adhesive failure can also be caused by adsorption of water or another solvent at the interface (DeLollis, 1973; Wake, 1982). If water is soluble in the polymer, high relative humidity is sufficient to allow water vapour molecules to diffuse through to the interface and displace the larger, physically adsorbed polymer molecules. Absorbed water may also lower the T_g of the polymer, affecting its strength and stiffness. Absorption of or immersion in a suitable solvent causes swelling of the adhesive and may result in adhesive failure. Polymer coatings will float away from continuous filament textiles immersed in a swelling liquid (Wake). Large differences in the properties of the adhesive and substrate, especially in coefficient of expansion, add to the stresses caused by solvent absorption or changes in temperature (DeLollis). Localized stresses due to interface imperfections, such as trapped air bubbles, add further to the possibility of adhesive failure due to polymer displacement (DeLollis). The use of low modulus adhesive polymers can prevent stress buildup (DeLollis).

Failure due to stresses applied under controlled conditions is used to study and compare adhesives in adhesive testing. Typical tests of adhesive joints measure tensile, shear, or creep properties, and bending, cleavage, fatigue, or impact strength (Gent & Hamed, 1990; Rice, 1990). Of particular interest in the study of flexible laminates is the measurement of resistance to peel. A flexible layer is peeled either from a rigid substrate at 180° or from a similar flexible layer at 90°. The force recorded as a result of this test is sensitive to the peel angle and rate of peel, to the moduli of the adhesive and adherend, and to the thickness of the adhesive (Wake, 1982, p. 140). More force is required to initiate the peel than to sustain it (Wake, p. 146). Furthermore, the relationship between adhesion and peel strength is non-linear, with an increase in adhesion resulting in a much larger increase in peel strength (Wake, p. 146). Further factors complicate the use of the 90° T-peel test. Failure can be initiated at either interface and will tend to continue at that interface. The angle of peel significantly departs from 90° during the peel. Gent and Hamed have noted that the energy expended in bending the peeled strip, which is dependent on the material's modulus, is greater at larger peel angles. They recommend the use of 45° angle peels, as long as the peeled strip does not stretch. Because of these complications, comparison of different adhesives or substrates based on peel strength may be misleading.

Composition of Adhesives

The formulation of an adhesive can be manipulated in a variety of ways in order to create products for particular applications. This manipulation begins with the polymer itself, the film forming material. However, few polymers are used as adhesives without further modification. Tailoring an adhesive through the addition of solvents and other additives is known as compounding (Jaffe, et al., 1990).

Polymers

Organic polymers used as adhesives have essentially the same type of molecular structure as those forming fibres such as silk and polyester. The nature of these polymers has been well summarized in the literature (McNeill, 1992; Newey, et al., 1992). Polymers are composed of large macromolecules consisting of repeating monomer units. The monomers may be identical or different, as in copolymers. Polymers in which the molecules can pack closely into a highly ordered arrangement are crystalline. If the molecules remain more randomly arranged, which occurs when side groups are bulky, the polymer is amorphous. Adhesives may be either long-chain polymers like fibres, or network polymers where molecules form a continuous three-dimensional structure. Networks result from small molecules that interact to form branched chains, or from cross-linking between long chains. Long-chain polymers are usually thermoplastic and soften upon the application of heat, since the long molecules are held together only by weak secondary bonding. Network polymers, on the other hand, are usually produced by thermosetting adhesives wherein the application of heat initiates the polymerisation of one large structure linked by covalent bonds.

Since its molecular structure affects properties related to application, setting, use, and degradation, polymers can be chosen and modified to meet specific requirements. The molecular weight and degree of branching of the polymer molecules can be controlled during polymerisation. High molecular weight results in high cohesive strength but slow contact and diffusion; low molecular weight gives the opposite. Tack, or the ability to bond instantly when brought into contact with a substrate, is maximized at intermediate molecular weights (Gent & Hamed, 1990). Polymer hybrids can be formed intermolecularly by blending polymers, or intramolecularly through random, graft or block copolymerisation. In general, hybrids are tougher than pure polymers (Skeist & Miron, 1990). Copolymerisation is one method of plasticising polymers. The introduction of different molecular groups into the polymer chain, often at random, reduces crystallinity and permits greater inter- and intramolecular motion, thus creating a more flexible material. Polar groups or cross-linking monomers can be incorporated through copolymerisation in order to improve adhesion to particular substrates and adhesive strength, respectively (Skeist & Miron).

Solvents

Solvents are needed to dissolve, disperse or swell the adhesive polymer in order that it may be applied effectively or, as is often the case in conservation, removed. A solvent will dissolve a polymer if the attraction between the solvent and polymer molecules is stronger than the attraction between the polymer molecules (Newey, et.al., 1992). Cross-linked polymer molecules cannot be dissolved but only swelled by a compatible solvent. In general, solvents dissolve substances of a similar polarity. Depending on the degree to which it dissolves a particular adhesive, a solvent can be regarded as good or poor with respect to that adhesive. A diluent may be used in conjunction with the solvent. A non-solvent for the polymer, the diluent modifies such properties of the solvent as viscosity and rate of evaporation (Weidener, 1969).

Solvents may also be incorporated into dispersion formulations for other purposes (Down, 1995; Jaffe, et al., 1990). They may be added as temporary plasticisers, reducing minimum film forming temperature but accelerating setting speed due to their volatility. At the same time, they swell and soften the polymer particles, improving coalescence. The swelling effect also increases the viscosity of the dispersion; thus, the solvent can act as a thickening agent. Solvents are used to increase wet tack, to dissolve tackifiers, and to lower the freezing temperature of dispersions. In addition, they can increase adhesion to solvent-sensitive surfaces: the solvent swells or partially dissolves the surface, allowing the adhesive to penetrate it.

Solvents also vary in volatility. The solvent or solvent mixture that is chosen for a particular adhesive formulation depends on whether the polymer is sufficiently soluble in it and on the method of adhesive application. Horie (1987) recommends mixtures with a high proportion of highly volatile solvents for brushed application. For spraying, however, a greater amount of solvent of medium volatility prevents the adhesive from solidifying before reaching the substrate. An optimum solvent mixture would contain a volatile poor solvent for the adhesive polymer along with a small amount of a good, less volatile solvent (Horie). A certain amount of solvent will remain in the adhesive film even after apparent drying and gradually evaporate over time. Solvents having a highly branched molecular structure have more difficulty diffusing through the polymer and thus are more likely to be retained. Such residual solvents affect the properties of the polymer (Horie).

Additives

Plasticisers. Although polymers can be plasticised through copolymerisation, external plasticisers, such as phthalates and benzoates, accomplish the same objective. These plasticisers are solvents for the polymer and promote adhesive flexibility, lower its T_g and reduce its cohesive strength by separating the polymer molecules (Gent & Hamed, 1990; Newey, et.al., 1992; Wake, 1982). They are often poor solvents of relatively low volatility and may remain in the adhesive long after it has set. Unlike copolymers, however, they are prone to migration and can render the surface of the adhesive sticky, cause adhesive films to embrittle over time and sometimes damage substrates (Jaffe, et al., 1990). The rate of migration depends upon the size of the molecules in the plasticiser. Compounds composed of heavier molecules diffuse out more slowly and thus provide more permanent plasticisation. As they are often more costly, however, they are often not used in commercial formulations (Selwitz, 1988). Despite the potential problems, external plasticisers may be added to copolymer dispersion adhesives for additional effect. Like solvents, they swell polymer particles, raising the viscosity of the solution so that, destabilized, it sets more quickly. In addition, they increase tackiness, reduce heat-sealing temperature and improve water resistance (Jaffe, et al.).

Tackifiers. These resins improve the tack or initial stickiness of the adhesive. Composed of bulky molecules of moderate molecular weight, they are plasticised by the polymer, although usually not very well (Gent & Hamed, 1990; Wake, 1982). At low shear rates, tackifiers promote wetting by reducing the polymer's resistance to deformation. At high shear rates, however, they contribute to higher polymer modulus and strength (Gent & Hamed).

Emulsifiers and stabilisers. Monomer and polymer particles remain suspended in an aqueous dispersion through the action of emulsifiers and stabilisers respectively. Surfactants act as emulsifiers during polymerisation and as one of three types of protection systems that are used to stabilize the final dispersion. The other two are colloids, such as poly(vinyl alcohol) or cellulosics, and a combination of colloid and surfactant. Each results in films of distinct properties (Jaffe, et al., 1990). Compared to surfactants, colloids tend to be poor stabilisers. Thus, the size of particles in colloid-protected dispersions is larger on average and has a wider distribution than that of particles in surfactant-protected adhesives. Colloid-protected dispersions flow better, set faster, and have stronger wet tack. However, they may be less suitable for spraying. How the stabiliser affects film coalescence has already been described. Films from surfactant-protected dispersions are clearer, glossier, and more water resistant, but give poorer results when heat-sealed or reactivated by solvent. Films from dispersions stabilized by both colloids and surfactants have properties intermediate to the others and are most suited to heat-sealing and solvent reactivation. Adhesion to particular substrates may also be affected by the type of protection system.

Other additives. Other materials are added to modify the properties of the adhesive before or after setting (Jaffe, et al., 1990). Initiators and modifiers required for initial polymerisation of the adhesive polymer may remain in the final product. Buffers adjust the pH of dispersions in order to provide optimum conditions for the emulsifier. In addition to acting as emulsifiers for dispersions, surfactants can improve bonding through better wetting and foam control. De Witte, Florquin, and Goessens-Landrie (1984) have noted that conservators sometimes add additional surfactant, if they feel the adhesive is not wetting the surface sufficiently. Thickeners and fillers increase adhesive viscosity and may improve adhesion to porous surfaces by reducing penetration (Jaffe, et al.). Thickeners also slow drying by releasing water slowly, thus increasing open assembly time (Down, 1995). Depending on the properties of the material used, fillers may add stiffness, increase elastic modulus, decrease tack and reduce cold flow (Gent & Hamed, 1990; Jaffe, et al.). Thickeners, fillers, and tackifiers also act as extenders, adding to bonding properties at a lower cost than additional polymer while maintaining high solids content. Humectants are hygroscopic materials that slow drying and prevent the formation of a skin. Waxes are added to hot-melt adhesives in order to reduce the working viscosity and thus promote wetting (Eastman & Fullhart, 1990). In ethylene/vinyl acetate adhesives for heat-sealing in conservation, waxes dissolve the polymer to permit wetting at low temperatures (Newey, et al., 1992). Antioxidants, anti-hydrolysis agents, and biocides are added to control or lower the rate of deterioration of the adhesive film. Freeze-thaw stabilisers prevent dispersions from freezing during shipping (Down). In addition to their intended purpose, these additives may affect the ageing properties of adhesives and are therefore of great concern to conservators (de Witte, et al.; Howells, Burnstock, Hedley, & Hackney, 1984; Horie, 1987).

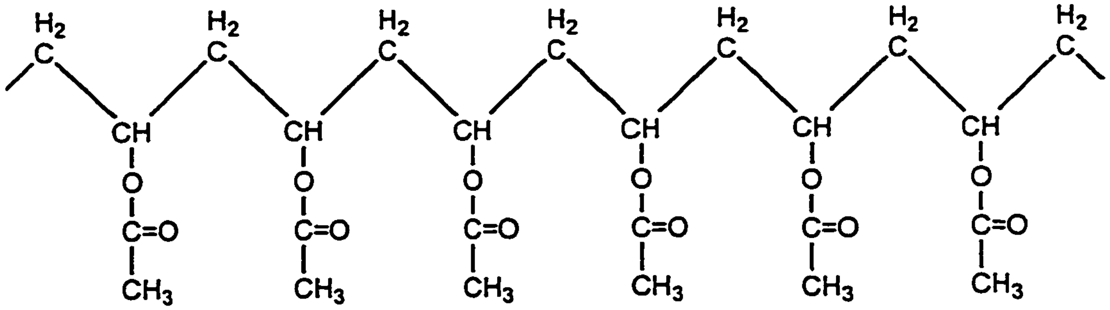
Poly(vinyl acetate) Adhesives

Poly(vinyl acetate) (PVAC) is polymerised from vinyl acetate (CH_2=$CHCO_2CH_3$), which in turn is produced from the reaction of acetylene or ethylene and acetic acid. Vinyl acetate polymerisation begins with the decomposition of an initiator to yield free radicals. Polymerisation takes place in one of four ways: bulk, solution, suspension, and emulsion (Horie, 1987; Weidener, 1969). Besides the monomer and initiator, bulk or mass polymerisation requires chain-transfer agents to limit the amount of branching of the polymer and resulting viscosity. Usually only low molecular weight grades are produced in this way. In solution polymerisation, a solvent is employed as the polymerising medium and as a diluent. The process does not require chain-transfer agents and tends not to yield a high molecular weight product. The solvent may be retained in the product or evaporated to produce a solid resin. A particular method of producing the solid results in "pearlized" resins. The polymer solution is suspended in water through agitation and the use of an suspending agent such as poly(vinyl alcohol). When the solvent and water are distilled off, the resin solidifies in the form of large beads coated with a thin film of poly(vinyl alcohol). Suspension polymerisation produces similar small beads, but with the use of suspending agents such as talc or gelatine and without solvents. In emulsion polymerisation, the monomer is dispersed in water through the use of emulsifiers, and a water-soluble initiator is used. Polymerisation equivalent to the bulk process occurs within each small particle suspended in the aqueous medium. Chain-transfer agents are usually not required. High molecular weight polymers can be produced using this method.

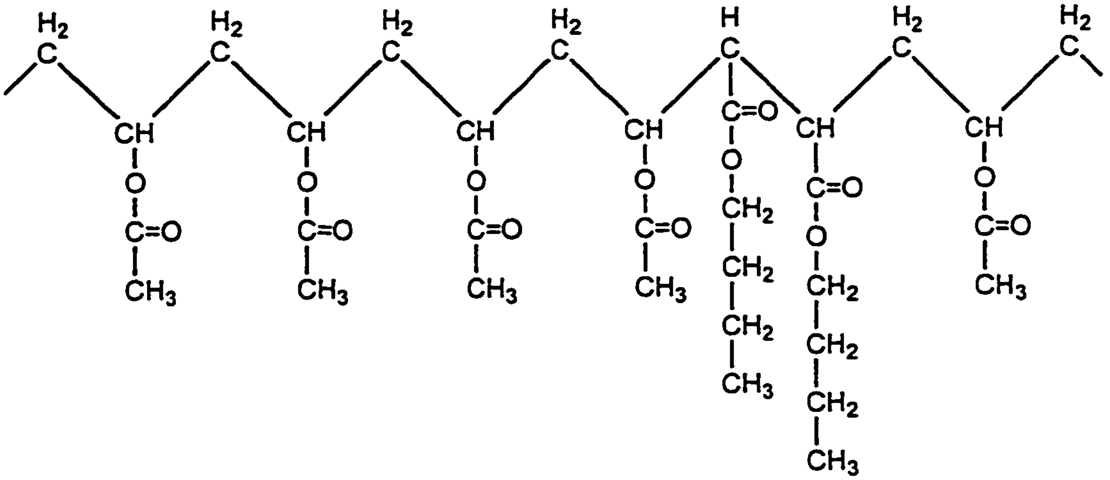
The properties of PVAC adhesives can be modified through copolymerisation. Monomers such as ethylene, alkylmaleates, alkylacrylates, alkylfumarates, and acrylic or crotonic acids are most frequently used in this respect. This study is concerned specifically with copolymers of vinyl acetate and dibutyl maleate or ethylene. The remaining parts of this section compare PVAC homopolymers and these copolymers.

Structure

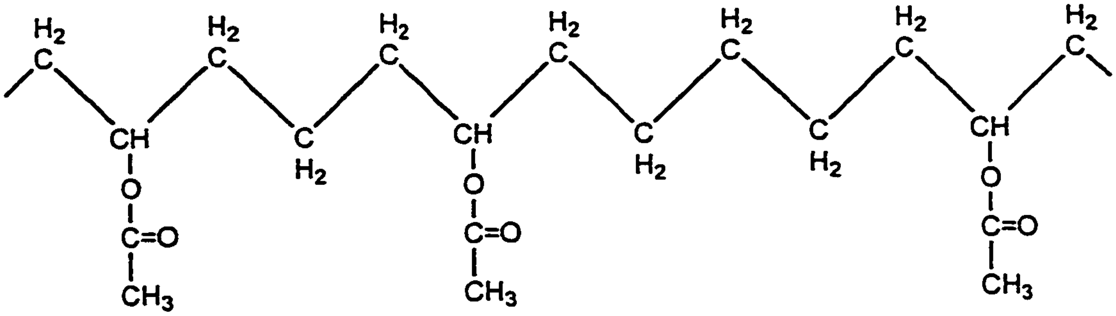
Poly(vinyl acetate) homopolymer. The PVAC molecule consists of aliphatic chains with acetate groups on alternating carbon atoms. The molecules may be linear, but are usually branched to some degree. The bulky acetate side groups and branching prevent crystalline ordering of the molecules (Weidener, 1969). Steric hindrance between alternate acetate groups restricts molecular movement (Jaffe, et al., 1990).



Vinyl acetate-dibutyl maleate copolymer. When vinyl acetate (VAC) is copolymerized with dibutyl maleate, butyl ester groups (- $CO_2CH_2CH_2CH_2CH_3$) are added to some of the carbon atoms on the polymer backbone. These groups add extra bulkiness to the molecules, forcing them to separate further.



Vinyl acetate-ethylene copolymer. The random copolymerisation of vinyl acetate and ethylene (ethene: $CH_2=CH_2$) produces a polymer similar to PVAC but with saturated aliphatic chains creating larger spaces between acetate groups. This spacing reduces steric hindrance and permits greater movement along the molecules (Jaffe, et al., 1990). Polymers where either vinyl acetate (VAE) or ethylene (EVA) predominates can be produced. Technically, the latter should be considered as a polyethylene copolymer, although it is usually categorized as a PVAC adhesive in the conservation literature (Down, et al., 1992, 1996; Pretzel, 1997a, 1997b).



Properties

The properties of an adhesive depend on the adhesive's composition, the specific nature of the components, and conditions of use. Thus, for example, the strength and toughness of a PVAC film depend on the molecular weight and the degree of molecular branching of the polymer. If the adhesive is a dispersion, factors affecting the degree of coalescence, such as the type of stabiliser, and the temperature and humidity during setting, also affect the strength. Since the possible variations in composition and use are numerous, generalisations about the relative properties of PVAC homopolymer and copolymer adhesives should be suspect without detailed information on the products used to produce the data. The adhesives literature includes a number of general and possibly useful observations about these adhesives plus data to support them, but provides little detail on where the data come from. Keeping in mind this limitation, the information from the literature is summarized here.

One of the major characteristics of PVAC adhesives is their flexibility. Because it is not a highly crystalline material, PVAC homopolymers are flexible in comparison to other vinyl polymers such as poly(vinyl chloride) (Weidener, 1969). However, due to the effects of steric hindrance, intermolecular attraction, a T_g that is usually above room temperature, PVAC homopolymers tend to be hard and stiff in use (Jaffe, et al., 1990). More flexible films can be obtained by the addition of external plasticisers such as dibutyl phthalate. Copolymerisation with dibutyl maleate or ethylene also produces more flexible products due to the addition of bulky side groups or the reduction of steric hindrance respectively. The effect is also permanent, unlike that of external plasticisers. Increased flexibility or rubberiness means lower T_g values. Whereas the T_g of PVAC homopolymer adhesives range from 18°C to 29°C with decreasing amount of external plasticiser, that of a copolymer can range much lower depending on the level of comonomer by weight. The T_g of VAC-dibutyl maleate and VAE copolymers may be as low as -10°C and -30°C respectively (Horie, 1987; Jaffe, et al.). Ethylene is the more effective plasticiser: less ethylene than dibutyl maleate is required to reduce the T_g by the same amount (Jaffe, et al.). The flexibility of EVA hot-melt adhesives is maximized in polymers having higher molecular weights and higher vinyl acetate content (Eastman & Fullhart, 1990).

Increased flexibility usually means decreased strength and creep resistance. Although weaker than other vinyl polymers, unplasticised PVAC homopolymers are generally stronger than plasticised versions. VAE copolymer dispersions, however, are stronger than their dibutyl maleate counterparts of the same or slightly lower T_g (Jaffe, et al., 1990). VAE copolymer and PVAC homopolymer dispersions are equally resistant to creep, and more so than dibutyl maleate copolymers, even when plasticised with 10% dibutyl phthalate (Jaffe, et al.). When used in solution, PVAC homopolymers are slow to reach their full strength and are susceptible to creep due to solvent retention (Weidener, 1969). Hot-melt EVA copolymers, because of their sensitivity to heat, creep at moderately elevated temperatures, and undergo cold flow at room temperature (Wake, 1982).

The vinyl acetate polymers also vary according to their sensitivity to heat, water, and chemicals. All thermoplastics, they are all highly sensitive to heat. But dibutyl maleate copolymers are especially heat sensitive (Jaffe, et al., 1990). PVAC homopolymers have poor resistance to cold, while the resistance of VAE copolymers is good (Shields, 1984). PVAC homopolymers are also more sensitive than the copolymers to cold and hot water (Jaffe, et al.; Shields), although none is insensitive and the resistance of a particular adhesive depends a great deal on other additives. VAE copolymer dispersions tend to be more resistant to acids and alkalis than PVAC homopolymers and VAC-dibutyl maleate copolymers. Acids and alkalis more easily hydrolyse acetate groups that are closely packed along the chain than those spaced further apart (Jaffe, et al.). Copolymerisation tends to reduce slightly the number of solvents in which an adhesive is soluble (Horie, 1987), but, in general, the PVAC homopolymers and copolymers are soluble in a wide range of solvents because of their open and polar molecular structure (Weidener, 1969).

The homopolymer and copolymer adhesives also differ in use. PVAC homopolymers and VAC-dibutyl maleate and VAE copolymers are usually used as dispersions. EVA copolymers are usually hot-melt adhesives (Eastman & Fullhart, 1990). PVACs and VAEs have been used in this manner too (Weidener, 1969; Wake, 1982). Both PVACs and EVAs are also applied from solution. PVAC solution adhesives generally have fewer additives than dispersions. They may be applied by spraying but tend to become stringy (Weidener). Films of all of them can be used as heat-seal adhesives.

Setting and wetting properties vary among and within the types. Hot-melts set more rapidly than dispersions, which set more rapidly than solution adhesives (Weidener). Among the dispersions, the homopolymers set faster than the copolymers. VAEs with high glass transition temperatures (lower vinyl acetate content) set faster than those with lower T_gs (Jaffe, et al., 1990). Setting as hot-melts or in heat-sealing depends in part on the heat conductivity of the substrate and requires pressure for adequate bonding (Flanagan, 1973; Wake, 1982). It is also sensitive to the temperature during application: temperatures beyond the recommended one slow setting speeds and can lead to poor bonds if the adhesive is squeezed out of the joint (Flanagan). Wetting of the substrates tends to be poorer in hot-melt or heat-sealing processes. EVA copolymers of lower molecular weight have lower melt viscosity, longer working times, and thus better wetting. Hot tack, however, is improved with higher molecular weight and higher vinyl acetate content (Eastman & Fullhart, 1990). Lower molecular weight EVAs and those having higher vinyl acetate content perform best at low temperatures (Eastman & Fullhart, 1990).

Adhesion and peel strength differ with adhesive type. PVACs are less resistant to peel stress than VAEs (Shields, 1984). Dibutyl maleate copolymer dispersions give lower peel strengths than ethylene copolymers (Jaffe, et al.). Heat-sealing strength is higher for EVA hot-melts with higher molecular weights and lower vinyl acetate content, although higher vinyl acetate content tends to improve adhesion (Eastman & Fullhart, 1990).

Degradation

Because the vinyl acetate family of adhesives has highly saturated molecular structures, they are relatively stable adhesives (Weidener, 1969). PVAC shows negligible depolymerisation on exposure to heat in the absence of air (Schnabel, 1981), but undergoes side group reactions, releasing acetic acid (McNeill, 1992). Photodegradation occurs in the absence of oxygen only at wavelengths below 300 nm. The process involves chain scission followed by cross-linking (McKellar & Allen, 1979), although the latter is considered the predominant reaction (Schnabel). Degradation from solar radiation is negligible, but the presence of impurities, which absorb at such wavelengths, can initiate it (Schnabel). Similarly, PVAC is resistant to biodegradation, but additives often used in dispersions may require the use of biocides (Jaffe, et al., 1990; Schnabel).

Testing of Vinyl Acetate Adhesives for Conservation

Since their introduction, adhesives derived from vinyl acetate have been used for the conservation of many types of artifacts. Like other modern adhesives, however, their properties over long-term use in museum and less ideal settings are not well known simply because they have not been around long enough. Rarely concerned with the degree of long-term stability that is crucial to conservation (20 to 100 years), industrial research on these adhesives is only partially helpful. Therefore PVAC and related adhesives have been included in a small but important number of studies on adhesive films conducted by conservation scientists. These studies take two forms: stability testing and investigations into the effects of composition on properties. They are reviewed here with an emphasis on results pertaining to PVAC, VAC-dibutyl maleate, VAE, and EVA adhesives.

Stability Testing

At the Canadian Conservation Institute, Down, et al. (1992, 1996) tested a large number of poly(vinyl acetate) and acrylic adhesives for their stability to accelerated light and dark ageing. Samples of adhesive films were light-aged by continuous exposure to fluorescent lights, with most UV radiation below 400 nm filtered out. Dark ageing took place in ventilated cupboards. Both sets of samples were kept at 22°C and 45% RH for up to five years. The full light exposure was equivalent to 50 or 200 years in a museum at 200 and 50 lux respectively. Changes in pH, emission of volatiles, flexibility, strength, and yellowing were measured. Criteria for assessing adhesive stability for each property were established and used to judge the appropriateness of the adhesives for conservation purposes. Properties of the adhesive films considered desirable for conservation were neutral pH (5.5-8.0), low emissions of volatiles (< 1 μg acetic acid/ g adhesive), medium tensile strength (12-15 MPa), flexibility (elongation > 20% or modulus

< 2000 MPa), and no yellowing ($A_t < 0.05$).

The study produced a number of general observations about the ageing properties of PVAC and acrylic adhesive films. The PVAC adhesives were found to be more acidic, less flexible, and stronger than acrylic adhesives. They were also more prone to the emission of volatiles, especially acetic acid, and yellowed approximately twice as fast. Light ageing usually resulted in a decrease in pH and a higher rate of yellowing. Flexibility tended to decrease upon dark ageing. PVAC homopolymers were more acidic than the copolymers. Formulations containing additives were more acidic than those without. Films from PVAC homopolymer resins became more neutral over time when aged in the dark, but not when aged in light. These films also released fewer volatiles than films cast from PVAC homopolymer and copolymer dispersions. Most volatile products were released over the first year of ageing, and much of that, for light ageing, during the first three months. Given the levels of emission, air drying of the film for one month prior to exhibition in a sealed container was considered sufficient to prevent damage to other materials. Not surprisingly, VAC copolymers were generally more flexible than homopolymers. They were also weaker, but still of sufficient strength for conservation purposes. Formulations containing additives, especially plasticisers, were more flexible and weaker than those without. The yellowing properties of VAC homopolymers and copolymers were similar. Of the PVACs, two VAEs, Jade 403 and R-2258, a VAC-dibutyl maleate copolymer, Mowilith DMC2, and an EVA, Beva 371, were singled out for best overall performance. The authors also identified vinyl acetate-ethylene and butyl acrylate copolymers as classes with good properties that warrant further research. Down (1995) is currently testing the effects of particular additives on the working properties and stability of films made from a VAE dispersion.

Horton-James, Walston, and Zounis (1991) tested the stability to accelerated light ageing of a range of acrylic, poly(vinyl acetate), starch, and cellulosic adhesives. The poly(vinyl acetate) products included PVAC homopolymers, VAE and EVA copolymers, and a VAC-acrylate copolymer. Films were characterized according to colour change, pH, elongation at break, stress at 10% elongation, solubility, and by results from Fourier-transform infrared spectroscopy and pyrolysis-gas chromatography. The dust retention of adhesive films exposed to a normal museum environment for five months was also noted. Other properties related to the appearance and performance of the adhesives when used to adhere flaking paint on facsimilies of ethnographic objects were also studied but do not pertain directly to textile backing treatments.

The vinyl acetate-derived adhesives differed considerably in their response to light ageing. All yellowed except the acrylate copolymer, which bleached. The pH of the films decreased on ageing except for that of the two VAEs and one of the PVAC adhesives. The solubility of the films remained relatively stable in most cases. The elongation of half the adhesives remained stable, while the other half changed but with no visible pattern by polymer type. The stress at 10% elongation remained stable for all adhesives. The results of the analytical testing were not consistent with those of the physical tests. In some cases, materials found to be the most stable in physical tests showed marked changes in chemical properties. Dust retention after five months exposure to ambient museum conditions was very low for the PVACs and the VAC-acrylate copolymer. The VAE and EVA copolymers, on the other hand, did trap dust. Noticeable tack of the adhesive surface and low T_g did not correspond consistently to the tendency to trap dust.

In a similar study, Howells, et al. (1984) measured changes in weight, colour, solubility, tensile properties, and pH of artificially and naturally aged adhesives. Six acrylic and eight PVAC products were tested. The vinyl acetate adhesives included two homopolymers (one plasticised with dibutyl phthalate), two VAC-acrylate copolymers, two VAEs, and a VAC-dibutyl maleate copolymer, Mowilith DMC2 (buffered and unbuffered with 20% calcium hydroxide). The study employed a variety of ageing techniques: natural ageing, accelerated ageing in sunlight, and thermal ageing at 59°C and 83°C.

Except for colour, the properties of the adhesive films remained relatively stable in response to ageing. Few significant changes in weight, tensile properties, and softening temperature and were recorded for most of the adhesives. The greatest weight changes were exhibited by four PVAC dispersions. Only one, a PVAC homopolymer, became stronger and more brittle due to ageing, while two, a plasticised PVAC homopolymer and a VAC-acrylate copolymer, lost strength and became more extensible. The softening temperature changed after thermal ageing only for the plasticised PVAC homopolymer. Changes in solubility and pH were slightly greater. Light ageing tended to increase the number of solvents in which the films were soluble, while dark ageing decreased it. The pH of extracts of almost all the adhesives became more acidic after thermal ageing. One VAE and the unplasticised PVAC homopolymer remained neutral. By contrast, colour changed dramatically for many of the samples. In general, thermal ageing resulted in the greatest changes. Exposure to sunlight yellowed some films but bleached others. Samples exposed to fluorescent lighting tended to be bleached, suggesting that the yellowing from sunlight may have been a thermal response. Dark ageing resulted in slight yellowing of only a few adhesives. Only one adhesive, Vinamul 3252, a VAE copolymer, exhibited no changes in properties throughout the testing.

Verdu, Bellenger, and Kleitz (1984) analysed a variety of thermally and photochemically aged adhesives using infrared spectrophotometry, chromatography and UV-visible spectrophotometry. Films of VAC copolymer, acrylic, cellulosic, and starch adhesives suitable for the consolidation of textiles were tested. The VAC adhesives included two VAEs, two VAC-acrylate copolymers, and the VAC-dibutyl maleate copolymer, Mowilith DMC2. Thermal degradation resulted in the browning of the vinyl acetate copolymers, but in little change in the colour of the other adhesives. Only the acrylic films and two VAC copolymers, Mowilith DMC2 and an acrylate copolymer, remained soluble after ageing. Thermal oxidation quickly destroyed the VAC copolymers except for one of the VAEs. All samples tended to bleach and then yellow in response to thermal oxidation and photochemical degradation. The authors attributed the yellowing of the vinyl acetate copolymers to a "zip elimination" of side groups in the molecules leading to conjugated double bonds on the polymer backbone. Only two adhesives, one a VAE, showed loss of mechanical properties due to light exposure. Paraloid F-10, a poly(butyl methacrylate) and an adhesive used in textile conservation, exhibited the best ageing properties.

As part of a paper on simple methods of testing resins for conservation, Blackshaw and Ward (1982) reported the results of a small study of vinyl acetate copolymers for heat lamination. The authors compared the pH, softening point, flexibility, and percent solubility before and after thermal ageing of films made from four adhesives: Vinamul 6815 and 6825 (VAC-acrylate copolymers), Mowilith DMC2 (VAC-dibutyl maleate copolymer), and Beva 371 (EVA). The VAC copolymers were found to be acidic, while Beva 371 had a neutral pH. The softening point of the Vinamuls was approximately twice that of the other two adhesives. All adhesives produced flexible films, but especially the Beva sample. The solubility of Beva 371 was also less changed by thermal ageing.

Feller and Curran (1970) examined the effect of light exposure on the solubility of ethylene-vinyl acetate copolymers. Films cast from four EVA dispersions of varying vinyl acetate content were subjected to 800 hours of xenon arc radiation. The percentage of soluble matter remaining after exposure was determined by dissolving the films in methylcyclohexane. Films of copolymers having a greater percent vinyl acetate content by weight contained less insoluble matter after exposure. Increasing insolubility is related to cross-linking of the polymer. Therefore, films from copolymers that were more than 25% vinyl acetate by weight showed a negligible tendency to cross-link.

Effects of Composition on Properties

De Witte, et al. (1984) studied the effect of surfactants, plasticisers, thickeners, and buffers on the properties of several acrylic and PVAC dispersions. Films of each dispersion were light aged using xenon arc radiation, and thermally aged at 80°C for some of the tests. The addition of more than 0.02% surfactant did not change the surface tension of the adhesive any further. Given such a low concentration, the influence of surfactants on ageing properties was not tested. The flexibility of films cast from PVAC homopolymers, externally plasticised PVAC, and internally plasticised VAC-dibutyl maleate copolymer were compared before and after light and UV ageing. Two of the unplasticised homopolymers were brittle even before ageing, while only one of the dibutyl phthalate plasticised homopolymers lost flexibility on ageing. Thickeners were tested on acrylic adhesives and, in most cases, did not affect the solubility of the films before or after ageing. The pH of the extracts of adhesive films was found to be comparable to that of the original dispersion. The authors interpreted this to mean that buffers contributing to the pH of the dispersion could be leached out of adhesive films in humid conditions.

Hansen, Derrick, Schilling, and Garcia (1991) found that the solvent used to prepare PVAC resin adhesives has an important effect on the ultimate properties of the dried adhesive film. The solvents chloroform, toluene, acetone, and an acetone/ethanol/water mixture were studied with respect to the adhesives AYAA, AYAC, AYAF, and AYAT. Chloroform is know to be the best of these solvents for PVAC. Solvent retention, tensile properties, and glass transition temperature, T_g, were measured. Toluene was shown to be retained by the films to a greater degree than the other solvents. Tensile properties were dependent on both the solvent used and the time of drying. In general, the polar acetone solvents produced AYAT films of higher modulus than the non-polar solvents. The same results were obtained for both high and low molecular weight polymers. T_g appeared to be more related to solvent concentration than to type of solvent. The values reported were almost all well above the expected value for PVAC, a difference that may have been due to the uncontrolled thermal history of the samples. FTIR analyses of films made from chloroform and acetone solutions were also studied. Differences in the FTIR spectra that parallelled differences in molecular weight of the polymers dissolved in chloroform were not seen in the spectra of the polymers dissolved in acetone. The authors suggested that acetone solvation produced aggregates of the polymer molecules that masked these differences.

Adhesive Backing Treatments in Textile Conservation

Adhesives have been used by professional conservators on textiles with varying degrees of success for at least forty years. Driven by the need for solutions to immediate, pressing problems, textile conservators have discovered the advantages and difficulties associated with using adhesives. Backing treatments are the most common of adhesive applications used on textiles. In these treatments, large areas of a textile or whole artifacts are attached to a new support fabric using an adhesive. The support is usually attached to the reverse of the artifact, but may also be used on the front as a facing if the reverse is not accessible.

Adhesives are also used to consolidate textiles or make local repairs. Consolidation involves the impregnation with adhesives of fibres so brittle they are "dusting away" (Landi, 1992; Lodewijks & Leene, 1972). This is often a problem with archaeological textiles, silk pile fabrics, and "rotting" silk tapestries (Landi, p. 111). Local reinforcement includes joining of fragments with threads coated with adhesives (Bede, 1993; Doré, 1980; Landi), reinforcement of seams, braids, tears and fragment edges (Landi; Jedrzejewska, 1972; Massa, Scicolone, & Cozzi, 1991), and spot welding to prevent unravelling (Jedrzejewska). Conservators have also used adhesives to apply patches to degraded areas of a textile (Mailand, 1998; Sack, 1997). This practice is discouraged by others because fabrics tend to deteriorate rapidly at the edges of patches (Bede; Hartog & Tinker, 1998; Mailand). When a textile component was originally adhered to a substrate or is a part of an artifact incorporating other materials such as wood, adhesives may be used to reattach it (Bede; Gill, 1995; de Groot, 1994; Hillyer, Tinker, & Singer, 1997). Although, the reasons for choosing to use adhesives, the adhesives used, and the properties required of them may be similar for backing treatments, consolidation, and local reinforcement, the purpose of each treatment and the techniques used are distinct.

As backing treatments are more widely used than the other adhesive applications and are more invasive than local treatments, their effects are of great concern to textile conservators. Reports of such treatments have been presented at conferences and published in the conservation literature. General works on textile conservation deal with the question of adhesive treatments. A few experimental studies have appeared that report on the effects of adhesive treatments. The result is a sizable technical literature on adhesive treatments for textiles. A survey of the aims, methods and research related to techniques used in adhesive backing treatments for textiles follows.

The Purpose of the Treatment

Textile conservators use adhesive backing treatments to provide support for fragile artifacts. Conservators resort to adhesives for securing a support fabric when degraded silks and textiles cannot be stitched or adequately supported by pressure mounts. Stitching is difficult and aesthetically obtrusive, if not professionally unacceptable, on very closely woven fabrics and painted textiles (Brooks, Eastop, Hillyer, & Lister, 1995; Himmelstein & Appelbaum, 1977; Jedrzejewska, 1981; Keyserlingk, 1990; Masschelein-Kleiner & Bergiers, 1984). Painted textiles may be damaged by pressure mounts: the paint layer may stick to or be flattened by the glass (Keyserlingk). Most textiles requiring adhesive treatments are simply too brittle to be stitched or too fragmentary to be handled without loss or damage. Silks that have suffered severe light degradation "shatter" at the slightest touch. Weighted silks may reach this condition without light exposure. Textiles rendered friable by iron mordants used in their manufacture pose a similar problem (Hillyer, et al., 1997). The stress of stitches on brittle yarns only causes more damage (Himmelstein & Appelbaum; Landi, 1992; Mailand, 1998). Very brittle three dimensional artifacts, such as garments, may require adhesive support if they are to be interpreted correctly for display. Although flat objects are most easily treated in this manner, many types of textiles suffer from these problems and have been given adhered supports (Table 2). Nevertheless, some textiles, such as thick or multilayered ones, may not be adequately supported by an adhered backing. Stress points may develop between adhered and unadhered fibres in the artifact because only the back surface is attached (Blum, 1982; Himmelstein & Appelbaum). The artifact and support may separate as a result. If the artifact is extremely weak, as are most archaeological textiles, the fibres may break at points of adhesion (Brooks, et al.).

An adhered support may occasionally be applied to the front of an artifact. The silk grounds of some embroideries are severely degraded. However, the stitches were often worked through an additional layer of linen behind the silk, in order to give them a sufficiently strong ground. The linen makes the reverse of the silk inaccessible and a backing treatment impossible. Thus a sheer fabric may be adhered to the face of the degraded silk ground for reinforcement (Bond, 1995; Lord, 1997; Petschek, 1995). Adhered facings have also been used to support an artifact temporarily during treatment. The removal of backings attached with adhesives can be facilitated in this way (Thomsen, 1984; Wagstaff, 1979). Similarly, a temporary facing can protect a fragile object during wet cleaning (Mailand, 1998; Mantilla de los Rios y Rojas, 1980).

Adhered supports have also been chosen as a means to reduce the time and

Table 2. Types of Textile Artifacts Given Adhesive Backing Treatments

Artifact	References[a]
Flags and Banners	
textile and embroidered	Anikowitch, 1980; Estham, 1980; Fischer & Rothaar, 1987; Foskett & McClean, 1998; Gentle, 1998; Himmelstein & Appelbaum, 1977; Kaindl, 1980; Keyserlingk, 1993; Lodewijks, 1980; Mäder, 1980; Mailand, 1998; Masschelein-Kleiner, 1980; Reeves, 1977; van Nes & Kip, 1980; Willcox, 1980
painted	Boersma, 1998; Brooks, et al., 1995; Carson, 1997; de Groot, 1997; Fischer & Rothhaar, 1987; Foskett & McClean, 1998; Kaindl, 1980; Keyserlingk, 1993; Lochhead, 1995; Muir & Yates, 1987; Peacock, 1983; Yates, 1987[b]
Furnishing Textiles	
wall hangings	Beecher, 1963; de Groot, 1994; Eastop, 1995; Finch, 1980; Giorgi & Palei, 1997; Hillyer, 1990; Landi, 1992; Marko, 1978
upholstery	Landi, 1973, 1992; Mailand, 1998; Pullan , 1995; Scott, 1974
Costume	
garments	Bede, 1993; Blum, 1982; Cruikshank, Lee, & Potter, 1998; Doré, 1980; Finch, 1980; Gentle, 1998; Hartog & Tinker, 1998; Hillyer & White, 1998; Mailand, 1998
trims and accessories	Landi, 1986, 1992
Other Textiles	
fabric lengths, fragments, etc.	Eaton & Wolbers, 1995; Hillyer, 1995; Himmelstein & Appelbaum, 1977; Landi, 1992; Reeves, 1977; Wagstaff, 1979
embroidery	Bede, 1993; Blum, 1982; Bond, 1995; Landi, 1973; Lord, 1997; Petschek, 1995; Seth-Smith, 1998
painted textiles	Cruikshank & Morgan, 1995; Hillyer, 1984; Masschelein-Kleiner, 1980
miscellaneous	Hillyer, et al., 1997; Himmelstein & Appelbaum, 1977; Katchanova, 1987; Sack, 1997; Vahlne, 1997; Wills, 1995

[a] treatment may not have been carried out or condoned by the author
[b] survey results

thus the cost required to treat artifacts. Initially adhesive treatments were regarded as "greatly labour-saving" and consequently suitable for many less valuable pieces (Beecher, 1963; Jedrzejewska, 1981; Katchanova, 1987; Lodewijks, 1972; Mailand, 1998). They could be used when the work required for a single artifact was beyond the ability of the small number of trained people available to manage (Marko, 1978). Some conservators were quick to disparage this reason for using adhesives, especially when inexperience often produced unsatisfactory results (Blum, 1982; Flury-Lemberg, 1988). Keyserlingk (1993) considers adhesive treatments to be as time-consuming as proper stitching treatments and to require as much skill. They are definitely no answer to poor sewing skills. Nevertheless, the lack of time for a full stitching treatment is still mentioned as justification for adhesive backing (Hartog & Tinker, 1998; Landi, 1992).

Ethical Considerations

The poor execution of some early adhesive treatments combined with the use of adhesives that subsequently proved to be unstable resulted in highly polarized views about the role of adhesives in textile conservation (Boersma, 1998; Brooks, et al., 1995). On the one side were the "stickers" who believed in the need for adhesive treatments and who focussed on refining techniques (Landi, 1992). On the other side were the "stitchers" who saw adhesives as completely incompatible with textile fibres and thought that any experimentation on irreplaceable artifacts should cease, at least until materials and techniques of proven stability had been developed (Flury-Lemberg, 1988). The key issue in this debate is reversibility. Ethical practice requires that the conservator balance the need to preserve and the need to use the artifact while maintaining an unfailing respect for the integrity of the artifact. This generally entails using stable techniques and materials that can be reversed or removed most easily and completely (IIC-CG & CAPC, 1989). Both conservators in favour of and against using adhesives on textiles agree that such treatment is never entirely reversible in practice (Flury-Lemberg; Jedrzejewska, 1981; Keyserlingk, 1992; Landi). Even if the resin should remain soluble--and this is never guaranteed, the latest research notwithstanding--complete removal from a porous, fibrous, and weakened surface without damage is impossible.

While the issues raised by the debate remain concerns, present practice emphasizes the quality of the treatment and the needs of particular artifacts (Brooks, et al., 1995; Hillyer, et al. 1997; Keyserlingk, 1992). Sewing and adhesive treatments both have advantages and disadvantages, and both can result in irreversible changes (Jedrzejewska, 1981; Keyserlingk, 1992). An adhesive treatment can be well or poorly executed; likewise a stitching treatment (Keyserlingk, 1990). The focus should be on choosing a method that preserves as much original evidence as possible (Jedrzejewska). Conservators appreciate that an adhesive treatment may preserve an artifact that would have disappeared completely otherwise (Foskett & McClean, 1998; Hartog & Tinker, 1998; Landi, 1992; Lodewijks & Leene, 1972). One must always bear in mind the real effects of any treatment on an artifact. Though some features of an object may have to be sacrificed in order to save others (Jedrzejewska, 1980), the decision to do so should never be taken lightly. However, an inbuilt prejudice against adhesive treatments is still evident among textile conservators (Hillyer, et al.). Many view such an interventive treatment as a last resort, used only when alternatives like encapsulation, pressure mounts, special storage mounts, and avoiding vertical display fail (Hillyer, et al.).

Adhesive Backing Techniques

Considerable detail about the methods used in adhesive backing treatments can be gathered from numerous published case studies, general articles, and manuals. The quality of individual reports, however, is inconsistent. Many case studies provide insufficient information on materials or techniques used. Adhesives are often identified only by product name. Ideally, the polymer type, trade name, and manufacturer should be identified, even when the product is widely used by textile conservators. Date of purchase is also helpful since products come and go on the market and formulations may be altered. In a few articles, the adhesive was not described at all beyond a general classification such as "glue" or "thermoplastic" (Katchanova, 1987; Schneider, 1980). Although the fabric support was usually identified, the means by which the adhesive was applied to it often was not. Even less frequently described was the substrate on which the adhesive was cast. The tool used to heat-seal the backing fabrics to the artifact was occasionally not specified (Boersma, 1998; de Groot, 1994; Giorgi & Palei, 1997; Hillyer, 1993; Katchanova, 1987). Detailed description of a treatment, though most informative, is not required in every case. Nevertheless, a brief summary of each of the major steps in the treatment, as outlined below, along with reasons for the choice of each material or technique would make reporting case studies an even more valuable way of building a shared understanding of how adhesives work.

Preparation of the Artifact

Before a textile artifact is adhered to a backing, it should be clean and the weave of its fabrics aligned. Dirt can interfere with the bond (Blum, 1982; Keyserlingk, 1990, 1993). The adhesive may not stick well to dirt which covers the fibres. Even if it does, the dirt may not be securely attached to the textile. Surface dust may stick to the adhesive, and darken it (Lord, 1997). The use of water or organic solvents is necessary for optimum cleaning. A textile may also need to be wetted out or humidified for effective treatment with starch pastes (Cruikshank & Morgan, 1995; Eastop, 1995; Masschelein-Kleiner, 1980; Pullan, 1995). Aligning the grain restores as much of the original orientation of the fabric as possible and prevents distortion and damage to the fabric once it is backed (Hartog & Tinker, 1998). Furthermore, the weight of an aligned textile is more evenly distributed and thus better supported by the backing fabric (Keyserlingk).

However, the nature and condition of the artifact limits to what extent it can be cleaned and aligned. Many artifacts have been treated with adhesive-coated backings without prior wet or solvent cleaning. Unstable dyes or paints may prevent full cleaning (de Groot, 1994; Hillyer, 1984; Vahlne, 1997). If only one type of cleaning is possible, it may not remove the soiling present (Bond, 1995). A complex structure, such as the multiple layers of embroideries or costume, may preclude anything other than vacuum cleaning of loose dirt. In addition, adhesives, oils, or resins that have saturated the textile fibres due to past treatments or the manner in which it was originally used (eg. burial shrouds) may not be completely removed even with full cleaning (Boersma, 1998; de Groot, 1997; Hillyer & White, 1998). Very brittle fibres may limit the amount of cleaning and alignment possible (Hartog & Tinker, 1998; Himmelstein & Appelbaum, 1977). The effects of incomplete cleaning or alignment on the long-term stability of adhesive-backed textiles has yet to be studied.

Particular artifacts may require other measures if an adhesive treatment is to be properly done. Flags or banners may be unstitched and their trims removed so that their reverse side can be properly supported (Boersma, 1998; de Groot, 1997; Keyserlingk, 1993; Peacock, 1983; Thomsen, 1984). Similarly, wall hangings may be separated from previous support layers in order to access the back of the degraded textile (de Groot, 1994). The seams of three-dimensional artifacts, such as costume, may be unpicked to give flat pieces that facilitate adhesive backing (Bede, 1993). Hartog and Tinker (1998) described snipping the split net along the seams of the sleeves of a dress in order to preserve original stitching while allowing the sleeves to be laid out flat. Upholstery fabric may be removed from the piece of furniture to permit adhesive backing (Landi, 1992; Mailand, 1998). Such interventions and the ethical questions they raise are associated with both stitching and adhesive treatments.

Choice of Adhesive

Characteristics of appropriate adhesives. In order to be used safely on textile artifacts, adhesives must fulfill several criteria. First the conservator must be able to apply the adhesive safely to the artifacts. The polymer, its solvents, or additives must not react adversely with the fibres, dyes, or other applied materials such as inks, paints, or even adhesives (used as consolidants, for example) (Leene, 1963; Newey, et al., 1992; Senvaitienė, Pinkevičiūtė & Lukšėnienė, 1981). Its pH should be neutral (Keyserlingk, 1990). It must not shrink, since a minimal amount will strain the fibres even if it does not visibly affect the appearance of the textile (Keyserlingk; Newey, et al.). The temperature and pressure required by the procedure must not be detrimental to the fibres (Flury-

Lemberg, 1988; Landi, 1992). Ideally it should be applied at room temperature (Leene). Facilities, such as fume extraction, must also be available to make it safe for the conservator to use the adhesive (Hillyer, et al., 1997; Keyserlingk).

Secondly, the dried adhesive should not alter the appearance or hand of the artifact. Excessive darkening or gloss is not acceptable (Lodewijks & Leene, 1972). Neither is a change in the texture of the fabric (Leene, 1963; Senvaitienė, et al., 1981). In backing treatments this usually means using an adhesive that can be applied in such a way that it penetrates the yarns as little as possible yet results in a secure bond. The adhesive, moreover, must be flexible and remain so over time, since an essential characteristic of fabrics and fibres is their flexibility (Blum, 1982; Keyserlingk, 1990; Landi, 1992; Lodewijks & Leene; Masschelein-Kleiner & Bergiers, 1984; Senvaitienė, et al.).

In addition, the adhesive must be stable over the long term so that it will continue to support the artifact and not affect it adversely. It must not release harmful degradation products or in any way increase the rate of deterioration of the textile (Blum, 1982; Flury-Lemberg, 1988; Keyserlingk, 1990; Landi, 1992; Lodewijks, 1972; Masschelein-Kleiner & Bergiers, 1984). It must not discolour or yellow (Blum; Keyserlingk; Landi; Lodewijks & Leene, 1972; Masschelein-Kleiner & Bergiers). The bond should neither weaken nor strengthen over time (Keyserlingk; Leene, 1963; Lodewijks & Leene). Under stress, the join should give, not the fibres (Bede, 1993; Newey, et al., 1992). At room temperature, the adhesive should not be sticky and attract dust (Bede; Masschelein-Kleiner & Bergiers). It should not interfere with future treatment, especially cleaning (Finch, 1980; Flury-Lemberg), nor with future study or analysis (Leene). Furthermore, it must remain soluble, and in solvents that are safe to use on the fibres and dyes of the textile (Blum; Lodewijks & Leene; Masschelein-Kleiner & Bergiers; Reeves, 1977). Masschelein-Kleiner and Bergiers have suggested that the physical properties of adhesives used on silk, such as moisture regain, tensile strength, and elongation at break, should match those of the fibres as much as possible in order to reduce the negative effects of ageing.

Adhesives used by textile conservators. A wide range of adhesive products has been used in textile backing treatments since the 1950s (Tables 3a and 3b). Two main groups can be identified: thermoplastic adhesives and water-soluble pastes made of starches and cellulose derivatives. Although thermoplastic adhesives are more widely used, interest in starch pastes has grown recently (Brooks, et al., 1995; Hillyer, et al., 1997). Many conservators continue to use the adhesive introduced during their training: Vinnapas EP1 for those from the Textile Conservation Centre at Hampton Court and Mowilith DMC2 for those from the Victoria and Albert Museum, for example (Hillyer, et

Table 3a. Vinyl Acetate-Derived Adhesives Used in Textile Backing Treatments

Adhesive Polymer	Product Name	References[a]
Vinyl Acetate Derivatives		
poly(vinyl) acetate	AYAA/AYAC (R)	Hillyer, et al., 1997[b]; Himmelstein & Appelbaum, 1977; Yates, 1987[b]
poly(vinyl alcohol)	Mowiol[c]	Leene, 1963; Lodewijks, 1980
vinyl acetate/dibutyl maleate copolymer	Mowilith DMC2[c] (D)	Blum, 1982; Boersma, 1998; Eaton & Wolbers, 1995; Gentle, 1998; Hillyer, 1984, 1990, 1993, 1995; Hillyer, et al., 1997[b]; Hillyer & White, 1998; Keyserlingk, 1990; Keyserlingk & Down, 1995; Landi, 1992; Lord, 1997; Vahlne, 1997; van Nes, 1983; *Vuistregels*, 1985; Yates, 1987[b]
	Mowilith DMC2[c]/DM5 (D)	Giorgi & Palei, 1997; Keyserlingk, 1990; Lochhead, 1995; Lodewijks, 1980; Marko, 1978; van Nes, 1983; van Nes & Kip, 1980; Yates, 1987[b]
	Mowilith DMV1[c]/DM5 (D)	Blum, 1982; Lodewijks & Leene, 1972; Yates, 1987[b]
vinyl acetate/acrylic copolymers	Mowilith DM5 (D)	Blum, 1982; Boersma, 1998; Hillyer, et al., 1997[b]; Willcox, 1980
	Vinamul 6815 (D)	Yates, 1987[b]
vinyl acetate/ethylene copolymer	Vinnapas EP1 (D)	Foskett & McClean, 1998; Hillyer, 1993; Hillyer, et al., 1997[b]; Keyserlingk, 1990; Landi, 1992; Yates, 1987
	Vinamul 3252 (D)	Finch, 1980; Hartog & Tinker, 1998; Hillyer, 1993, 1995; Hillyer, et al., 1997[b]; Hillyer & White, 1998; Yates, 1987[b]
	Vinamul 3254 (D)	Finch, 1980; Hillyer, et al., 1997[b]; Yates,1987[b]
	Elvace 1874[c] (D)	Bede, 1993; Hillyer, et al., 1997[b];
	Elvace 40705	Bede, 1993
	Elvace 675CX	D. Bede, personal communication, November 12, 1996
	Jade 403 (D)	Keyserlingk & Down, 1995
vinyl acetate/caprate copolymer	Vinamul 6515[c] (D)	Blum, 1982; Cruikshank, et al., 1998; Marko, 1978
	Vinamul (Setamul) 6525[c] (R)	Beecher, 1963; Blum, 1982; Boersma, 1998; Leene, 1963; Yates, 1987[b]
vinyl acetate/butyl acrylate/ acrylic acid copolymer	A-45K (R)	Senvaitienė, et al., 1981
ethylene/vinyl acetate copolymer	Beva 677[c]	Scott, 1977
	Beva 371 (R)	Grant, 1995; Hillyer, et al., 1997[b]; Keyserlingk, 1990; Keyserlingk & Down, 1995; Landi, 1992; Lochhead, 1995; Lord, 1997; Mailand, 1998; Muir & Yates, 1987; Peacock, 1983; Reeves, 1977; Yates, 1987[b]

R = resin; D = dispersion

[a] treatment may not have been carried out or condoned by the author

[b] survey results [c] product no longer used or available

Table 3b. Acrylic, Starch, and Cellulosic Adhesives Used in Textile Backing Treatments

Adhesive Polymer	Product Name	References[a]
Acrylics		
poly(butyl methacrylate)	Acryloid/Paraloid F10 (R)	de Groot, 1994; Hillyer, et al., 1997[b]; Keyserlingk, 1990, 1993; Landi, 1992; Mäder, 1980; Yates, 1987[b]
	Lascaux P550-40TB (R)	Hillyer, 1993; Hillyer, et al., 1997[b]; Keyserlingk, 1993; Keyserlingk & Down, 1995
poly(ethyl acrylate)/poly (methyl methacrylate) copolymer	Lascaux 360HV (D)/ Lascaux 498HV (D)	Hillyer, et al., 1997[b]; Keyserlingk, 1990; Keyserlingk & Down, 1995
poly(butyl acrylate)/poly (methyl methacrylate) copolymer	Rhoplex AC33 (D)	Carson, 1997
poly(ethyl acrylate)/poly (methyl methacrylate)/poly (ethyl methacrylate) copolymer	Texicryl 13-002	Hillyer, et al., 1997[b]
polyacrylic acid ester	Polyacryl D320	Fischer & Rothhaar, 1987
Starches		
wheat starch		Anikowitch, 1980; Hillyer, et al., 1997[b]; Leene, 1963; Lodewijks & Leene, 1972; Masschelein-Kleiner, 1980; Pullan, 1995; Seth-Smith, 1998; Thomson, 1984, 1992; Wagstaff, 1979; Wills, 1995; Yates, 1987[b]
rice starch		Hillyer, et al., 1997[b]
arrowroot starch/sodium alginate		Cruikshank & Morgan, 1995; Hillyer, et al., 1997[b]
potato starch		Eastop, 1995
starch blend	Stadex	Hillyer, et al., 1997[b]
Cellulose Ethers		
hydroxypropylcellulose (HPC)	Klucel G/Klucel L	Bond, 1995; Hillyer, et al., 1997[b]; Petschek, 1995
sodium carboxymethyl-cellulose(SCMC)	Blanose 7MC	Cruickshank & Morgan, 1995; Landi, 1992; Yates, 1987[b]
methylhydroxyethylcellulose		Yates, 1987[b]
methylcellulose		Hillyer, et al., 1997[b]

R = resin; D = dispersion

[a] treatment may not have been carried out or condoned by the author

[b] survey results

al.). Lack of opportunity to gain experience with other adhesives since the treatment is used infrequently accounts for this conservatism. Conservators who can easily consult with those who have experience with adhesive treatments in paintings, paper, and ethnographic conservation are more likely to expand treatment options (Hillyer, et al.).

Justification of adhesive choices. The adhesives used by textile conservators today have proven to be relatively stable in one or more scientific investigations (Hillyer,et al., 1997). Several conservators have cited research results to support their choice of adhesive. Excellent testing results in studies at the Victoria and Albert Museum (Pretzel, 1993, 1997a, 1997b) and the Courtauld Institute (Howells, et al., 1984) were recognized by Hartog and Tinker (1998), and Hillyer and White (1998) in choosing Vinamul 3252. Bede (1993) credited the excellent ageing qualities of Elvace 1874 as demonstrated by tests for paper conservation (Baer, Indictor, Schwartzman, & Rosenberg, 1975). Himmelstein and Appelbaum (1977), citing the same body of work, chose poly(vinyl acetate) resins over dispersions because of their documented higher solubility and their greater flexibility if used properly. Peacock (1983) referred to the work of Berger (1972) in support of her choice of Beva 371. Petschek (1995) found evidence of the relative stability of Klucel G in Feller and Wilt's research on cellulose ethers (1990). In large institutions, conservators may be able to rely on accelerated ageing tests conducted by scientists in the institution's research laboratories (Hillyer, 1984; Wills, 1995). Without referring to any particular research, conservators often mentioned the adhesive's stability as an important factor (Cruikshank & Morgan, 1995; de Groot, 1994; Hillyer, et al., Lord, 1997). Properties related to long-term stability such as continuing reversibility in reasonably safe solvents, retention of colour, and lack of volatile emissions were also noted (Carson, 1997; Hillyer, et al.; Lord). Keyserlingk (1990) reviewed the characteristics of several adhesives used in textile conservation in light of interim results from the adhesives testing program at the Canadian Conservation Institute (Down, et al., 1992, 1996). Although starch pastes tend to stiffen with age and are susceptible to biodeterioration in humid environments (Lodewijks & Leene, 1972; Masschelein-Kleiner, 1980), some conservators have defended their use on the basis that at least these less than ideal long-term ageing properties are known (Masschelein-Kleiner; Thomsen, 1992). Many conservators still feel, however, that research has not provided enough appropriate information on long-term changes or the interrelationship between adhesive, support fabric, and artifact (Hillyer, et al.).

The results of apparently unpublished comparative testing have also been referred to as justification. Senvaitienė, et al. (1981) cited their own research on fifteen polymers in support of their choice of A-45K, a copolymer of vinyl acetate, butylacrylate, and acrylic acid. This adhesive dissolved in several organic solvents and produced colourless, transparent films that were very flexible and had a suitably matte finish. Ageing tests of the copolymer indicated that it was sufficiently stable. Mäder (1980) based his choice of Paraloid F10 on the results of testing of more than twenty adhesives by Muhlethaler at the Swiss National Museum. These reports would have been more useful if the results of the testing had been described in greater detail. Which adhesives were not chosen and why can be very informative. Other authors mentioned research in progress that does not appear to have been made readily accessible to the conservation field (Melville Smith, 1980; Reeves, 1977).

The handling qualities of adhesives can be considered as important as their chemical stability (Keyserlingk, 1990). Experience with an adhesive that is easily worked may influence choice (Bede, 1993; Cruikshank & Morgan, 1995; Hartog & Tinker, 1998; Hillyer, 1984; Hillyer & White, 1998; Peacock, 1983). The slight tack of adhesives such as Beva 371 and Vinamul 3252 have been mentioned as useful in the course of treatment (Hillyer, et al, 1997; Hillyer & White; Mailand, 1998). The lack of suitable fume extraction facilities prevents many textile conservators from using adhesives that must be dissolved in organic solvents (Hillyer, et al.; Hillyer & White; Keyserlingk). The availability of the adhesive in small quantities is also a factor (Bede).

The properties of the chosen adhesive are frequently mentioned. Characteristics referred to in general include flexibility (Bede, 1993; Carson, 1997; Cruikshank & Morgan, 1995; Hillyer, et al., 1997; Lord, 1997; Mailand, 1998; Muir & Yates, 1987), pH (Hillyer, et al; Hillyer & White, 1998), bond strength (Cruikshank & Morgan; Hillyer, et al.; Lord; Mailand; Muir & Yates), activation temperature (Hillyer, 1984; Hillyer, et al.), glass transition temperature (Hartog & Tinker, 1998; Hillyer, et al.; Hillyer & White), thermoplasticity (Himmelstein & Appelbaum, 1977), short-term reversibility in suitable solvents (Muir & Yates; Peacock, 1983), transparency, and sheen (Cruikshank & Morgan; Hillyer, et al.; Lord; Muir & Yates). In many cases the conservator explicitly described how the adhesive met the needs of the particular artifact being conserved. Scott (1974) chose to use a thermoplastic adhesive rather than rice paste because a vacuum hot table could provide the even pressure needed during bond formation without crushing the pile of the embroidered velvet panel she was conserving. Similarly, Lord (1997) used Beva 371 since she could attach the prepared support to a very fragile and soft surface by means of a heat gun and spatula. By contrast, Cruickshank and Morgan chose to use a starch paste instead of a thermoplastic adhesive because their artifact, an ancient

Egyptian shroud, could have been damaged by the heat required in heat-sealing. Peacock chose Beva 371 for backing a painted silk banner in part because the adhesive was specifically developed to be activated at a temperature considered best for treatment of old, distorted paint films. Temperatures of 65°C to 70°C render the paint slightly plastic, which permits bringing it into contact with the supporting fabric. Others have indicated that Beva 371 remains soluble in organic solvents that are safe for paints (Hillyer, et al.). Lochhead (1995) also used Beva 371 for the painted areas of banners for these reasons, but substituted Mowilith DMC2 for supporting any unpainted areas since Beva 371 could stain plain silk. Boersma (1998) used Mowilith DMC2 for its low heat-sealing temperature in order to protect the heat-sensitive paint on a banner. Moreover, she chose a poly(vinyl acetate) adhesive since it was considered more compatible with residual adhesive from earlier treatments that remained in the banner. De Groot (1994) chose Paraloid F10 over Mowilith DMC2 because the acrylic adhesive is less sensitive to humidity fluctuations than the poly(vinyl acetate). The wall panels that she was in charge of conserving would be reinstalled in a relatively uncontrolled environment. The excellent flexibility of Vinamul 3252 was important to Hartog and Tinker since they needed to maintain the drape of net dresses. The importance of flexibility for costume artifacts has also been recognized by others (Hillyer, et al.). As described below, conservators may use small scale tests of possible adhesives to help make a decision (Grant, 1995; Lord, 1997; Wills, 1995). Many remain fully aware of the short-comings of the adhesive they finally choose (Lord; Muir & Yates; Petschek, 1995).

Preparation of the adhesive. Almost all adhesives need some form of preparation before they can be used for textile backing treatments. Adhesives soluble in organic solvents or water are usually not available in ready-to-use formulations. Several recipes have been published for starch pastes (Lodewijks & Leene, 1972; van Steene & Masschelein-Kleiner, 1980; Wills, 1995). Modification through acid treatment and the addition of a biocide (van Steene & Masschelein-Kleiner) or through the addition of gelatine, glycerine, alcohol, and a biocide (Lodewijks & Leene, 1972) can produce a more flexible, quicker-drying and mould-resistant product. Adhesives, such as Beva 371, Acryloid (Paraloid) F10, and the poly(vinyl acetate) resins, may be dissolved in a variety of organic solvents. For example, conservators have reported using solutions of Beva 371 in toluene (Keyserlingk, 1990; Keyserlingk & Down, 1995), VM&P naptha (Mailand, 1998), white spirit (Keyserlingk; Muir & Yates, 1987), petroleum spirits (Muir & Yates), and xylene (Lord, 1997; Peacock, 1983). Thomson (1984) experimented with acetone and toluene solutions of AYAA and AYAC before deciding to use a combination of both solvents and both adhesives for the preparation of a temporary facing. Although dispersion adhesives can be used straight, most conservators dilute them to make application easier. Solutions of 5 to 60 percent adhesive in distilled water have been reported (Bede, 1993; Hillyer, 1984, 1990; Landi, 1992), but 10 to 25 percent is now common (Boersma, 1998; Hillyer, 1993, 1995; Keyserlingk & Down). Hartog and Tinker (1998) tested several concentrations of Vinamul 3252 in order to find the minimum amount of adhesive needed for a sufficiently strong bond. Mixing dispersions with different properties, such as adding a more flexible but tacky adhesive to a slightly stiffer one, may produce an adhesive with working properties that are preferable to those of the individual products for certain applications. Mowilith DM5 and DMC2 and Lascaux 360HV and 498HV are often used in combination for this reason (Keyserlingk).

Backing Fabrics

Fabrics used and why. The backing fabric supports the artifact while interfering as little as possible with its visibility and flexibility (Lodewijks, 1980). Beecher (1963) suggested that the support should be stronger but weigh less than the artifact for best results. Various support materials have been used for textile adhesive treatments (Table 4). Most maintain a good degree of flexibility. In the eighteenth and nineteenth centuries, flags were often glued onto silk or canvas of all weights (Foskett & McClean, 1998; Mäder, 1980). Lodewijks and Leene (1972) warned that the texture of coarse fabrics like canvas or thick tulle can become imprinted on the artifact if it is made of a thinner material. They also suggested that the hardness of the yarns can contribute to the wear of the textile during handling. More recently, closely woven fabrics of cotton (Bede, 1993; Eastop, 1995; Hillyer, et al., 1997; Reeves, 1977), silk (Hillyer, et al.; Masschelein-Kleiner, 1980; Reeves), polyester (Landi, 1986; Scott, 1974), wool, or linen (Yates, 1987) have served as backings. Thin Japanese paper has also been used (Cruickshank & Morgan, 1995; Masschelein-Kleiner; Pullan, 1995). Such materials maintain flexibility but obscure the adhered surface.

Early attempts to provide for transparency of the backing material were either visually intrusive or destroyed the flexibility of the artifacts. Many turn of the century stitching treatments of flags utilized nets or tulle of linen, cotton, or silk (Mäder, 1980). The nets maintained a good degree of flexibility and allowed a certain degree of visibility. The coarseness of the yarns, however, rendered these nets aesthetically unacceptable (Lodewijks, 1972). Lodewijks (1980) described attempts to mount silk flags on acrylic sheet (Perspex) and polyester film (Mylar). These were abandoned because the

Table 4. Backing Materials Used in Textile Backing Treatments

Backing Fabric	References[a]
silk crepeline	Bede, 1993; Blum, 1982; Boersma, 1998; Bond, 1995; Carson, 1997; de Groot, 1997; Eaton & Wolbers, 1995; Fischer & Rothhaar, 1987; Foskett & McClean, 1998; Gentle, 1998; Himmelstein & Appelbaum, 1977; Hillyer, 1993; Hillyer, et al., 1997[b]; Keyserlingk, 1990, 1993; Keyserlingk & Down, 1995; Landi, 1992; Lochhead, 1995; Lodewijks, 1980; Lord, 1997; Muir & Yates, 1987; Peacock, 1983; Petschek, 1995; Thomson, 1984; Vahlne, 1997; Willcox, 1980; Wills, 1995; Yates, 1987[b]
polyester crepeline (Stabiltex, Tetex)	Bede, 1993; Boersma, 1998; de Groot, 1994; Giorgi & Palei, 1997; Hillyer, 1990, 1995; Hillyer, et al., 1997[b]; Hillyer & White, 1998; Keyserlingk, 1990, 1993; Keyserlingk & Down, 1995; Landi, 1992; Lochhead, 1995; Lodewijks, 1980; Mäder, 1980; Muir & Yates, 1987; Thomsen, 1992; van Nes & Kipp, 1980; Willcox, 1980; Yates, 1987[b]
nylon net	Bede, 1993; Beecher, 1963; Blum, 1982; Cruikshank, et al., 1998; Doré, 1980; Finch, 1980; Gentle, 1998; Hartog & Tinker, 1998; Hillyer, 1984; Hillyer, et al., 1997[b]; Hillyer & White, 1998; Landi, 1992; Lochhead, 1995; Marko, 1978; Yates, 1987[b]
other sheer fabrics	Anikowitch, 1980; Beecher, 1963; Hillyer, 1990; Mailand, 1998; Marko, 1978
nonwoven	Hillyer, et al., 1997[b]; Katchanova, 1987
other fabrics	Bede, 1993; Eastop, 1995; Hillyer, 1984, 1990; Hillyer, et al., 1997[b]; Hillyer & White, 1998; Himmelstein & Appelbaum, 1977; Katchanova, 1987; Landi, 1986, 1992; Masschelein-Kleiner, 1980; Reeves, 1977; Thomsen, 1984; Yates, 1987[b]
Japanese paper	Brooks, et al., 1995; Cruickshank & Morgan, 1995; Hillyer, et al., 1997[b]; Masschelein-Kleiner, 1980; Pullan, 1995; Seth-Smith, 1998; Wagstaff, 1979; Yates, 1987[b]
polyester film	Lodewijks, 1980

[a] treatment may not have been carried out or condoned by the author
[b] survey results

materials were overly rigid.

An acceptable balance between transparency and flexibility has been found in fine, sheer fabrics that are presently favoured for adhesive treatments: silk and polyester crepeline, and nylon net. Of these, silk and polyester crepeline are used most extensively (Hillyer, et al., 1997; Yates, 1987). Although sometimes more obtrusive, other sheer fabrics, such as organdies, chiffons, other nets and tulles, and nonwovens, have also been employed (Anikowitch, 1980; Beecher, 1963; Hillyer, 1990; Mailand, 1998; Marko, 1978). In many treatments, artifacts adhered to sheer backings may be further adhered or stitched to another, firmer support fabric or mount (de Groot, 1997; Hillyer, 1984, 1990; Hillyer & White, 1998; Himmelstein & Appelbaum, 1977; Katchanova, 1987; Keyserlingk, 1990, 1993; Landi, 1992; Masschelein-Kleiner, 1980; Peacock, 1983; Thomsen, 1984). Such treatment can eliminate access to the supported side of the artifact and can add considerably to the stiffness of the textile, if not rendering it rigid. Yet the conservation of the object may require it. In these cases, the sheer backing stabilizes the fragmented object so that it can be handled safely during attachment to the second support fabric (Hillyer, 1995; Hillyer & White). The second layer of fabric may serve three functions (Landi, p. 120). First, it isolates the adhesive, which, if slightly tacky at room temperature, will attract dust or stick to adjacent materials. A layer of silk crepeline may be sufficient for this purpose (Landi). Secondly, it provides an aesthetically more pleasing fill for losses in the artifact and a more solid support for stitching. Finally, if stitching is done for further support, for repair, or to attach the artifact to a display mount, the adhesive backing minimizes the amount of stitching needed (Hillyer; Hillyer & White). The reverse of the artifact, therefore, may remain more readily accessible than if the artifact were stitched or adhered directly to a solid support.

Factors affecting choice. Ideally the choice of backing fabric depends on the needs of the particular artifact, but working characteristics also affect decisions. Silk crepeline remains the substrate of choice, at least in the United Kingdom and Europe (Hillyer, et al., 1997). It is almost transparent (Bede, 1993; Fischer & Rothhaar, 1987; Keyserlingk, 1990, 1993; Lodewijks, 1980) and relatively matte (Bede). It is easily and relatively safely dyed to match the colour of the artifact (Bede; Hillyer, et al.; Keyserlingk). It conforms well and thus can support uneven surfaces (Hillyer, et al.; Keyserlingk). Nevertheless, it is not very strong and is very susceptible to light degradation (Ellis, 1997; Lodewijks; Keyserlingk). Keyserlingk has suggested that the difference due to light ageing may not be significant in the context of backing treatments since light exposure is often minimal. The adhesive coating may also retard the deterioration of the silk fibres (Bede; Keyserlingk). However, many artifacts needing an adhesive backing treatment exhibit significant losses. The support backing is exposed to light in these areas and the adhesive coating is often removed in order to prevent dirt buildup. Degradation in these exposed areas could seriously impair the ability of the backing to act as a support. Furthermore, the adhered support may not be shielded from light if used as a facing on artifacts that are double-sided or whose reverse is not accessible.

In contrast, polyester crepeline, which is known by the trade names Stabiltex or Tetex, is more opaque than silk crepeline, but is also stronger and more durable (Bede, 1993; Ellis, 1997; Fischer & Rothhaar, 1987; de Groot, 1994; Hillyer, et al., 1997; Keyserlingk, 1990, 1993; Lodewijks, 1980). Because of its tendency to generate static electricity (Keyserlingk) and its relatively stiff fibres (Fischer & Rothhaar), polyester crepeline is more difficult to manipulate and finish tidily. It does not conform well and will lift away from surfaces that are uneven, like the distorted silk around painted areas of flags and banners (Keyserlingk). Polyester is also difficult to dye (Bede; Fischer & Rothhaar; Hillyer, et al.; Keyserlingk; Lodewijks), requiring either high temperatures and pressure or hazardous chemicals to act as carriers for low temperature dyeing. Dyeing is usually left to the manufacturer who produces only a few colours, which rarely match those of particular artifacts (Fischer & Rothhaar; Keyserlingk; Lodewijks). Some conservators have dyed polyester crepeline themselves (Landi, 1992).

Nylon net is highly transparent and may be more visually acceptable for the backing of laces and nets (Hartog & Tinker, 1998; Hillyer, 1990; Hillyer, et al, 1997). Bede (1993) stated that it can give a stronger bond. Like silk crepeline, it conforms well to uneven surfaces, such as the backs of many embroideries, although it has been found to peel away from compound weaves (Hartog & Tinker). It may be more appropriate for heavier textiles like cottons, very smooth but stiff velvets, and thick satins (Bede; Landi, 1992). Its rough surface is not ideal for lightweight fabrics and friable silks (Bede). It dyes well and is available in a wide range of colours (Bede). Edges are finished easily and neatly by trimming (Bede). It is available in five metre widths, allowing large banners to be backed without joining sections (Hillyer, et al.). Like silk, nylon degrades when exposed to light (Hatch, 1993; Hudson, et al., 1993). However, cases where both nylon net and silk crepeline have been used on the same artifact have shown the net to be more resistant to degradation (Gentle, 1998; Hartog & Tinker). As for silk, the adhesive coating has been suggested to perform a protective function (Hartog & Tinker). The use of nylon net has declined, nevertheless, since it is prone to distort and stretch when the adhesive is applied, especially if the net is suspended (Gentle; Hillyer, et al.). Subsequent reversion to its original dimensions may cause wrinkling on treated artifacts (Gentle).

Paper has also been used by a surprisingly large number of conservators (Hillyer, et al., 1997). It is especially malleable because it has no weave structure, and will thus support uneven surfaces (Hillyer, et al.). It is often used in conjunction with starch pastes (Cruikshank & Morgan, 1995; Hillyer, et al.; Masschelein-Kleiner, 1980; Pullan, 1995; Seth-Smith, 1998; Wagstaff, 1979) and on artifacts, such as Japanese scrolls, that are traditionally made and repaired in this way (Hillyer, et al.). Some conservators feel that paper is more compatible with cellulosic textiles (Cruikshank & Morgan; Hillyer, et al.).

Preparing the backing fabric for adhesive application. Backing fabrics are washed and, if necessary, dyed before the adhesive is applied. Washing removes finishes, sizes, and manufacturing residues that could be potentially harmful to the artifact and could interfere with the adhesive bond (Brooks, et al., 1995; Landi, 1992, p. 59). Gentle washing techniques are necessary for preparing open weave fabrics such as silk and polyester crepeline since the weave is easily distorted (Landi, p. 60). If necessary, the fabric is dyed to match the colour of the artifact, so that it will appear almost invisible. These preparation steps are identical to those used for stitched supports.

Preparing the Adhesive Support

The first step of an adhesive backing treatment, after the artifact has been cleaned, is to apply the adhesive to the support material. Of the handful of techniques reported (Table 5), conservators commonly use some sort of brush, sponge, or roller (Hillyer, et al., 1997). The backing fabric is carefully laid out on top of a non-stick material, such as polyethylene, polyester film, or Teflon-coated glass fabric. The fabric is aligned and held in place with weights (Keyserlingk, 1993; Landi, 1992) or, for net, velcro strips attached to the sides of the table (Hartog & Tinker, 1998). Correct tension is especially important for nylon net (Hartog & Tinker). The diluted adhesive is then brushed over the fabric. The method of brushing varies from conservator to conservator. Keyserlingk (1993; Keyserlingk & Down, 1995) recommended working from the secured

Table 5. Methods of Applying Adhesives to Backing Material

Method	References[a]
brush	Anikowitch, 1980; Bede, 1993; Boersma, 1998; Bond, 1995; Carson, 1997; Cruickshank & Morgan, 1995; Fischer & Rothhaar, 1987; Gentle, 1998; Hillyer, 1993, 1995; Hillyer, et al., 1997[b]; Keyserlingk, 1990, 1993; Keyserlingk & Down, 1995; Landi, 1992; Lochhead, 1995; Lodewijks, 1980; Lodewijks & Leene, 1972; Masschelein-Kleiner, 1980; Petschek, 1995; Pullan, 1995; Seth-Smith, 1998; Wills, 1995; Yates, 1987[b]
sponge	Hillyer, 1984; Hillyer, et al., 1997[b]; Hillyer & White, 1998; Landi, 1992; Lochhead, 1995; Willcox, 1980; Yates, 1987[b]
roller	Hartog & Tinker, 1998; Hillyer, 1995; Hillyer, et al., 1997[b]; Landi, 1992; Yates, 1987[b]
spray	Himmelstein & Appelbaum, 1977; Hillyer, et al., 1997[b]; Keyserlingk, 1990; Keyserlingk & Down, 1995; Landi, 1992; Lord, 1997; Mailand, 1998; Muir & Yates, 1987; Peacock, 1983; Reeves, 1977; Scott, 1974; Senvaitienė, et al., 1981; Yates, 1987[b]
film	Landi, 1986, 1992
immersion	Yates, 1987[b]

[a] treatment may not have been carried out or condoned by the author
[b] survey results

top edge in continuous, even strokes that do not overlap in order to avoid adhesive build up. Lodewijks and Leene (1972) illustrated a more random application. Bede (1993) and Landi suggested brushing from the centre out. According to Bede, the coating levels out as it dries, so evenness during application is not important. Hartog and Tinker used a single application by roller on nylon net. Rolling over a second time with a wrung out roller removed adhesive from the upper surface. The conservator must carefully remove air bubbles that separate the fabric and substrate in order to ensure an even adhesive coat (Bede; Keyserlingk; Landi). Depending on the adhesive or concentration of adhesive used, these techniques produce two types of coatings: a film that coats only the yarns (Bede; Hillyer, et al., Keyserlingk), or a continuous film reinforced by the fabric on one side (Hillyer, et al., Landi). Brushing is also used to coat Japanese papers with starch pastes, often using techniques derived from paper conservation (Hillyer, et al.; Masschelein-Kleiner, 1980; Pullan, 1995).

The substrate against which the backing fabric is coated with adhesive and the type of backing fabric used may affect the nature of the adhesive coating. Several materials have been used as substrates (Table 6). Each affects the surface appearance of the coating and the ease with which the backing can be peeled away (Brooks, et al.,

Table 6. Supports for Backing Material During Adhesive Application

Support	References[a]
polyethylene	Brooks, et al., 1995; Hartog & Tinker, 1998; Hillyer, 1993; Hillyer, et al., 1997[b]; Keyserlingk, 1990; Landi, 1992
polyester film (Mylar, Melinex)	Boersma, 1998; Bond, 1995; Brooks, et al., 1995; Cruikshank & Morgan, 1995; Hillyer, et al., 1997[b]; Keyserlingk, 1990; Landi, 1986, 1992; Lodewijks & Leene, 1972; Petschek, 1995; Pullan, 1995; Seth-Smith, 1998
Teflon-coated glass fabric	Brooks, et al., 1995; Hillyer, et al., 1997[b]; Keyserlingk, 1990, 1993; Keyserlingk & Down, 1995; Landi, 1992
silicon elastomer-coated glass cloth	Bede, 1993
silicone release paper	Hillyer, et al., 1997[b]; Lochhead, 1995; Pretzel, 1997a
stretcher (suspended)	Gentle, 1998; Hillyer, 1984; Hillyer, et al., 1997[b]; Himmelstein & Appelbaum, 1977; Keyserlingk & Down, 1995; Landi. 1972, 1992; Peacock, 1983; Willcox, 1980
other	Anikowitch, 1980; Masschelein-Kleiner, 1980

[a] treatment may not have been carried out or condoned by the author
[b] survey results

1995; Hillyer, et al., 1997; Keyserlingk, 1993). Adhesive coatings that are cast against polyethylene have a medium sheen and are easy to release from the substrate, unless prepared at low humidities (Z. Tinker, personal communication, November 18, 1997). Polyethylene is cheap but relatively difficult to lay out completely flat and smooth (Landi, 1992, p. 121). A substrate of polyester film (Mylar or Melinex) produces shinier coatings that can be more difficult to release. When very thin polyester film (12 µm) is used, the coated backing can be peeled off in narrow strips. This facilitates the treatment of very large banners (Hillyer, et al.). Adhesive coatings cast on Teflon-coated glass fabric are thinner, and more matte than those prepared on other substrates. They are also very easy to release from the substrate (Hillyer, et al.; Landi). Teflon-coated glass fabric is very expensive, but durable and can be reused for years (Keyserlingk). Backing fabrics prepared on it are peeled off when dry and rolled in silicone release paper for storage until application to the artifact, unlike those prepared using polyethylene or polyester film, which are usually left on the substrate. Nonwoven polyester can be used for a similar effect for starch paste treatments (Masschelein-Kleiner, 1980). Other non-stick materials, such as waxed paper or silicone release paper, cockle when wetted by aqueous adhesives, leaving the fabric not properly coated with adhesive (M. Keyserlingk, personal communication, November 16, 1995). Silicone release paper may be used, however, with adhesives dissolved in organic solvents (Lochhead, 1995; Pretzel, 1997a). The degree to which the adhesive penetrates the yarns of the fabric may depend on the type of fibre. Hillyer has suggested that more adhesive remains on the surface of hydrophobic polyester fabrics than on silk crepeline or cotton (Hillyer, et al.; L. Hillyer, personal communication, February 13, 1998).

Adhesives have also been brushed or sponged onto suspended fabric (Landi, 1992). Several coats of adhesive are applied along the warp and weft of net or polyester crepeline held in a specially designed apparatus (Landi, p. 183). Because the fabric is suspended, the adhesive will only coat the yarns. One or both sides of the fabric can be coated. Gentle (1998) reported difficulties in maintaining the tension of nylon net using this method. When coated, the net would sag, making the next coat difficult to apply. Thus, the fabric was often restretched between coats. This may have resulted in nets set in an overstretched state.

Adhesives soluble in organic solvents, such as Beva 371 or AYAA/AYAC, can be sprayed onto the fabric surface (Hillyer, et al., 1997; Keyserlingk & Down, 1995; Peacock, 1983). The support fabric is stretched taut over a wooden stretcher frame with warp and weft aligned. Several coats of adhesive are sprayed onto the fabric as evenly as possible, letting each coat dry before the next is applied. The nature of the adhesive coat is affected by the distance from which it is sprayed. Keyserlingk suggested spraying Lascaux Hot-seal Adhesive from approximately five feet so that the adhesive forms a fine, almost dry dust on the fabric (M. Keyserlingk, personal communication, November 17, 1995). Reeves (1977) described an application of the adhesive directly to the back of the artifact. Such practice is no longer recommended (Keyserlingk, 1990). Because of the toxic nature of the organic solvents, a fumehood or spray booth and appropriate protective clothing are required (Hillyer, et al.; Keyserlingk & Down). Lacking a large enough fumehood, Peacock prepared a sprayed backing outdoors. The direction of air currents relative to the stretcher may affect the amount of adhesive coating the fabric, especially when small pieces are sprayed from a distance. A sprayed coating may have different properties than a brushed coating of the same adhesive. Keyserlingk reported that when Beva 371 is sprayed onto the backing fabric, it gives stronger bonds at lower temperatures than when it is brushed on.

The adhesive can also be applied to the support fabric by immersion (Yates, 1987) or as a film (Landi, 1986, 1992). An adhesive film can be cast onto polyethylene or silicone-elastomer-coated glass cloth using either spraying or brushing (Landi, 1992). Beva 371 is available in a ready made film, though it is thick and has a tendency to darken fabrics (M. Keyserlingk, personal communication, November 16, 1995; Landi, 1992). Few conservators use either of these techniques for textile backing treatments.

Attaching the Support to the Artifact

The adhesive-coated backing is attached to the artifact in three main ways: through direct application while the adhesive is still wet, and by reactivation of the dried adhesive either by means of a solvent or by heat (Table 7). The manner in which the artifact is adhered to the prepared support depends on the properties of the adhesive chosen.

Direct application. In direct or wet application, coating the support material and adhering the artifact to it are combined into one operation. This technique is used almost exclusively with pastes made from starches or cellulose derivatives, since they are not thermoplastic. Masschelein-Kleiner (1980), Pullan (1995), and Seth-Smith (1998) described the method in detail. The artifact is laid face down onto a non-woven polyester and carefully wetted. The support material, usually Japanese paper, is placed on polyester film and also wetted. The adhesive is then brushed thinly onto the paper backing. The prepared backing is then laid onto the back of the damp artifact and the

Table 7. Adhesion Techniques

Technique	References[a]
Direct Application	Anikowitch, 1980; Eastop, 1995; Finch, 1980; Hillyer, et al., 1997[b]; Masschelein-Kleiner, 1980; Pullan, 1995; Seth-Smith, 1998; Thomsen, 1984; Wills, 1995; Yates, 1987[b]
Solvent Reactivation	
brushed on	Bond, 1995; Petschek, 1995
cold-lining	Cruickshank & Morgan, 1995; Hillyer, et al., 1997[b]; Yates, 1987[b]
unspecified	Bede, 1993; Hillyer, et al., 1997[b]
Heat-sealing	
spatula or tacking iron	Bede, 1993; Boersma, 1998; Brooks, et al., 1995; Carson, 1997; Eaton & Wolbers, 1995; Fischer & Rothhaar, 1987; Hartog & Tinker, 1998; Hillyer, 1984, 1995; Hillyer, et al., 1997[b]; Hillyer & White, 1998; Himmelstein & Appelbaum, 1977; Keyserlingk, 1990, 1993; Landi, 1972, 1986, 1992; Lochhead, 1995; Mäder, 1980; Mailand, 1998; Peacock, 1983; Yates, 1987[b]
flat iron	Bede, 1993; Beecher, 1963; Boersma, 1998; Brooks, et al., 1995; Cruikshank, et al., 1998; Grant, 1995; Hillyer, 1995; Hillyer, et al., 1997[b]; Keyserlingk, 1990, 1993; Keyserlingk & Down, 1995; Landi, 1992; Lodewijks, 1972, 1980; Lodewijks & Leene, 1972; Peacock, 1983; Senvaitienė, et al., 1981; Willcox, 1980; Yates, 1987[b]
vacuum hot table	Bede, 1993; Brooks, et al., 1995; Hartog & Tinker, 1998; Hillyer, 1984, 1990, 1995; Hillyer, et al., 1997[b]; Landi, 1973, 1992; Marko, 1978; Reeves, 1977; Scott, 1974; Yates, 1987[b]
hot air gun and spatula	Lord, 1997
infrared heat	Beecher, 1963; Clark & Sebera (cited in Hillyer, et al., 1997)
unspecified	Blum, 1982; Boersma, 1998; de Groot, 1994; Gentle, 1998; Giorgi & Palei, 1997; Hillyer, 1993; Katchanova, 1987; Lodewijks, 1972; *Vuistregels*, 1985

[a] treatment may not have been carried out or condoned by the author
[b] survey results

polyester film removed. Gentle pressing with rollers brings the backing into contact with the artifact. Drumming or tamping with brushes improves adhesion along surface irregularities. The backed artifact is allowed to dry slowly in order to avoid stretching and to give a perfect fit between artifact and support. A flat finish of artifacts backed with paper can be achieved by moistening the artifact, and pasting the extended edges of the paper backing to a drying board or Formica table. A suction table can also keep the artifact flat when mounting and drying and can help remove excess water (Thomsen, 1984). In addition, Thomsen sandwiched the artifact between padded boards to keep it flat during drying. Direct application has also been used to install silk wall coverings in situ (Eastop, 1995).

Wet application of starch pastes requires considerable skill for good results (Keyserlingk, 1993; Pullan, 1995). The adhesive can penetrate through textiles and leave dark spots or visible residue (Lodewijks & Leene, 1972; Mäder, 1980; Pullan). According to Landi (1992, p. 130), a conservator can learn from experience when the paste has reached a point of maximum "tack" at which penetration is less of a problem. The wetting of the artifact, which helps to achieve a good bond, may do so by enabling the paste to move into the textile fibres (Pullan). The result can be a very stiff artifact which may be damaged if flexed (Pullan). The dangers of swelling and problems with unstable dyes are also concerns (Landi).

Solvent reactivation. One way to reduce the risk of the adhesive penetrating the artifact and the affiliated problems with stiffness and spotting is to use a solvent reactivation technique. A suitable solvent is applied to the dried adhesive, which swells and becomes tacky. The coated backing is then applied to the artifact. Bond (1995) and Petschek (1995) brushed on industrial methylated spirit (IMS) or propanone and ethanol respectively to reactivate Klucel G in order to attach silk crepeline facings to very fragile embroideries. The use of organic solvents protected water-soluble paints (Petschek) and gave a quick-setting bond without undue pressure (Bond). Lodewijks and Leene (1972) described a similar technique for synthetic resins but cautioned that it required skill to perform well, much like direct application. Too much solvent may liquify the adhesive, which penetrates the textile in spots as a result. It may also remove thin adhesive coatings from the surface of the kind of open fabrics that textile conservators use, resulting in no adhesion at all (Bond). Too little solvent will also produce insufficient adhesion. Furthermore, the procedure must be completed quickly, with no room for error in placement.

Cruickshank and Morgan (1995) further minimized the risk of liquid penetration by using humidification to reactivate a sodium carboxymethyl cellulose-arrowroot starch paste. Vacuum pressure helped achieve a suitable bond. The prepared mulberry paper support was laid out on a vacuum table, heated to 32°C and humidified. The linen artifact, also humidified, was then positioned on the support and covered with a non-woven release sheet and a latex cover for sealing. Over a two and a half hour period, the humidity and pressure around the artifact were raised and then allowed to drop again. A maximum of 90% RH, and 36 millibars of pressure for 15 minutes was reached in order to reactivate the adhesive and secure the bond.

Heat-sealing. If a thermoplastic adhesive is used, it can be reactivated with heat. Heat-seal techniques predominate in textile conservation today (Hillyer, et al., 1997). This method allows more time to carefully align the grain of the artifact to the backing fabric and involves less risk of adhesives soaking through (Himmelstein & Appelbaum, 1977; Lodewijks & Leene, 1972). Although relatively low temperatures are needed to soften the adhesives that conservators use (usually 60°C to 80°C, well under the 120°C cool setting on a domestic iron), the potentially damaging effects of heat are a concern (Cruikshank & Morgan, 1995; Hillyer, et al.).

Most conservators use either a vacuum hot table or hand-held irons or spatulas (Table 7). The technique employed depends on the available technology and the nature of the artifact. The vacuum hot table is suitable for flat, smooth, non-textured textiles. Landi (1973, 1992) has described the process in detail. Sandwiched between layers of polyester film, the artifact and prepared support are placed on a metal plate and covered with a rubber sheet. The metal plate is gradually heated to a temperature sufficient to soften the adhesive. The rubber sheet, weighted down along the edges, provides the seal that enables sufficient pressure to be generated to bond the artifact and the support together. The artifact can be placed under or on top of the backing according to its needs, although usually the backing fabric is placed against the heated metal plate. Adhesion takes place in one operation under relatively even temperature and pressure. The high pressure levels (300 to 400 mm Hg) that were used in past treatments (Hillyer, 1984; Landi, 1973, 1992; Marko, 1978) are now considered to be unnecessary and damaging (Blum, 1982; Hillyer, et al., 1997). Recent treatments have shown that pressures of 40 mm Hg are sufficient to secure an adequate bond. Although a considerable length of time may be required to heat the metal plate and afterwards let it cool, maximum heat and pressure are maintained for only a few minutes (Landi).

When a vacuum hot table is not available or not recommended for the artifact, spatulas or irons are used. Certain artifacts cannot be heat-sealed on a vacuum hot table. Distorted fabric surrounding heavy paint layers or thick embroidered decoration can be permanently creased under vacuum pressure (Keyserlingk, 1993; Reeves, 1977). Three dimensional textiles, such as costume, must of necessity be treated with hand held irons, unless they are dismantled (Landi, 1992). Landi recommended starting with manual techniques before using a hot table, in order to have more direct exposure to how the treatment works and how it can be manipulated. Some conservators are concerned, however, that the relatively uneven pressure of a hand-held instrument may affect the stability of the bond (Hillyer, 1995; Hillyer & White, 1998; Landi).

The method is relatively simple. The artifact is laid face down on a slightly padded surface. Landi (1992) suggested cotton flannelette covered with polyester film (Melinex). Lochhead (1995) used felt-padded tables lined with silicone release paper. Keyserlingk (1993) described a roughened silicone 'ironing board' that can be placed under the artifact to prevent crushing of surfaces while using an iron or spatula. Lodewijks (1972) recommended laying velvets or velours onto a fabric with a deeper pile. The prepared support is laid on the reverse of the artifact and covered with release paper before applying heat (Bede, 1993; Keyserlingk; Landi). The temperature of the heat source can be monitored by using a surface thermometer (Bede) or temperature strips (Himmelstein & Appelbaum, 1977; M. Keyserlingk, personal communication, November 17, 1995). The temperature of the face of the spatula or iron may not correspond to the dial settings or may not be indicated at all, so it should be tested (Hartog & Tinker, 1998). Higher temperatures may be needed when working manually than when using a hot table (Landi). The heat is applied for no more than 10 to 15 seconds, one small section at a time (Bede). The treated area is allowed to cool to room temperature before moving to the next section (Keyserlingk). Sometimes the backing is first tacked in place with a smaller spatula to ensure that the grain is aligned, and then heat-sealed with a larger iron (Peacock, 1983), at a higher temperature (Himmelstein & Appelbaum), or by using a vacuum hot table (Hillyer, 1995) to secure the bond. Although the heat is usually applied to the backing fabric (Bede; Katchanova, 1987; Keyserlingk; Landi; Peacock), it has been applied through release paper over the face of the artifact (Himmelstein & Appelbaum; Lodewijks & Leene, 1972). The backing may be tacked in place from the front to ensure correct alignment and then fully heat-sealed from the back (Bede).

Grain alignment and supplementary stitching. Careful alignment of the grain and supplementary stitching ensure the effectiveness of backing treatments. The flexibility of the treated artifact is maximized if the grain of the backing fabric and artifact are well matched (Bede, 1993). Cutting the prepared support into pattern pieces for complicated structures like costume facilitates alignment, although perfect matching is not always possible (Hartog & Tinker, 1998). Slight differences in grain create a wavy, moiré pattern on the supported side. On small artifacts, this may be avoided by placing the grain of the backing fabric on the bias (M. Keyserlingk, personal communication, November 17, 1995). Stitching along seams and along the edges of the artifact and of losses, or couching fragile areas and the long floating yarns of complex weaves to the backing improves the durability of the treatment, prevents the release of the bond due to flexing, and gives extra protection to vulnerable areas (Bede; Blum, 1982; Brooks, et al., 1995;

Hartog & Tinker; Hillyer, 1990; Hillyer & White, 1998; Landi, 1992; Lochhead, 1995; Lord, 1997; Marko, 1978).

Reversing the Treatment

Due its importance as a conservation principle, the reversibility of adhesive treatments for textiles demands comment. First, the adhesive coating must be reversible in the short term so that it can be removed from areas of the backing exposed through losses in the artifact. Conservators have devised a number of methods for this purpose. The usual technique is to apply an appropriate solvent by brush or swab to the exposed area (Keyserlingk, 1993; Mailand, 1998; van Nes & Kip, 1980). Using suction (Keyserlingk) helps to confine the solvent to the desired area. Hillyer and White (1998) laid the rough side of small bits of long fibre acid free paper on exposed areas of Vinamul 3252, dampened the paper with acetone and peeled it away, taking along the adhesive coat. Boersma (1998) employed thin pieces of polyester film and heat to remove a Mowilith DMC2 coating in a similar manner.

Of greater concern is the long-term reversibility of adhesive treatments. Improved methods of conservation treatment, increased historical understanding of the structure of the artifact, or the poor execution of a prior treatment may make retreatment desirable (Blum, 1982; Flury-Lemberg, 1988; Hartog & Tinker, 1998; Hillyer, et al., 1997; Landi, 1992; van Nes, 1983). Although many techniques have been used (Table 8), reversibility of adhesive treatments is commonly understood to necessitate dissolving the adhesive in

Table 8. Methods of Reversing Adhesive Backing Treatments

Method	References[a]
solvent	Boersma, 1998; Cruikshank, et al., 1998; de Groot, 1997; Hartog & Tinker, 1998; Keyserlingk, 1993; Landi, 1992; Mailand, 1998; Marko, 1978; Thomsen, 1984
vapour	Foskett & McClean, 1998; Landi, 1992
swelling	Blum, 1982; Gentle, 1998; Hofenk de Graaf, 1992; Keyserlingk, 1993; Landi, 1992; van Nes, 1983; *Vuistregels*, 1985
heat	Himmelstein & Appelbaum, 1977; Landi, 1992; Lord, 1997; Mailand, 1998
peeling	Bede, 1993; Himmelstein & Appelbaum, 1977; Thomsen, 1984
enzymes	Foskett & McClean, 1998; de Groot, 1997; Landi, 1992

[a] treatment may not have been carried out or condoned by the author
[b] survey results

a suitable solvent. Case studies have shown that this is possible to a degree, even on textiles that had been impregnated with adhesive. Hartog and Tinker applied an industrial methylated spirits (IMS)/deionised water solution by swabs to enable peeling of a poly(vinyl acetate)-coated net and flushing out of adhesive residue from the artifact. Combined solvent swabbing and wet cleaning, with the artifact supported by a screen after the old support was removed, enhanced removal and minimized redeposition. Marko (1987) used a similar technique to remove patches from the back of a tapestry. Both Boersma (1998) and Cruikshank, Lee, and Potter (1998) used the heat of a hot air blower to peel off the backing fabric, followed by solvents to remove poly(vinyl acetate) adhesive residues. Boersma sprayed the toluene/isopropanol solvent mix onto blotting paper cut to fit around painted areas to control spreading. Cruikshank, et al. similarly sandwiched the artifact between IMS-soaked blotting paper, but added a poultice, Sepiolite, an absorbent clay, mixed with IMS on top with a non-woven polyester as an interlayer. In both cases evaporation was restricted for a period of time to allow the solvent to work.

Using organic solvents to reverse adhesive treatments raises concerns regarding the safety of both the artifact and the conservator. Extended solvent treatment can leave fibres dull, brittle, and dry, although subsequent humidification or wet cleaning may improve their condition, at least for the short term (Boersma, 1998; Hartog & Tinker, 1998). The effect of the solvents on dyes is an additional complicating factor (Ballard & Czubay, 1992). Equally troubling are the possible deleterious effects on the health of the conservator (Hillyer, et al., 1997). Even with proper safety garments and ventilation, these treatments can be so strenuous that the conservator may only be able to work for short periods at a time (Boersma). The logistics of dealing with and disposing of the large quantities of solvent necessary for large textiles are also beyond the capacity of most textile conservation laboratories (Ballard & Czubay; Finch, 1980).

Backings attached with pastes can generally be removed with water, either by water bath (de Groot, 1997; Thomsen, 1984), liquid water brushed over the support (Landi, 1992, p. 55), or steam (Foskett & McClean, 1998; Landi). Removal of starch residues, however, usually requires enzymes (Foskett & McClean; de Groot; Landi), since starch is not soluble in cold water (Daniels, 1995). De Groot used blow-driers to maintain the temperature required for the enzyme solution to work followed by a rinsing shower for objects that could not be immersed in the usual manner.

The long-term solubility of the adhesive may be less critical for the reversal of the kind of superficial bond created by recent heat-sealing techniques. The backing can often be removed without dissolving the adhesive. Reapplication of heat or gentle pulling may be sufficient to break the bond and peel off the backing (B. Appelbaum, personal communication, February 11, 1998; Bede, 1993; Himmelstein & Appelbaum, 1977; Landi, 1992; Lord, 1997; Mailand, 1998). The backing should always be peeled from the artifact, not vice versa (Landi, p. 57). According to van Nes (1983), moistening artifacts with water swells Mowilith DMC2 enough to permit removal of the backing. Scarcely any residue remains on the surface of the artifact or in the fibres. Other conservators have also used water to swell and release a bond formed with a poly(vinyl acetate) dispersion adhesive (Blum, 1982; Gentle, 1998; Hofenk de Graaf, 1992; Keyserlingk, 1993; Landi; *Vuistregels*, 1985). Landi has suggested that swelling of the fibres alone may be sufficient to reverse a bond even if the adhesive is hydrophobic (p. 57), although others disagree (*Vuistregels*). As a strategy for choosing a technique for reversing a bond, Landi recommended trying them in this order: swelling with moisture, heat, and, as a last resort, solvents (p. 57).

The applicability of any of these treatments depends on the condition of the artifact and the backing fabric, as well as the nature of the adhesive. A technique that may be used with relative success when the support is in good condition, may not be possible if both artifact and support are very brittle and the adhesive bond is strong (Foskett & McClean, 1998). If the adhesive support still provides the needed degree of consolidation, and additional support can be added by stitching, it may not be necessary to subject fragile artifacts to the stress of reversing the backing treatment (Gentle, 1998). Backings attached to very brittle artifacts that have been consolidated with the same adhesive may not be removable using a solvent technique without endangering the stability of the fibres (Jedrzejewska, 1980). Ideally, the adhesive used for consolidation should not be soluble in the solvent that dissolves the backing adhesive.

Caring for the Treated Artifact

Artifacts that have been treated with adhesive backings or facings require special consideration in terms of handling, display and storage. Because the bond produced with most adhesives in backing treatments is relatively weak, it may not permit much flexing of the artifact. Flat textiles are often mounted onto rigid supports (B. Appelbaum, personal communication, February 11, 1998; Giorgi & Palei, 1997; Keyserlingk, 1993; Hillyer, 1984; Himmelstein & Appelbaum, 1977; Pullan, 1995; Scott, 1974; Wagstaff, 1979). Garments may also be given specially designed display mounts (Hillyer & White, 1998). Frames or exhibition cases can protect artifacts from dust and damage due to light and humidity

(Bond, 1995; Himmelstein & Appelbaum; Thomsen, 1984). Artifacts with exposed adhesive, for example those treated with adhesive facings, must be protected from dust, since fine particles can eventually become permanently embedded in a polymer film with a glass transition temperature below room temperature (Finch, 1980; Horie, 1987; Horton-James, et al., 1991; Landi, 1992). When artifacts are reinstalled in historic settings where the environment is not well controlled, preventive conservation measures, such as the installation of window shades or the closing of curtains to block direct sunlight, can retard further degradation (de Groot, 1994; Hillyer, 1990). Rolled storage, the norm for flat textiles, is not appropriate for those treated with adhesives (Blum, 1982; Keyserlingk). Special storage boxes and handling mounts designed for the particular artifact (Cruikshank & Morgan, 1995) are ideal. Costume artifacts may be especially vulnerable with regards to both display and storage (Blum). Mounting garments onto mannequins requires considerable handling. Adjacent adhesive surfaces in pleats and gathers, for example, may stick together if they are allowed to touch. New creases cannot be steamed out in the usual manner, since the steam can release the bond. Similarly, the adhesive backing may limit possibilities for future cleaning. In general, mounts and additional supports should account for the fact that those who handle the artifacts in the future may not have textile conservation training (Himmelstein & Appelbaum).

Research Related to Adhesive Backing Treatments

Despite the extensive use of adhesives for backing textiles revealed by the literature, almost no research has addressed the properties of artifacts treated in this way. Stable products with appropriate physical properties such as flexibility or transparency can be identified by testing adhesive films. However, studying the properties of adhesive films may not clarify what properties are critical for a particular application (Horton-James, et al., 1991; Pretzel, 1997a). The following review summarizes observations and the results of testing related to adhesive backing treatments in textile conservation. In addition, research on similar adhesive laminates produced in the garment industry and in the conservation of other flexible materials will be assessed for its relevance to the understanding of adhesive backing of textiles.

Observations of the Effects of Natural Ageing

In the absence of much research on the stability of adhesive backing treatments, observations by conservators about the effects of past treatments are a valuable source of information. These comments reflect the stability of the treatment under the kinds of conditions that most treated artifacts endure. Since the factors that may affect the artifact in such environments are complicated and not fully known, however, statements of cause should be viewed critically. Observations of interest relate to the maintenance of the bond, to changes in appearance and flexibility of the artifact, and to the deterioration of the artifact.

A number of conservators have commented on the stability of the adhesive bond when reviewing previous adhesive backing treatments. Many bonds made with vinyl acetate-derived adhesives were found to still be holding ten to forty years after treatment (Boersma, 1998; Cruikshank, et al., 1998; Gentle, 1998; Hartog & Tinker, 1998; Landi, 1992; Mailand, 1998). The banners reported by Gentle had been displayed on a steep angle for 17 years and exposed to high and fluctuating humidities. Similarly, many of the flags and banners surveyed by Boersma had been displayed or stored in less than ideal environments. Foskett and McClean (1998) described starch bonds still effective after at least one hundred years of continuous display. In some cases, however, deterioration of the bond has been noted. Boersma described blisters where the bond had not held on banners treated with a poly(vinyl acetate) adhesive approximately 30 years earlier. She suggested that stress differences caused by uneven heat on the domestic iron used for heat-sealing may have caused the loss of adhesion in these spots. She also found bonds beginning to fail on some properly stored flags treated with small amounts of adhesive. Landi noted the release of an adhesive backing from curtains on open display. The backings should have been reinforced with stitching from the beginning (p. 211). Hartog & Tinker reported areas of bond loss between a net support and a net dress. They reactivated the bond by heat-sealing but noted that such treatment may have only temporary effect (see also Hillyer, et al., 1997). Blum (1982) also reported fabrics lifting from net supports on garments.

Despite the efficacy of the bond, the appearance of the artifact may have been adversely affected by the adhesive treatment. Textiles treated in the 1960s or earlier were often found to be discoloured, dirty, tacky, shiny, and/or stiff (Blum, 1982; Boersma, 1998; Cruikshank, et al., 1998; Finch, 1980; Hartog & Tinker, 1998). The edges of some of the banners described by Boersma had curled. The fabric of a dress had wrinkled due to shrinkage of the adhesive net backing (Gentle, 1998). Overstretching of the fabric during adhesive application may have been the cause. Blum described instances where the impression of the net was retained on the artifact even after reversing the treatment. She credited overly high heat-sealing pressures or staining by the adhesive for this effect.

Other conservators reported no changes in artifacts after 10 to 20 years of not always ideal storage (Landi, 1992; Mailand, 1998)

The treatment does not protect the silk fabrics of the artifact or backing from further deterioration. Gentle (1998) noted the degraded state of silk crepeline backings on two banners after 17 years of open display. Although the backings were still consolidating brittle silk yarns, they could no longer effectively support the banners for hanging display. Similarly, the green silk backings on the 100-year-old banners treated by Foskett and McClean (1998) were weak and brittle, split from being held under tension on a stretcher frame and thus no longer performing any supportive function. Backing may prevent damage of silks on costume, but if applied as patches will lead to increased damage in the unsupported areas (Mailand, 1998). The fine warp face of silk damask wall coverings treated with either adhesives or stitching and subsequently exposed to sunlight "dusted" away, leaving loose weft yarns (Hillyer, 1990; Landi, 1992, pp. 252-253). The 17th century fabrics had still been flexible enough to be removed for treatment in the 1950s, but were no longer so 30 years later. Although Hillyer suggested that the rigidity of the net in the uncontrolled environment contributed to the relatively greater breakdown of the warp face of the adhesive-treated panels, other factors may have contributed. The adhered panels were on a different wall than the stitched ones, suggesting differences in light exposure. That the panels were given different treatments previously supports the hypothesis that they were degrading at different rates due to their location. However, the two treatments, for which no records exist, were not necessarily completed at the same time (Hillyer). Landi noted that the adhesive-treated wall coverings at least retained the pattern of the damask.

Mock-up Testing

Small-scale testing of materials and techniques plays an established role in conservation decision-making. Mock-ups usually focus on the effects of particular products in the context of particular techniques for the purposes of treating particular artifacts. Though less rigorous than experimental testing, they are a valuable source of information. Horie (1987) has recommended that all conservators conduct such tests and maintain files of samples. These samples can be used later for assessing methods for reversing treatments. Simple, standardized procedures increase the value of such tests for comparative purposes. Horie described such tests for determining solubility, dirt pick-up, and adhesive power of polymers that are applicable to backing treatments.

The results of mock-up tests were reported in only a few case studies.

Conservators usually used them for choosing an adhesive and occasionally a backing fabric. Wills (1995) attached samples of silk to silk crepeline stretched over a frame using four starch and cellulosic adhesives and assessed the appearance of the textile visually and the degree of adhesion through simple bending tests. Wheat starch paste was chosen due to its good adhesive properties and matte appearance. Similarly, Lord (1997) tested a rather arbitrary handful of adhesives on new and naturally aged silk satin with solvent and heat reactivation techniques. After comparing the appearance of the resulting laminates and the ease with which they were produced, she chose Beva 371 over Klucel G for an embroidery facing treatment. Thomsen (1984) experimented with various combinations of the PVAC adhesives AYAA and AYAC in toluene and acetone in order to find the best option for a temporary silk crepeline facing. She examined the coated fabric microscopically for adhesive penetration, qualitatively assessed the peel strength to silk fabric and tested the degree of reversibility to soaking in water. Acetone evaporated too quickly and toluene too slowly to give effective coatings, so a mixture of the solvents was used. Similarly, a mixture of the resins gave the best results. All samples could be separated by peeling without leaving any apparent residue when soaked in water. Grant (1995) compared Mowilith DMC2 and wheat starch paste on four backing materials for the patch treatment of a floorcloth banner. The appearance and the strength and reversibility of the bond of the various backings were evaluated on the edges of the banner itself. Grant obtained best results with wheat starch paste on polyester crepeline. Cruickshank and Morgan (1995) used small scale tests to compare vacuum heat-sealing and cold-lining techniques. Scanning electron microscope images of both untreated and treated ancient linen showed that cold-lining caused less mechanical damage to the fibres.

Studies of Adhesive Backing Treatments

A few published studies have addressed issues related to adhesive backing of textiles in a more rigorous, experimental manner. Katchanova (1987) investigated the effect of accelerated light-heat ageing on wool and silk fabrics adhered to a nonwoven material impregnated with an unidentified thermoplastic adhesive. After ageing, the fabrics were separated from the nonwoven backings. Both these and aged fabrics that had not been lined were analysed using infrared spectroscopy, X-ray radiography and chemical analysis. Changes in the molecular structure of the two fabric were identical. Katchanova concluded, as a result, that the adhesive did not affect the ageing process of the fibres. In a related experiment, silk was shown to dissolve more quickly after exposure to temperatures of 60°C, 70°C, 80°C, and 100°C. Thus heat treatment for silk artifacts may not be advisable. The author neither described the methods used in greater detail, nor presented any data for this set of experiments.

Senvaitienė, et al. (1981) studied the properties of the acrylic copolymer A-45K in situ on fabrics. The bond strength and rigidity of natural silk samples backed using this polymer and using wheat flour paste were compared before and after accelerated light-heat ageing. Samples prepared with the synthetic polymer lost over 80% of their resistance to lamination (sic) due to ageing, but still retained higher levels than those made with the paste. Both types of samples exhibited little change in rigidity and air permeability due to ageing. Aged wool, cotton, and silk strips consolidated with the polymer showed less change in breaking strength and elongation at break relative to the unaged, plain fabrics than aged unimpregnated fabrics. Infrared absorption spectra of the same type of silk and cotton samples, with the polymer removed after ageing, revealed little change in the aged samples, impregnated or not. However results for unaged, impregnated strips for these tests were not reported. Without comparisons of the rates of change of consolidated and unconsolidated samples, conclusions about the protective effect of the polymer are premature. Like the Katchanova study, this paper gave insufficient detail on experimental methods, although standard Soviet test methods were cited. Furthermore, ambiguous terminology and lack of discussion of some of the results make the findings difficult to interpret.

Masschelein-Kleiner and Bergiers (1984) also studied the effect of adhesives on silk through consolidation. Undyed, new, silk taffeta samples immersed in solutions of poly(vinyl acetate) (PVAC), poly(vinyl alcohol) (PVAL), poly(vinyl butyral), several cellulosic adhesives, and hydrolysed wheat starch were exposed to xenon arc radiation at 38°C. Load, elongation at break, and the fraction soluble in water before and after ageing were measured for all consolidated samples and for unconsolidated controls. All adhesives except wheat starch improved strength and elongation before ageing. Samples consolidated with PVAC, PVAL, and wheat starch retained higher strength and elongation values than untreated silk after ageing. The methyl cellulose consolidants offered no protection from loss of tensile properties, while the presence of poly(vinyl butyral) and hydroxyethylcellulose appeared to accelerate it. Despite the relatively good results for PVAC and PVAL, Masschelein-Kleiner and Bergiers rejected these adhesives because the first, with its low glass transition temperature, picks up dust at room temperature, and the second eventually becomes insoluble. Although they recognized the disadvantages of wheat starch, they recommended it as the best option for the consolidation of silk.

Leene (1969, 1972, 1980) investigated the effect of impregnation or coating with Mowital B60 (poly(vinyl butyral)), mixtures of Mowilith dispersions (poly(vinyl acetate copolymers) and Paraloid F10 (acrylic resin) on the flexibility of various fabrics. Using the cantilever method for calculating flexural rigidity, flexibility was compared before and after ageing in controlled dark conditions and in sunlight with fluctuating temperature and relative humidity. Compared to consolidation by Mowital B60, both the Mowilith and Paraloid F10 coatings distinctly impaired the drape of the fabrics. The stiffness of samples impregnated with several concentrations of Mowital B60 showed no significant stiffening after 11 years of dark ageing at 20 ±1 °C and 65 ±2% RH, nor after 3 years of uncontrolled light ageing. Samples coated with a Mowilith DM5 and DMV1 mixture and exposed to sunlight had stiffened slightly after 7 years exposure. When aged at 40°C in either 15% or 80% RH, the Mowilith-coated samples did not stiffen but became sticky at the higher relative humidity. Samples coated with Paraloid F10 increased in stiffness significantly over 3 years of ageing in sunlight, but did not become sticky at higher relative humidity levels. In addition, Leene (1980) reported that layering fabrics and joining them by stitching also increases their stiffness. The percentage increase depends on the number of stitches per area and the tension of the stitching.

A much more comprehensive comparative study of adhesive backed textiles was carried out by Pretzel and the textile conservators at the Victoria and Albert Museum under Hillyer (Hillyer, 1993; Pretzel, 1993, 1997a, 1997b). They prepared and tested silk 'objects' adhered to new backing fabrics with a variety of poly(vinyl acetate) and acrylic adhesives that have been used in textile conservation. Samples for tests of mechanical properties were aged at 60°C and 70% RH for 35 days. The adhesives were rated on peel strength, reversibility, pH, ease of application and handling, requirement for fume extraction, heat-sealing temperature, staining, tear strength, and glass transition temperature. An evaluation matrix with a scoring and weighting system was constructed, from which a conservator could calculate scores for the adhesives in light of the requirements of a particular treatment problem.

Although very useful for the practicing conservator in that it evaluated adhesives in the context of their application on textiles, this study failed to provide equally important information on the rate of change of properties due to ageing, since no unaged samples were tested. Measurements were taken over time only for the pH values of silk crepeline coated with the various adhesives. This revealed a trend towards more neutral values for initially slightly acidic or alkaline films with increased drying time, suggesting that conservators should prepare coated supports well in advance of treatment use (Hillyer, et al., 1977). The pH values reported, however, are affected by the presence of the crepeline. Furthermore, as Pretzel (1997a) acknowledged, keeping the project manageable required excluding certain factors that may have significant effects on any of the properties tested in the context of an actual treatment. One type of fabric backing was evaluated for each test: polyester crepeline for mechanical properties and silk crepeline for pH. The samples were aged only at elevated temperature and humidity levels, whereas treated artifacts, if placed on display, are subjected to the effects of light. The conservator should be mindful of these limitations when using the matrix.

Studies of Other Types of Textile Laminates

Research relating to bonded fabrics, fabric-fusible interlining laminates and coated fabrics can provide useful insight for the textile conservator even though the properties desired for such laminated structures differ markedly from those desired for the preservation of historic textiles. Experience and research in the production of these fabric laminates using acrylic copolymer dispersions and hot-melt adhesives have resulted in a body of knowledge regarding factors affecting the stiffness and bond strength of laminated fabrics. Stiffness is related largely to the continuity of the adhesive layer and the degree of adhesive penetration into the fabrics. Discontinuous adhesive application techniques such as random powder coating, random web deposition, and dot or pattern printing produce laminates of greater flexibility than the use of a continuous adhesive film (Holker, 1975). The stiffness of the laminates increases the more the adhesive is able to penetrate the fabrics, especially closely woven fabrics, since the adhesive welds the yarns together where they cross (Allewelt & Bauer, 1974; Holker). The strength and durability of the bond depend on the properties of the fibres and adhesives used as well as factors relating to the production process. Fabrics made from hairy, long-staple yarns produce stronger bonds than those made from tightly spun yarns or smooth, continuous filament fibres, although the presence of loose fibres will decrease bond strength (Holker). Fabric finishes used in the textile industry may affect bond strength, but many do not (Allewelt & Bauer; Holker). Effective bond strength of fused laminates depends on careful control of the fusing process (Holker). If the temperature is too low for the particular adhesive or heat is applied for too short a time, the laminate peel strength will be low due to poor wetting. On the other hand, very high temperatures or long periods of heat exposure will also produce laminates of low bond strength since the adhesive migrates from the interface into the fabrics and may even penetrate through to the surface (Allewelt & Bauer; Holker). Mechanical flexing is not thought to be an important factor in the bond failure of fabric laminates because the fabrics bear the stress rather than the discontinuous adhesive layer (Holker).

Studies from the garment industry have focussed on predicting the properties of fused laminates of facing fabric and fusible interlining from those of the components. Fan, Leeuwner, and Hunter (1997) determined that the mass of fabric-interlining laminates is equal to the sum of the mass of the components while their thickness is slightly less than but proportional to that of the components. Dhingra and Lau (1996) found that the modulus of the laminate was approximately equal to the sum of the moduli of the components and suggested that the components act independently under tension. The bending and shear rigidities of the laminates are, by contrast, larger than the sum of those of the components. Fan, et al. and Shishoo, Klevmar, Cednäs, and Olofsson (1971) developed equations that predicted extension, bending, and shear properties of laminates from the values of component fabrics.

Shishoo, et al. (1971) also commented on how adhesive coat and fabric types influenced the properties of the laminates. The bending stiffness of the laminates, as determined by the cantilever test, was 4 to 10 times greater than the sum of the bending stiffnesses of the face fabric and interlining. Overhang lengths of the laminate strips determined by the same test were approximately equal to the sum of the overhangs of the components, not half of the sum as expected. Therefore a significant proportion of the stiffening must have been due to the fusion of the components. Measuring the stiffness of peeled components confirmed this interpretation. The bending stiffness of laminates containing dot-coated adhesive was lower than those with random coatings. The lower the amount of adhesive, the lower the stiffness as well. The direction of bending, whether face fabric up or down, also influenced the measured stiffness, a characteristic also noted by Dhingra and Lau (1996). This may be due to residual stresses in the adhesive from the fusing process, stresses which result in curling of some samples when placed in a humid atmosphere. The stiffness was also affected by the relative orientation of the component fabrics, with the properties of the interlining predominating. Laminates in which the warps of both fabrics were oriented in the same direction were much stiffer than those in which the fabrics were aligned at 90° or 45°. The shearability of laminates was less in those having dot-coated as opposed to randomly coated or continuous film adhesives, and especially so in those where the distance between the dots was large. The type of adhesive polymer also affected shear stiffness. Woven interlinings gave higher shearability values than nonwoven ones. Thus the properties of fabric-fusible interlining laminates could be controlled by careful choice of component materials.

In their report on adhesion in urethane-coated fabrics, Bluestein, Loewrigkeit, McGimpsey, and Van Dyk (1979) mentioned several factors that influence the strength of the bond between the coating and fabric. The presence of residual volatiles in the coating affect the bond. Moreover the rate of drying the tie-coat between the coating and fabric was critical, with slower drying giving stronger bonds. Other factors included the solids content and particle size range of the tie coat, and the type of thickener incorporated into the urethane dispersion. Fabrics with a more heavily napped surface also gave stronger peel strengths than smoother or more lightly napped fabrics.

Studies of Flexible Adhesive Laminates in Conservation

Lining of paintings. Studies of the flexible laminates produced when paintings are lined can provide excellent information on factors affecting such structures, as long as the purpose of such research is accounted for. The differences between paintings and textiles, even textiles with painted components, are significant enough to warrant caution when transferring the results of lining research to backing treatments for textiles. In the words of Berger and Zeliger (1973), "easel paintings with priming and paint film are much more similar in their mechanical structure to automobile tires and ceilings made of reinforced concrete than they are to textiles" (p. 49). The principal purpose of lining a painting is to preserve the paint layer. As stiff a support as possible, usually provided by a tough, closely woven fabric and the maintenance of tension on the resultant laminate, is required for this purpose (Berger & Russell, 1987, 1990, 1993). Although a transparent lining would be preferred from a conservation perspective (Berger & Zeliger), the need not to obscure the back of a canvas is not as high a priority among paintings conservators as it is for textile conservators. Nevertheless, research on the lining of paintings has isolated factors that affect the strength of the adhesive bond in these laminated structures, as well as the effects of accelerated ageing on them.

The bond strength of lined model paintings is strongly influenced by the type and condition of the materials used. Different adhesives have yielded different peel strengths on otherwise identical samples (Berger, 1972; Daly Hartin, et al, 1993; Hawker, 1987; Katz, 1985; Phenix & Hedley, 1984; Roche, 1996). The strength given by a particular adhesive is further affected by the solvent used to dissolve the resin (Pullen, 1991), by the percentage dilution by volume (Pullen), and by the type of polymer or solvent that might be added as a thickener (Phenix & Hedley). Thicker adhesive coatings have generally produced stronger bonds, especially at higher heat-sealing temperatures (Gayer, 1992; Hardy, 1992; Hawker; Pullen), but only to a point (Hawker). Slight evidence that adhesives given less time to dry after application to the lining fabric generate stronger bonds has been presented, but it may not be significant (Allard & Katz, 1987; Pullen). The type of lining fabric has also been shown to affect peel strength. In general, fabrics with a greater amount of raised nap or greater surface texture which could embed into the adhesive gave stronger bonds (Daly Hartin, et al.). Fabrics with a tighter weave also produced higher peel strengths than more open fabrics (Phenix & Hedley). Thicker lining supports, created by adhering several layers of the fabric together, increased peel strength as well (Daly Hartin, et al.). Whether the lining or canvas was sized or consolidated before lining could increase or decrease peel strength depending on the interaction of the sizing with the adhesive or lining fabric (Allard & Katz; Berger; Daly Hartin, et al.; Hardy; Katz; Pullen). Although sizing often increased peel strength, the presence of a weak consolidant on the canvas that could not be removed before lining impaired adhesion (Berger).

Bond strength is also affected by variables in lining techniques. Peel strength generally increased with the temperature of heat-sealing (Gayer, 1992; Hardy, 1992; Hawker, 1987; Pullen, 1991), but, as for adhesive thickness, only to a point (Hawker). Higher peel strengths may result if the heat-seal temperature is maintained longer, since the adhesive has more time to flow and wet the canvas (Hawker). The amount of pressure applied during lining is also considered to be a factor (Allard & Katz, 1987; Katz, 1985). The method of reactivating the adhesive--by heat or by solvent--may alter the peel strength of some adhesives significantly (Duffy, 1989; Katz). Increasing the volume of solvent applied per unit area of lining generally has resulted in higher peel strengths when solvent reactivation is used, although the type of adhesive determines the exact pattern (Phenix & Hedley, 1984). Natural or artificial ageing also affect bond strength. Several studies found that peel strengths increased the longer the interval between lining and testing (Berger, 1972; Hawker; Phenix & Hedley), although others saw no clear trends (Daly Hartin, et al., 1993). Accelerated light and thermal ageing have also been shown to affect bond strength, but with no definite pattern. Berger recorded both increases and decreases in response to heat ageing depending on the product tested. Duffy found that the strengths of bonds with acrylic dispersions generally increased when samples were aged in elevated light and heat levels, although a few remained stable. Roche (1996) noted that peel strengths decreased on laminates composed of mylar and steel but increased on samples composed of polyester and linen. Migration of the adhesive into the fabric and the resulting greater mechanical bond may account for this discrepancy. When the surface energy of the adhesive was greater than that of the support, this increase in strength did not occur. Since peel strength tests were used to measure bond strength in most of these studies, some of the differences may be due to the properties of the materials involved rather than the strength of the bond between adhesive and substrate (Daly Hartin, et al.).

Duffy (1989) also considered the effects of light/thermal ageing on other properties of polyester sailcloth laminates adhered with acrylic dispersion adhesives. Although many of the films cast from the adhesives and the polyester fabric yellowed due to the ageing conditions, the adhesives sandwiched between polyester remained clear. Ageing caused no discernible change in flexibility despite increases in peel strength which may indicate cross-linking of the adhesives. Ageing of adhesive films reduced the percentage swelling in water and toluene. Duffy suggested that water alone would not reverse an aged acrylic film.

Berger and Zeliger (1973) considered the effects of adhesive consolidation on fabric properties. Adhesive impregnation reduces the ability of fibres and yarns to slide past one another, thus changing the way in which the fabric responds to stress. The strength of open fabrics is generally reduced by impregnation since the yarns can no longer "pull together" to "withstand" stress (p. 47). The properties of the impregnating resin make a difference. Brittle materials stiffen and weaken fabrics. Soft resins, on the other hand, may render fabrics more flexible and increase their tear strength by reducing the friction between the fibres. A compressible but weak resin can reduce the stress concentration on fibres by preventing them from bending over too far, while the fibres give strength to the composite material. When the fibres are themselves very brittle and weak, the resins provides reinforcement, strength, and flexibility. Such consolidation is irreversible, however, and should only be used as a last resort.

Paper conservation. Baer, et al. (1975) tested several poly(vinyl acetate) (PVAC) dispersions for possible applications in paper conservation. The adhesives included two PVAC homopolymers, three vinyl acetate-ethylene (VAE) copolymers, and three vinyl acetate (VAC)-dibutyl maleate copolymers. Most samples were heat-aged at 95°C for up to 180 days. Properties measured in relation to supports of Whatman chromatography paper included adhesive add-on for single and sandwiched strips ("loading"), fold endurance, tensile properties, reflectance, colour change, and pH. Adhesive films were also tested for colour change and pH, as well as for percent weight loss (from the liquid state), and the solubility in water and toluene.

The series of tests revealed distinct differences among the properties of the adhesive products as well as the importance of the substrate-adhesive interaction. Although loading of the adhesive was slightly less when sandwiched between two strips of paper than when coating a single strip, the differences among the adhesives was greater, indicating distinct handling properties. When coated paper was taken to full rupture on the fold endurance test, the relationship between the adhesive coating and the paper substrate differed for the three main types of adhesive. The PVAC adhesives ruptured at the same time as the paper, and lost almost all strength when aged. In the other samples, the paper ruptured first, and the fold strength remained stable or even increased with ageing. The fold strength of the paper in the VAC-dibutyl maleate copolymer-coated samples was comparable to that of uncoated paper, suggesting an independent relationship between the two materials. The relationship of adhesive and paper in most of the VAE-coated samples, however, was more complex and interdependent, since a higher fold strength was measured for the paper. Tensile tests of adhered paper sandwiches showed increased tensile strength and decreased elongation at break following heat ageing. The results did not correlate with the values for adhesive add-on or fold endurance. The reflectance measured on the untreated side of coated paper strips decreased with ageing while the colour of the coated side yellowed to varying degrees depending on the adhesive. Colour change was not entirely related to polymer type for, although the PVAC products both yellowed, adhesives of the other two polymer types both did and did not discolour. Films of all the adhesives were slightly acidic, but became less so with ageing, probably due to the volatilization of acetic acid, which would not necessarily occur at room temperature. The surface pH of the uncoated side of aged paper strips, however, matched that of uncoated paper. At ambient conditions (23°C), considerable solvent was retained in 10 to 15 gram samples after 1 day but had evaporated after nine days. At higher temperatures (70°C and 95°C), evaporation was essentially complete in 1 day. All films became insoluble in water or toluene after ageing, although they swelled in toluene.

Leather conservation. Selm's (1991) summary of a research study pertaining to the conservation of upholstery leathers included test results of adhesive support techniques. Nonwoven fabrics coated with adhesives applied as a continuous film or in a dot pattern were compared for their flexibility and their stability to dry heat ageing. The bond strengths of these fabrics attached to leather using either a wet application or heat-sealing technique were also assessed. The adhesives tested were the acrylic copolymer, Lascaux 360 HV, both on its own and as a mixture with Lascaux 498HV, the ethylene-vinyl acetate copolymer, Beva 371, in paste and film form, and the vinyl acetate-ethylene copolymer, Vinamul 3254. A continuous film of adhesive increased the stiffness of the nonwoven fabrics greatly. When applied in a dot pattern, on the other hand, the stiffness of the support fabric increased only slightly. Fabric samples coated with adhesive were dimensionally stable and did not discolour when exposed to dry heat. Laminates of leather and nonwoven support fabrics had higher peel strengths if bonded by a continuous film of adhesive than if bonded by adhesive applied in a dot pattern. The peel strength was usually higher if the adhesive was applied to the support fabric rather than to the leather for all application techniques. The least viscous adhesive, Vinamul 3254, formed the strongest bonds when the leather and support fabric were joined while the adhesive was still wet. Beva 371 paste produced the strongest bonds using heat-sealing techniques.

Properties of Mowilith DMC2 and Beva 371

Of particular interest are the research results related to two adhesives that are equivalent to those used in this study: Mowilith DMC2 and Beva 371. Mowilith DMC2 is a vinyl acetate-dibutyl maleate copolymer that is now sold under the tradename Appretan MB extra. Beva 371 is an ethylene-vinyl acetate copolymer very similar to Lascaux Hot-seal Adhesive 371. These two adhesives have been used extensively for heat-seal treatments in conservation and have been included in many of the research studies that have just been described. Since the properties of these adhesives may be useful in interpreting the results of this study, they are summarized here. The results from adhesives testing research and research on flexible laminates in paintings, paper, and leather conservation are listed in Tables 9a and 9b respectively. The observations of textile conservators who have used these adhesives are summarized in Table 9c.

Table 9a. Comparison of the Properties of Mowilith DMC2 and Beva 371: Adhesives Testing

Property	Study	Mowilith DMC2	Beva 371
polymer composition	Berger, 1972		EVA copolymers: A-C 400(170g), Elvax 150 (150g); ketone N (300g); Cellolyn 21 (40g); paraffin (100g)
	Howells, et al., 1984	vinyl acetate, di-n-butyl maleate (65:35)	ethylene, vinyl acetate (80:20)
additives	Down, et al, 1992, 1996	soap, cellulose	Ketone resin N, paraffin
pH	Blackshaw & Ward, 1982	dispersion: 3.9	solution: 6.4
	Down, et al, 1992, 1996	dispersion: acidic, became more so with dark ageing film: remained neutral in dark and light ageing	film: remained neutral in dark and light ageing
	Horton-James, et al., 1991		film (ready made): became acidic on light ageing
	Howells, et al., 1984	became slightly acidic after thermal ageing	
emission of volatiles	Down, et al, 1992, 1996	moderate emission of acetic acid; also released acetaldehyde, ethyl acetate, isobutanol, n-butanol, water, dibutyl ether	insignificant emissions of acetic acid; also released xylene and water
flexibility	Blackshaw & Ward, 1982	good	very good
	Down, et al, 1992, 1996	extension increased slightly with dark ageing, decreased slightly with light ageing; modulus of elasticity decreased slightly in dark ageing, increased slightly with light ageing	extension decreased moderately in dark ageing, decreased significantly with light ageing; modulus of elasticity increased moderately in dark ageing, increased significantly with light ageing
	Howells, et al., 1984	no substantial change after light or thermal ageing; stiffness very sensitive to temperature changes around 20°C	
	de Witte, et al., 1984	not embrittled by light or UV ageing	
tensile properties	Down, et al, 1992, 1996	tensile strength decreased slightly with dark ageing, increased slightly with light ageing	tensile strength remained relatively stable in dark ageing, increased slightly with light ageing
	Horton-James, et al., 1991		significant loss of extension at break of Beva film due to light ageing; no change in stress at 10% elongation
	Howells, et al., 1984	no substantial change after light or thermal ageing	

Table 9a. Comparison of the Properties of Mowilith DMC2 and Beva 371: Adhesives Testing (con't)

Property	Study	Mowilith DMC2	Beva 371
tensile properties (con't)	Verdu, et al., 1984	stable mechanical resistance on light ageing but decreased on thermal oxidation	
colour change	Down, et al, 1992,1996	slight yellowing upon dark and light ageing (not visible)	moderate yellowing upon dark ageing (not visible); visible yellowing with light ageing
	Horton-James, et al., 1991		significant yellowing due to light ageing
	Howells, et al., 1984	slight yellowing upon drying; significant yellowing on thermal ageing; slight yellowing with natural light and dark ageing; slight bleaching on accelerated light ageing	
	Verdu, et al., 1984	rapid browning due to thermal ageing; bleaching, then rapid yellowing on thermal oxidation; long, slight bleaching, then yellowing on light ageing	
weight	Howells, et al., 1984	slight loss (2-6%) after thermal ageing of buffered films	
softening temperature	Blackshaw & Ward, 1982	68°C	60°C
	Howells, et al., 1984	remains at 78°C after thermal ageing	
solubility	Blackshaw & Ward, 1982	reduced solubility in water, slightly reduced solubility in IMS, and increased solubility in acetone after thermal ageing	increased solubility in acetone and constant solubility in IMS, xylene, and trichloroethylene after thermal ageing
	Horton-James, et al., 1991		reduced solubility in toluene/acetone mixture after light ageing
	Howells, et al., 1984	soluble in a wide range of solvents including xylene, toluene, acetone and IMS; buffered film not soluble in propan-2-ol; thermal ageing resulted in diminished response to propan-2-ol	
	Verdu, et al., 1984	remained soluble after thermal degradation and oxidation	
dust retention	Horton-James, et al., 1991		moderate tendency to trap dust under ambient museum condition

Table 9b. Comparison of the Properties of Mowilith DMC2 and Beva 371: Testing of Flexible Laminates in Conservation

Property	Study	Mowilith DMC2	Beva 371
flexibility	Leene, 1972; 1980	retained after 2 years in sunlight (temperature and RH uncontrolled); stiffened slightly after 7 years	
peel strength	Berger , 1972		peel strength increased by 13% in 2 years, decreased by 10-24% after 14 months of heat ageing
	Daly Hartin, et al., 1993		correlated to degree of fabric embedding in adhesive; no significant change after 4 years; variability among replicates
	Gayer, 1992; Hardy, 1992;		increased with increased number of coats or layers of film, and with increased lining temperature
	Hawker, 1987		increased with increased number of coats or layers of film, with increased lining temperature, and with time after lining to a point; depends on interaction of coat weight and temperature
	Katz, 1985		little difference between heat-sealed and xylene reactivated; stronger to canvasses sized with Paraloid B72; adhesive residue remained on lining
	Pretzel, 1997a, 1997b	acceptable (0.06±0.02 N/mm); adhesive residue remained on backing fabric only	good (0.12±0.01 N/mm); adhesive residue remained on silk and backing fabric

white = textile backing treatments; shaded = lining of paintings or leather

Table 9b. Comparison of the Properties of Mowilith DMC2 and Beva 371: Testing of Flexible Laminates in Conservation (con't)

Property	Study	Mowilith DMC2	Beva 371
peel strength (con't)	Pullen, 1991		increased with increased number of coats, increased lining temperature and faster drying time; decreased with increased dilution and with varsol rather than toluene/naptha as solvent
	Selm , 1991		heat-activated bonds stronger than bonds formed from paste applied wet
working qualities	Pretzel, 1997a, 1997b	good ease of application and handling; high heat-seal temperature (110°C), but not solvent based	difficult to apply adhesive and handle prepared film; low heat-seal temperature (85°C) but solvent based
pH	Pretzel, 1997a, 1997b	acceptable; slightly acidic pH on silk crepeline (5.4±0.1) became more neutral (7.58±0.17 after 25 days); moderately high acid value	good; slightly alkaline pH on silk crepeline (8.4±0.2) became more neutral (7.73±0.40 after 12 days); low acid value
reversibility	Pretzel, 1997a, 1997b	hot peel strength acceptably low (0.0.009 ± 0.002 N/mm); adhesive residue remained on backing fabric only	hot peel strength acceptably low (0.0.003 ± 0.001 N/mm); adhesive residue remained on silk and backing fabric
other	Pretzel, 1997a, 1997b	backed silk stained silver but not silk when pressed in contact for 70 hrs at 70±1°C	backed silk stained both silver and silk when pressed in contact for 70 hrs at 70±1°C

white = textile backing treatments; shaded = lining of paintings or leather

Table 9c. Comparison of the Properties of Mowilith DMC2 and Beva 371: Observations of Textile Conservators

Property	Reference	Mowilith DMC2	Beva 371
appearance	Blum, 1982	gloss shows through loosely woven fabric	
	Gentle, 1998	shrinkage of net support over 14 years caused fabric to wrinkle	
	Grant, 1995	translucent on floorcloth	smooth and shiny on floorcloth
	Hartog & Tinker, 1998	30 year old heavily impregnated net shiny[a]	
	Hillyer, 1984	heat ageing (60°C or 100°C for 3 days) has negligible effect	
	Landi, 1992		ready made film can darken fabrics permanently
	Mailand, 1998		no yellowing or dust build up on past treatments
	Muir & Yates, 1987		matte; can stain/darken fabrics in higher concentrations
tack	Hartog & Tinker, 1998	30 year old heavily impregnated net sticky; dirt attached[a]; new films similar in tack to Vinamul 3252, less tacky than Vinnepas EP1	
	Landi, 1992	low risk of self-adhesion	
	Lord, 1997		tacky at room temperature; must be protected from heat and dust
	Mailand, 1998		not tacky but retains "tooth" that permits partial adhesion with finger pressure
	Marko, 1978	less tacky than Vinamul	
	Muir & Yates, 1987		waxy feel at higher concentrations
flexibility	Hartog & Tinker, 1998	30 year old heavily impregnated net stiff[a]	
	Hillyer, 1984	heat ageing (60°C or 100°C for 3 days) had negligible effect	
	Mailand, 1998		flexible enough for fabric to retain creases, stitch lines, folds, etc.

[a] may have been combined with Mowilith DM5

Table 9c. Comparison of the Properties of Mowilith DMC2 and Beva 371: Observations of Textile Conservators (con't)

Property	Reference	Mowilith DMC2	Beva 371
flexibility (con't)	Muir & Yates, 1987		good
bond strength	Gentle, 1998	bond secure after 17 years in environment of high and fluctuating humidity (on silk crepeline) and after 14 years of continuous display (on nylon net)	
	Grant, 1995	firm bond to floorcloth	
	Hartog & Tinker, 1998	heavily impregnated net* adhered to net lace dresses after 30 years; loss of adhesion in a few places	
	Keyserlingk, 1990		gives stronger bond than other adhesives used in textile treatments; stronger applied by spray than by brush
	Landi, 1992	still holding on artifacts treated 17 to 20 years ago; adhesion lost on lower edge of curtains on open display	
	Mailand, 1998		low enough for mechanical peeling
	Muir & Yates, 1987		good (for painted flags)
	Vuistregels, 1985	good	
working qualities	Hillyer, 1995	easy to handle over large areas	
	Keyserlingk, 1990	many do not remove adhesive from losses	exposed adhesive removed with solvents
	Landi, 1992	do not use diluted below 12.5% adhesive by volume	ready made film too thick for most textile conservation purposes
	Lord, 1997		coated silk crepeline difficult to handle and cut into shapes
	Mailand, 1998		moderate pressure sufficient; heat-sealing backing over loss in artifact causes adhesive to migrate into fabric interstices; not soluble in water: therefore, can be used on temporary facings for wet cleaning; coated backing fabric stores indefinitely

*may have been combined with Mowilith DM5

Table 9c. Comparison of the Properties of Mowilith DMC2 and Beva 371: Observations of Textile Conservators (con't)

Property	Reference	Mowilith DMC2	Beva 371
working qualities (con't)	Muir & Yates, 1987		solvents toxic
	Peacock, 1983		light tacking and peeling possible to adjust position of support; requires ventilation
reversibility	Gentle, 1998	14 year old backing removed with damp poultices	
	Grant, 1995	adhesive from backings peeled using moisture remained on floorcloth; residue gelled in water but difficult to remove	
	Hartog & Tinker, 1998	heavily impregnated net and residual adhesive[a] on artifact removed successfully with IMS/deionised water solution in conjunction with wet cleaning	
	Hillyer, et al., 1997		remains soluble in white spirits which does not dissolve painted decoration
	Lord, 1997		reversible in hot air
	Mailand, 1998		removed with rolling action of solvent-soaked swabs (perchlorethylene, mineral spirits, naptha)
	Muir & Yates, 1987		reversible in white spirits, aromatic hydrocarbons
	van Nes, 1983	surface bonds completely reversed by swelling	
	Vuistregels, 1985	soluble in alcohols; backing reversed by swelling	
other properties	Blum, 1982	backed artifact stored rolled retained curl	
	de Groot, 1994	sensitive to humidity fluctuations	
	Muir & Yates, 1987		good water barrier

[a] may have been combined with Mowilith DM5

CHAPTER III METHODS

Sample Preparation

Eleven different types of samples were prepared to represent laminates and their components. Four types of fabric laminates simulating the treated artifact were created by adhering one of two backing fabrics to new silk habutae with one of two poly(vinyl acetate) copolymer adhesives. Samples of unlaminated plain habutae and the corresponding coated backing fabrics were also prepared. Since conservators often choose backing fabrics based on fabric properties alone, uncoated samples of each backing fabric were also included for comparison with coated backing fabrics.

Fabrics

A light-weight *Bombyx mori* silk, Japanese silk habutae (Testfabrics # 609) served as the "artifact". The fabric is a degummed, unweighted, plain weave silk with a balanced warp and weft count. Two fine, open, plain weave fabrics, silk and polyester crepeline, were used as support fabrics. All fabrics were undyed.

Fabric preparation. Three 160 cm lengths were cut from one piece of each fabric. These were wet cleaned using standard textile conservation techniques. The fabrics were first soaked in distilled water at 37°C for 15 minutes. Next they were immersed in a 0.2% (w/w) Shur-Gain anionic detergent solution for 10 minutes. The temperature of the wash solution was 40°C for the silk habutae and 50°C for the backing fabrics. Finally the fabrics were rinsed in distilled water five times, and air dried flat at room temperature.

Fabric characterisation. The weave and yarns of each fabric were analysed using standard procedures (Table 10). Mass was measured according to the procedures of CAN/CGSB-4.2 No. 5.1-M90: Unit Mass of Fabrics (CGSB, 1997c), using 10 die-cut specimens. Fabric count was determined following the test method Can/CGSB-4.2 No. 6-M89/ISO 7211/2-1984(E): Determination of number of threads per unit length, method C (CGSB, 1989). Linear density was calculated using the procedures of CAN/CGSB-4.2 No. 5.2-M87: Linear Density of Yarn in SI Units (CGSB, 1987). Thirty 25 cm lengths of both warp and weft yarns of each fabric were measured precisely for this calculation following the method for removing yarn crimp outlined in CAN/CGSB-4.2 No. 39-M88: Yarn Crimp (CGSB, 1993). Yarn lengths were selected randomly from across the surface of the fabric (10 per 160 cm piece). The yarn diameters of the two backing fabrics were

Table 10. Characteristics of the Fabrics

		Mass (g/m^2)	Count (yarns/cm)		Linear Density (tex)[a]		Yarn Diameter (μm)	
Fabric	Weave		warp	weft	warp	weft	warp	weft
Artifact:								
silk habutae	plain	37.2	50	41	3.47	3.53	–	–
Backing Fabrics:								
silk crepeline	plain	9.5	30	27	1.52	1.61	52	53
polyester crepeline	plain	12.9	23	25	2.69	2.62	66	63

[a]tex = g/km of yarn

determined using a Carl Zeiss/Jena polarisation microscope, Amplival pol.d, with a calibrated eyepiece micrometer. Randomly selected warp and weft yarns on 16 samples of each fabric were measured at yarn intersections. The reported values are averages of 90 and 250 measurements for polyester and silk crepeline respectively.

Sampling procedure. Each of the three pieces of silk habutae was cut into 126 samples, measuring 140 x 68 mm (warp x weft). These were assigned to a laminate or plain silk treatment group (see Table 11) using a random numbers table. Each piece of silk or polyester crepeline was cut into 99 samples, measuring 170 x 90 mm (warp x weft). These were randomly assigned to either an adhesive coating group or to an uncoated backing fabric treatment group. The latter samples were trimmed to 140 x 68 mm. Samples containing obvious flaws were not included. All samples were pressed lightly with a General Electric Light'n Easy steam iron (permanent press setting B) using a smooth, damp, cotton press cloth.

Adhesives

Two adhesive products were used to produce the laminates: Appretan MB extra and Lascaux Hot-seal Adhesive 371[1]. Appretan MB extra, an equivalent to Mowilith DMC2, is a vinyl acetate-dibutyl maleate copolymer dispersion with soap and methyl

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[1] Neither of these adhesives is readily available to conservators today. Appretan MB extra, still manufactured for Clariant Canada, is not available in small quantities. The sample tested was donated by Hoechst Canada (subsequently acquired by Clariant). The Lascaux product, manufactured by Alois K. Diethelm AG, Switzerland, was recently withdrawn from the market due to safety issues regarding the solvent trichloroethylene. The company hopes to develop a replacement formulation (M. Ahearn, personal communication, May 15, 1998).

cellulose additives (Down, et al, 1992, 1996; Keyserlingk & Down, 1995). The dispersion is about 55% solids, of medium particle size, and a pH of about 4.5 (Clariant, 1984). Its minimum film-forming temperature and glass transition temperature are 5°C and 10°C respectively and the dispersion remains stable for 1 year under normal conditions (Clariant). Lascaux Hot-seal Adhesive 371 (hereafter referred to as Lascaux 371), like Beva 371, consists of an ethylene-vinyl acetate copolymer, ketone resin N, and paraffin as a 20% solution in toluene and 1,1,1 trichloroethylene (Alois K. Diethelm AG, 1993). The adhesive was sold in a 300 ml spray can format, with propane/butane gas as the propellant (Alois K. Diethelm AG).

Adhesive preparation. The adhesives were used following methods outlined in a Canadian Conservation Institute seminar on the use of adhesives for textile conservation (Keyserlingk & Down, 1995). Dilute solutions of Appretan MB extra were prepared by mixing 15 ml of the adhesive dispersion with 150 ml of distilled water and 1 drop of the wetting agent, Kodak PhotoFlo 200. Lascaux 371 is ready to use as a spray adhesive.

Adhesive Application

Each 170 x 90 mm backing fabric sample was coated with adhesive separately. Samples were prepared in batches of 18: 9 silk and 9 polyester. Four batches were coated with each adhesive for each 160 cm piece of fabric. The techniques suggested by Keyserlingk and Down (1995) were modified after preliminary testing in order to produce the most even and consistent adhesive coating. Each sample was examined visually after coating and any irregularities in the adhesive coating recorded.

Appretan MB extra. The dilute adhesive was applied with a 100 mm paint brush onto 170 x 90 mm samples clamped by means of a steel bar to a Teflon-coated glass fabric surface. The warp and weft of each sample were carefully aligned before coating. The adhesive was applied in one even brush stroke and any bubbles removed. The samples were allowed to air dry thoroughly at room temperature (at least six hours) before being peeled from the surface and stored in silicone release paper sleeves. The first four batches were coated in the summer in conditions of approximately 22°C and 58% RH, as measured by a Fisher Scientific Digital Humidity/Temperature Meter 11-661-70. In order to replicate these conditions during the winter when the relative humidity in the lab fell below 25%, a Biotech ultrasonic humidifier and a polyethylene tent suspended over the work surface were used during the coating and drying of subsequent batches. The conditions resulting from this set up were 20 ±2°C and 55 ±10% RH.

Lascaux 371. Lascaux 371 was sprayed from a distance of 1.5 metres through a cardboard tube (155 x 13 x 26 cm) that fit into a fume hood. The 170 x 90 mm samples were held taut at the end of the tube in a removable holder designed to allow quick insertion and removal, and easy grain alignment. At the other end of the tube, the spray can was mounted onto a stand that could be taken out for shaking before each coat and then replaced in the same position. Samples were sprayed long enough--4 seconds in most cases--to produce adhesive add-ons within the range recorded for the Appretan samples. Coated samples were allowed to dry in a fume hood for at least 5 hours and then stored in silicone release paper sleeves.

Calculation of adhesive add-on. Each sample was weighed before and after adhesive application. Coated samples were dried in air under ambient conditions for at least 21 hours before weighing. Samples were conditioned for at least eight hours in a standard atmosphere of 65 ±2% RH and 20 ±2°C prior to weighing. Adhesive add-on was calculated as follows:

$$\text{add-on } (\text{g/m}^2) = [\text{mass after coating (g)} - \text{mass before coating (g)}] / \text{area coated } (0.014 \text{ m}^2) \quad (11)$$

where the value for the area is equivalent to coating 150 x 90 mm. The average add-on for each set of four batches was calculated for each adhesive. Three samples of each fabric whose add-on deviated most from the average or whose coating showed significant irregularities were discarded. The remaining samples were randomly assigned to laminate or uncoated backing fabric treatment groups (Table 11) and then stored in the dark for at least two weeks prior to heat-sealing.

Heat-sealing

The coated backing fabrics were heat-sealed to silk habutae samples in a modified drymount press, simulating the technique of using a hand held iron. An ERO-0204 temperature controller attached to the press by a thermocouple controlled the temperature within ± 1°C. The fully locked position of the press during heat-sealing ensured consistent pressure. A heat-sealing time of 20 seconds and temperatures of 95°C (Appretan) and 65°C (Lascaux) were chosen after pretesting. All samples, including unlaminated ones, were 'heat-sealed' in this manner, eliminating this treatment as a variable. The samples were heat-sealed in six batches, three for each adhesive (A, B, and C).

Laminated samples were prepared as follows. Three samples of silk habutae, one for each light exposure group of a particular sample type, were laid face down and grain aligned onto a matboard guide covered with a silicone release paper sleeve. Habutae and backing fabric positions were marked in black on the guide in such a way that they were visible through the release paper. The assigned coated backing fabric samples were centred over the habutae, adhesive side down and grain aligned with that of the habutae. The three samples were then covered with the top of the release paper sleeve and transferred to a marked, central position on the bed of the drymount press. After heat-sealing, the samples were removed from the press and allowed to cool before peeling from the sleeve. Unlaminated samples were also positioned on the marked guide and heat-sealed in sets of three. Positions on the guide were assigned randomly by light exposure group for each set of three. After heat-sealing, samples were trimmed on four sides to 140 x 68 mm (warp x weft) where necessary. The sample treatment groups resulting from this preparation are given in Table 11.

Accelerated Light Ageing

Two thirds of the samples were exposed to xenon arc radiation in an Atlas Ci35W Weather-Ometer fitted with soda lime and borosilicate filters to give radiation simulating daylight through window glass (Atlas Electric Devices, 1986). Samples were set into standard black test masks (SL-8A-3T) with the full front panel removed, backed with acid-free matboard, and fitted into metal specimen holders. The habutae face of the laminates

Table 11. Experimental Treatment Groups and Assigned Codes

		Treatment Groups		
Sample Type	Light Exposure:	0 hours	86 hours	172 hours
plain fabrics				
silk habutae *(artifact)*		H-0	H-86	H-172
silk crepeline *(backing fabric)*		S-0	S-86	S-172
polyester crepeline *(backing fabric)*		P-0	P-86	P-172
coated backing fabrics (adhesive - backing fabric)				
Appretan - silk crepeline		AS-0	AS-86	AS-172
Appretan - polyester crepeline		AP-0	AP-86	AP-172
Lascaux - silk crepeline		LS-0	LS-86	LS-172
Lascaux - polyester crepeline		LP-0	LP-86	LP-172
laminates (artifact - adhesive - backing fabric)				
silk habutae - Appretan - silk crepeline		HAS-0	HAS-86	HAS-172
silk habutae - Appretan - polyester crepeline		HAP-0	HAP-86	HAP-172
silk habutae - Lascaux - silk crepeline		HLS-0	HLS-86	HLS-172
silk habutae - Lascaux - polyester crepeline		HLP-0	HLP-86	HLP-172

and the adhesive side of the coated backing fabrics were exposed. Ultraviolet radiation was not filtered to acceptable museum standards in order to produce changes in properties in the available time significant enough for comparison.

Ageing took place in six runs corresponding to the heat-sealing batches (A, B, and C for each adhesive). Each run consisted of two periods of 86 hours. Samples assigned to the 86-hour exposure groups were removed after the first period. The total energy dose monitored at 420 nm and an irradiance of 0.82 watts/m^2 was 250 ±0.5 kJ/m^2 for the 86 hour exposure and 500 ±0.7 kJ/m^2 for the 172 hour exposure. Settings and operating conditions for each run are given in Appendix A (Table A1). Settings were chosen to give as low a temperature as possible while maintaining relative humidity levels around 50%. Average conditions in the Weather-Ometer were: black panel temperature, 50 ±1°C; relative humidity, 50 ±10%; dry bulb temperature, 29 ±3°C. Since the age of the xenon burner and the filters affects radiation transmission (Tweedie, et al., 1971), the values in operating hours are also listed for each run in Appendix A (Table A2). After ageing, samples were removed from the holders and masks and stored in the dark. The unexposed samples were stored in the dark throughout this period.

Measurement of Sample Properties

After ageing, the colour, stiffness, tensile properties, and peel strength of the samples were measured. Stiffness, tensile, and peel strength tests were conducted on conditioned samples under standard test conditions of 65 ±2% and 20 ±2°C. Fifteen samples were analysed for each treatment group, five from each light ageing run.

Colour Change

Change in colour was determined instrumentally using a Hunterlab D25M-9 tristimulus colorimeter and following the procedures of AATCC test method 153-1985: Colour Measurement of Textiles--Instrumental (American Association of Textile Chemists and Colorists [AATCC], 1985). Standard Illuminant C was used to approximate the visible region of the daylight spectrum. The Hunterlab colorimeter has a 45°/0° illumination/viewing geometry. The instrument was calibrated before each batch of readings. Six batches corresponded to the accelerated light ageing runs. The first three (Appretan A and B, and Lascaux A) and last three batches (Appretan C, and Lascaux B and C) were measured using different colorimeters of the same type due to a breakdown of one instrument after the third batch.

Measurements were taken through a 50.8 mm specimen port using a 1931 CIE 2°

standard observer. Samples were stacked 5 deep on top of a white tile during measurements. Due to the open weave of the backing fabrics, the tile was partially exposed during readings of these samples. Readings were taken from the front of the samples: the habutae face of the laminates, the exposed side of the plain fabrics, and the adhesive side of the coated backing fabrics. Two readings, in the warp and in the weft direction, were averaged for each sample.

Colour change was measured using the CIE 1976 L^* a^* b^* system. Measurements corresponding to lightness/darkness (L^*), red/green (a^*), and yellow/blue (b^*) were recorded. The overall colour change, ΔE_{CIELAB}, was calculated from these measurements using the following equation:

$$\Delta E_{CIELAB} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5} \qquad (12)$$

where $\Delta L^* = L^*_{sample} - L^*_{standard}$, $\Delta a^* = a^*_{sample} - a^*_{standard}$, and $\Delta b^* = b^*_{sample} - b^*_{standard}$. The standard in each case was an average of 10 measurements from the unexposed samples of each treatment group. Additional ΔE_{CIELAB} values were calculated for the unexposed laminates using the habutae standard and for the unexposed coated backing fabrics using the corresponding uncoated backing fabric standards.

Stiffness

The stiffness of the samples was determined using the cantilever method as described in ASTM D 1388-96: Standard Test Method for Stiffness of Fabric (ASTM, 1996). Following colour change measurements, each sample was trimmed of its unexposed edges, cut into two 120 x 25 mm (warp x weft) specimens and conditioned for at least eight hours. Each specimen was placed on the horizontal platform of the stiffness tester and a bar set on top of it. Specimens were pushed over the edge of a plane inclined at 41.5° to the horizontal until the leading edge touched the scale on that plane. The distance read from this scale is the length of overhang. Four readings were taken from each specimen: top and bottom, recto and verso. Warp flexural rigidity, a measure of the fabric's stiffness, was calculated from the average of these overhang measurements and from the mass of the fabric per unit area as follows:

$$\text{flexural rigidity, } G \text{ (mg-cm)} = W \times (O/2)^3 \qquad (13)$$

where W = weight per unit area (mg/cm^2) and O = length of overhang (average of four readings in cm). The mass and dimensions of the unexposed samples in each treatment group were measured prior to cutting the samples in half. An average value for the weight per unit area for each treatment group was calculated from these data. The warp flexural rigidity values for the two specimens from each sample were averaged.

The stiffness tester was slightly modified in order to minimize problems with slippery fabrics, tacky adhesives, and static electricity. The metal bar used to push the samples was lined with a piece of very fine emery paper for batch A of each adhesive and, as that was not sufficiently satisfactory, with a slightly rough bond paper for batches B and C since the plain metal did not grip the backing fabrics enough. In addition, the coated side of all Lascaux-coated and some Appretan-coated backing fabrics was tested with a piece of Teflon-coated glass fabric lining the horizontal platform of the apparatus, since the slightly tacky adhesive stuck to the metal plate. Trials showed that these alterations did not affect the overhang measurements. Samples affected by static electricity (polyester samples and those rubbed against the Teflon-coated glass fabric) were placed on a grounded metal plate between measurements.

Tensile Properties

Tensile strength, extension at break, and energy to rupture were determined following the test method CAN/CGSB-4.2 No. 9.1-M90: Breaking Strength of Fabrics--Strip Method--Constant-time-to-break Principle (CGSB, 1997a). Tests were conducted on an Instron Universal Testing Instrument Model 4202, using a 50 kg load cell and 75 mm pneumatic grips with rubber faces. The gauge length (the distance between the upper and lower grips before testing) was 75 mm. The crosshead speed was adjusted for each treatment group to give break times within 20 ±3 seconds.

Specimens used for the stiffness testing of silk habutae and the coated and uncoated backing fabrics were cut into two 120 x 12.5 mm (warp x weft) strips. These were ravelled to a width of 10 mm (31 and 24 warp yarns for silk and polyester backing fabrics respectively). Strips from the centre of the original sample were used for testing. Pretesting for crosshead speed was conducted on edge specimens. Ten millimetre wide strips were cut from the left side of the specimens used for stiffness testing of the laminates. Pretest strips came from extra samples in each laminate treatment group.

Values representing the tensile properties of the samples were calculated from the measurements recorded by the Instron. Peak load values in kilograms were multiplied by a factor of 9.81 to give breaking load in Newtons. The extension at break was calculated from elongation values as follows:

extension (%) = (change in length (ΔL)/original length (L_o)) × 100 (14)

where ΔL is the elongation at peak load and L_o is the gauge length (75 mm). The Instron determines energy to rupture by calculating the area under the load/elongation curve in units of kilogram-force-millimetres (kg-f-mm). These values were converted to S.I. units (N-m) by multiplying by 0.00981. Final values for each sample were calculated from the average of the measurements of its two specimens.

Peel Strength

The peel strength of each laminated sample was determined by a T-peel test according to the procedures of the test method CAN/CGSB-4.2 No. 65-M91: Determination of Strength of Bonds of Bonded, Laminated and Fused Fabrics (CGSB, 1997b). Tests were conducted on the Instron Universal Testing Instrument Model 4202, using a 2.5 N load cell and 6 mm spring-loaded fibre grips set at a gauge length of 25 mm.

The specimens for this test were the 15 mm wide strips remaining after tensile strips were cut from the laminate samples. These were ravelled to approximately 13 mm in order to prevent ravelling of the edges during the peel test. The bond at the top of the specimen was released by wetting with saliva and the first 40 mm peeled manually. The separated ends were reinforced with paper tabs so that the edges not held in the grips were not distorted during peeling. The silk and coated support fabrics were placed in the upper and lower clamps respectively. The test strips were then peeled over the remaining 80 mm at a crosshead speed of 50 mm/min. This rate, adopted from the test method, ISO 36: 1993 (E): Rubber, vulcanized or thermoplastic--Determination of adhesion to textile fabric (International Organization for Standardization [ISO], 1993), was in keeping with those used in conservation science research.

The peel strength was calculated manually from the resulting graph. The five highest and five lowest peak forces were recorded and these ten values averaged. The exact widths of the ravelled habutae and backing fabric were measured after peeling each specimen and averaged to the nearest millimetre. The peel strength per millimetre was calculated as follows:

peel strength (mN/mm) = average peak force (mN) / average width of specimen (mm) (15)

The values of the peel strength for the two specimens from each sample were averaged.

Microscopic Analysis

The surfaces of all types of coated backing fabrics and peeled laminates were examined using optical and scanning electron microscopy.

Optical microscopy. The adhesive surface of the various coated backing fabrics was viewed using an Olympus KHC-Bi binocular microscope at magnifications of 100X, 400X and 1000X. Uncut backing fabric samples supported on a glass slide were examined after coating and before heat-sealing to characterize the nature of the adhesive layer. After all other testing was complete, small specimens were cut from samples exposed to 0, 86, and 172 hours of radiation and examined for visible changes in the adhesive. The peeled surfaces of laminates from the 0 and 172 hour groups were also examined for evidence of adhesive transfer and fibre damage.

Scanning electron microscopy. The same types of surfaces were examined by scanning electron microscopy. One specimen was chosen to represent each of the following categories: AS-0 (front and back), AP-0 (front and back), LS-0, and LP-0 (all before heat-sealing); AP-172, and LP-172; HAS-0, HAS-172, HLS-0, and HLS-172 (peeled surfaces). A JEOL JSM 6301 FXV scanning electron microscope was used. Specimens were mounted on metal stubs with conductive carbon tape and sputter coated with a thin layer of gold. Images were viewed using 1.5 KV, working distances of 12 to 14 mm, and magnifications of 65X, 270X, 900X, 1600X, and 11,000X. Images were stored digitally as tif files.

Statistical Analysis

The hypotheses outlined in chapter 1 were tested using the statistical software SPSS for Windows, release 7.5. The individual 140 x 68 mm samples exposed to xenon arc radiation were considered as the experimental units, since the backing fabric samples were coated separately. The overall experimental design was a randomized complete block design due to the three blocks of fabric to which the treatment groups were randomly assigned. Since the pieces of each fabric were drawn from the same bolt, they were assumed to be identical. Thus variation due to the blocking factor was not considered in the analyses. Similarly, treatment procedures for each batch of samples were assumed to be identical. The focus of these analyses is the effect of materials rather than preparation techniques or testing procedures. Possible effects of such variation were noted, however, and accounted for in the analyses if necessary.

Due to the complex nature of the sample types, analyses were carried out on subsets of the data as summarized in Table 12. Two-way or three-way analyses of

Table 12. Summary of Experimental Variables for ANOVA Analyses

Data Subset	Dependent Variables	Independent Variables	
		Factors	Levels
Part I: Comparison of the Properties of Laminates and their Components			
plain silk and laminates	colour change (ΔE) flexural rigidity tensile strength extension at break energy to rupture	sample type	H HAS HAP HLS HLP
		exposure	0 hours 86 hours 172 hours
laminates and coated backing fabrics pairs	flexural rigidity tensile strength extension at break energy to rupture	lamination	laminated unlaminated
		exposure	0 hours 86 hours 172 hours
Part II: Effects of Adhesive and Backing Fabric Type on Laminate Properties			
laminates	flexural rigidity tensile strength extension at break energy to rupture peel strength	adhesive	Appretan MB extra Lascaux 371
		backing fabric	silk crepeline polyester crepeline
		exposure	0 hours 86 hours 172 hours
coated and uncoated backing fabrics	flexural rigidity tensile strength extension at break energy to rupture	adhesive	none Appretan MB extra Lascaux 371
		backing fabric	silk crepeline polyester crepeline
		exposure	0 hours 86 hours 172 hours

variance (ANOVA) were performed for each relevant dependent variable in order to determine which interactions and main effects of the independent variables were significant. Subsequent testing followed the strategy summarized by Milliken and Johnson (1984). If a test indicated significant three-way interaction, two-way analyses of the data at each level of one of the factors were conducted. If three-way interaction was not significant, variables involved in two-way interactions were analysed at that level. Factors not involved in two-way interactions were tested for main effects. Significant differences between levels of the factors of interest were determined using the multiple comparison procedures available through the one-way ANOVA. Results from Tukey's Honestly Significant Difference test or Tamhane's T2 test were reported depending on whether the assumption of equal variances for the data was satisfied or not. If a two-way interaction of the factors was significant, multiple comparisons were performed on the basis of all treatment combinations. If the interaction was not significant, the comparisons were made on the basis of one factor after averaging over the results of the other factor.

Exposure level was included as a categorical variable in the analyses. Although such a continuous random variable would usually be treated as a covariate in this type of analysis, the levels in this study are sufficiently restricted for a categorical approach to be justified. Including exposure level as an independent variable also permitted direct testing of the significance of differences in rate of change of the dependent variables by examining the interaction of *exposure* with the other factors. When the data are represented by a multiple line graph with the mean value of the property assigned to the y-axis, exposure level indicated by the x-axis, and the levels of the second factor given by individual lines, interaction is exhibited when the lines cross or the slope of the lines is very different. Lack of interaction, on the other hand, means that the lines are essentially parallel. The slope of the lines in such a graph is equivalent to the rate of change of the property. Thus the results of the test for interaction can be interpreted in terms of the rate of change of the dependent variable at each level of the other factor.

Before analyses were carried out, the data in each cell of the subset were examined for normality of distribution and equality of variance. If the data showed strong departures from these assumptions, the nonparametric Kruskall-Wallis H test was used to confirm the significance of the main effects. Since ANOVA is relatively robust to departures from normality and to inequality of variance if the cell sizes are equal, however, slight differences were tolerated.

In addition to the statistical analyses, the rate of change and percent change from the initial state were calculated. Rate of change was determined by finding the difference of the means for a property of a particular treatment group at 0 and 86 hours and at 86 and 172 hours and dividing those values by the number of hours in an exposure period (86 hours):

rate (1st exposure period) = [mean (86 hrs) - mean (0 hrs)] / 86 hours (16)

rate (2nd exposure period) = [mean (172 hrs) - mean (86 hrs)] / 86 hours (17)

The resulting value represents the slope of the lines on graphs showing the change in a property over time. These values were helpful in interpreting the significance of the interaction analyses.

Percent change was calculated by subtracting the mean value of a property for a particular treatment group at 86 hours and at 172 hours from that at 0 hours and determining what percentage of the mean value at 0 hours these differences were:

% change at 86 hrs = [mean (86 hrs) - mean (0 hrs)] / mean (0 hrs) x 100 (18)

% change at 172 hrs = [mean (172 hrs) - mean (0 hrs)] / mean (0 hrs) x 100 (18)

The percent values were calculated in addition to the rate values because rates in set units per hour can be misleading if the initial properties of the samples are very different. For example, the loss of a certain amount of tensile strength from a weak fabric may render it too weak to use while exactly the same loss from a strong fabric will have a negligible effect on its ability to perform certain functions. More information about the light degradation properties of the laminates and their components was derived from considering both rate and percent change.

CHAPTER IV RESULTS AND DISCUSSION

Introduction

This chapter consists of two parts corresponding to the two main questions addressed by this study. Part I compares the properties and light stability of the laminates and their components, plain silk habutae and coated backing fabrics. Emphasis will be placed on the similarities and differences between plain habutae and the laminates, since the plain habutae represents the artifact, the component of greatest concern to textile conservators. Part II examines the effects of the types of adhesive and backing fabrics on the properties of the laminates. Analysis of these materials as coated and uncoated backing fabrics is included to further clarify which effects are due to the materials as such and which are dependent on the adhesion of the backing materials to silk habutae. The raw data used in the analyses are listed in Appendix B. Summaries of the major ANOVA analyses are found in Appendix C.

Part I: Comparison of the Properties of Laminates and their Components

The purpose of this first section is to examine as closely as possible the properties of silk-adhesive-backing fabric laminates. Much could be learned about their properties from studying the laminates themselves. Comparison with their components, however, allows the particular properties of the laminates to be more precisely distinguished and permits a better understanding of the role of adhesion on those properties. Furthermore, comparing the laminates with plain habutae best exposes the effects of adhesive backing treatment on the silk "artifact".

Plain versus Backed Silk

For adhesive backing to be acceptable, it should ameliorate those properties of silk which in historic artifacts have degraded to the point of endangering the textile, while not negatively affecting any others. In terms of the properties examined in this study, improvement in tensile properties is desirable since the backing should increase the strength and toughness of the artifact so that it can be safely handled. On the other hand, changes in colour or stiffness are less desirable, since these would change important characteristics of the textile. Any acceleration of the rate at which these properties change or deteriorate when exposed to light is unacceptable. The artifact would then have been better preserved without the treatment. In response to these concerns, this first section considers how adhesive backing significantly changes the properties of silk habutae, including its stability to light.

Colour Change

Statistical analyses of the colour change (ΔE_{CIELAB}) data indicated significant differences among plain silk and the laminates due to *sample type* and *exposure*. The ΔE_{CIELAB} mean values for each type at each exposure level, as given in Table 13, show that, after 172 hours of exposure, plain silk had undergone the greatest change in colour (due mostly to yellowing, or increases in b*), followed by polyester-backed silk, and finally silk-backed silk. These differences are significant, but the effect depends on the level of exposure: that is, the interaction between the factors *sample type* and *exposure* is significant, F (8, 210) = 23.429, p = .000. Before exposure the ΔE_{CIELAB} for all types is essentially zero since the colour change of each sample is measured against a standard calculated from the unexposed samples of its own type. After 172 hours, however, a clear difference, which appears to be related to the type of backing (none, polyester, silk), is apparent. Kruskall-Wallis tests confirmed the lack of significant difference between the types before exposure, χ^2 (4, N = 75) = 3.463, p = .484, and the significance of differences at 86 hours, χ^2 (4, N = 75) = 55.979, p = .000, and at 172 hours, χ^2 (4, N = 75) = 55.814, p = .000. This suggests that the sample types were not yellowing at the same rate. According to these results, habutae backed with silk or polyester crepeline yellowed more slowly than plain habutae when exposed to light (Figure 5).

This conclusion is counterintuitive and not supported by visual evidence. The

Table 13. Colour Change (ΔE_{CIELAB})† of Plain and Backed Silk by Level of Light Exposure

		86 hours		172 hours	
Sample Type	Code	Mean	Std.Dev.	Mean	Std.Dev.
Plain Silk					
habutae	H	$5.85^{d,e,f}$	0.63	7.54^{g}	0.54
Laminates					
habutae - Appretan - silk	HAS	$4.23^{a,b}$	0.40	5.69^{e}	0.23
habutae - Appretan - polyester	HAP	$5.16^{c,d}$	0.33	6.62^{f}	0.40
habutae - Lascaux - silk	HLS	4.01^{a}	0.28	$5.54^{d,e}$	0.54
habutae - Lascaux - polyester	HLP	$4.79^{b,c}$	0.38	6.44^{f}	0.43

†calculated against standard from unexposed samples of type from the same ageing run (n =15)
^{a,b,etc}means with the same letter are not significantly different as determined by Tamhane's T2 test at α = .05.

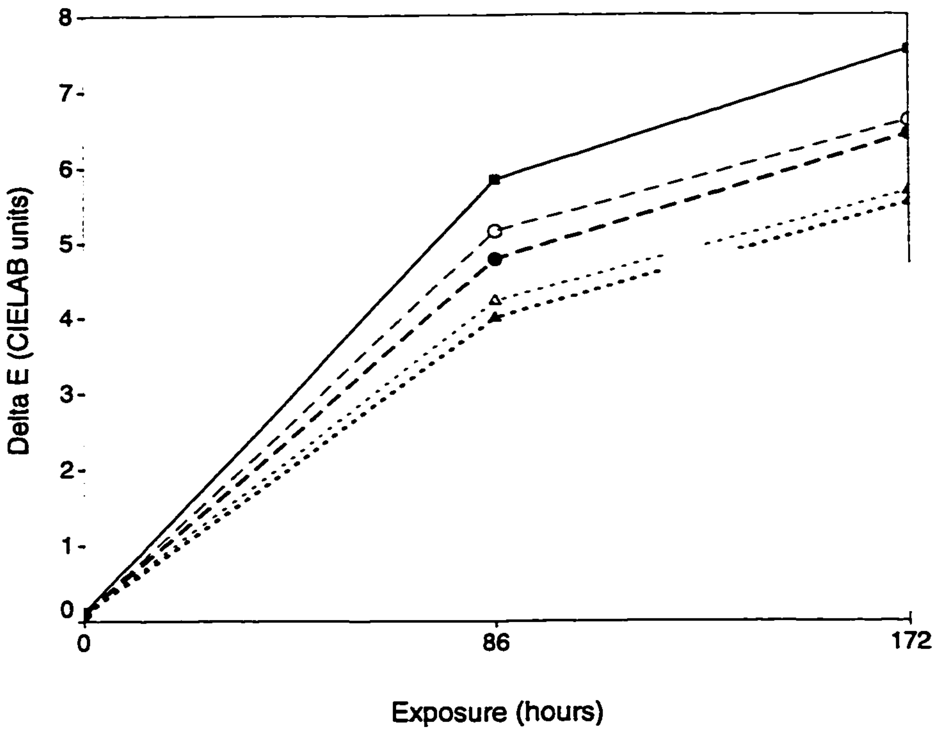

Figure 5. Colour change of plain and backed habutae on exposure to light.

backings did not protect the habutae facing from light degradation in any obvious way. More rapid yellowing due to accelerated degradation caused by the presence of the backing materials might be predicted, but not slower yellowing. Nevertheless, the mean ΔE_{CIELAB} for plain habutae (7.54 CIELAB units) is approximately 1 and 2 CIELAB units greater than those for the polyester-backed (6.44 or 6.62 CIELAB units) and silk-backed (5.54 or 5.69 CIELAB units) laminates respectively. A statistically significant colour change (ΔE_{CIELAB}) may not be visible, but a difference of 2 CIELAB units is large enough to be noticed. Similar differences of approximately 1.5 to 2 CIELAB units between the ΔE_{CIELAB} values at 86 and 172 hours for each sample type were easily discerned. The plain and backed habutae samples, however, did not exhibit clear visible differences in colour after 172 hours of light exposure.

These differences in the rate of yellowing can be largely explained by the effect of the backing fabric on the colour of the translucent habutae. Comparison of readings from the laminates against a plain habutae standard of the same exposure level shows precisely how the colour of the habutae was modified by the colour of the backing fabric (Table 14). Unexposed habutae backed with silk crepeline was somewhat darker

Table 14. Colour Difference of Laminates from Plain Habutae at Each Exposure Level

	ΔL^* (light-dark)		Δa^* (red-green)		Δb^* (yellow-blue)		ΔE_{CIELAB} (total change)	
Laminate (by exposure level)	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
0 hours[a]								
habutae - Appretan - silk	-1.36	0.18	-0.12	0.05	1.82	0.09	2.28	0.17
habutae - Lascaux - silk	-1.51	0.19	-0.10	0.06	1.75	0.12	2.32	0.14
habutae - Appretan -polyester	-0.12	0.13	-0.05	0.03	0.41	0.11	0.45	0.12
habutae - Lascaux - polyester	-0.25	0.13	-0.06	0.02	0.45	0.13	0.54	0.12
86 hours[b]								
habutae - Appretan - silk	-0.66	0.19	0.16	0.11	0.24	0.17	0.74	0.22
habutae - Lascaux - silk	-0.89	0.24	0.16	0.06	0.39	0.26	1.00	0.29
habutae - Appretan -polyester	0.25	0.18	0.06	0.11	-0.32	0.22	0.46	0.23
habutae - Lascaux - polyester	0.04	0.28	-0.01	0.06	-0.19	0.16	0.34	0.14
172 hours[c]								
habutae - Appretan - silk	-0.57	0.22	0.19	0.06	0.05	0.51	0.77	0.26
habutae - Lascaux - silk	-0.47	0.12	0.16	0.07	-0.10	0.28	0.57	0.11
habutae - Appretan -polyester	0.32	0.13	0.02	0.05	-0.51	0.24	0.63	0.21
habutae - Lascaux - polyester	0.35	0.12	0.00	0.08	-0.60	0.14	0.70	0.15

[a] calculated against the unexposed plain habutae standard from the same ageing run (n = 15)
[b] calculated against the 86-hour plain habutae standard from the same ageing run (n = 15)
[c] calculated against the 172-hour plain habutae standard from the same ageing run (n = 15)

(negative ΔL^* values), very slightly greener (negative Δa^* values), and distinctly yellower (positive Δb^* values) than unexposed plain habutae. This statistically significant difference ($\alpha = .05$) was visible to the naked eye. Unexposed habutae backed with polyester crepeline did not differ visibly from unexposed plain silk, but its measured colour change was significantly different nonetheless ($\alpha = .05$) and included slightly higher values for b^*. After exposure to light, the colours of the laminates were still significantly different from the corresponding plain silks, but not in the same manner as the unexposed samples. With increasing exposure, the colour of silk-backed habutae became more similar in lightness and yellowness to that of plain habutae (ΔL^* and Δb^* values approach zero), but also more red (positive Δa^* values). The colour of the polyester-backed habutae, on the other hand, became similar to that of plain habutae in its red-green dimension ($\Delta a^* = 0$) but increasingly measured as lighter (positive ΔL^* values) and bluer (negative Δb^* values). At 172 hours, these ΔE_{CIELAB} values for silk and polyester-backed laminates are significantly different from the mean ΔE_{CIELAB} value for exposed plain habutae samples calculated against the same plain habutae standard.

The magnitude of these differences, 0.57 to 0.77 CIELAB units, is not sufficient to be visible. They are also are not significantly different from each other ($\alpha = .05$). This corroborates the observed similarity between the final colour of the exposed plain and backed habutae samples.

The effects of the backing fabrics on the laminate colour can be used to explain the colour change results reported in Table 13 without postulating differences in the rates of degradation of the samples. First, colour differences in the unexposed laminates affect the standards for each sample type and in turn the ΔE_{CIELAB} values for the exposed samples calculated using these standards. L*, a*, and b* readings from unexposed samples were averaged and used as the standard against which the colour change of all samples was calculated for each sample type. The initial differences in colour resulted in standards for the laminates that were yellower (higher b* values) than the standard for plain habutae. If the habutae in all of these samples yellowed to exactly the same degree, and this yellowing masked some of the initial yellowness contributed by the backing fabric, those sample types having standards with the highest b* values (silk-backed laminates) would have the lowest calculated values for Δb^* and, since most of the colour change was due to changes in b*, the lowest ΔE_{CIELAB} in turn, as was the case. The changes in b* support the interpretation that yellowing of the habutae masked the yellowness of the backing fabrics (Figure 6). With increasing exposure, the b* values of plain silk and the silk-backed laminates became increasingly alike. After 172 hours of light exposure, the Δb^* values for silk crepeline laminates, as calculated against an exposed plain habutae standard, were close to zero (Table 14).

Secondly, the presence of the backing fabric influenced the degree to which the yellowness of the exposed habutae deepened when the five samples were stacked for colour measurement. This effect, especially apparent in the polyester-backed samples, can also be seen in the changes in b* values (Figure 6). Before light exposure, polyester-backed laminates were very slightly yellower than the plain habutae. The exposed polyester-backed laminates, on the other hand, were slightly less yellow than the corresponding exposed plain habutae. Delta b* values for these laminates, as calculated against the corresponding plain habutae standard, remain similar to those at 0 hours but are negative instead of positive (Table 14). Assuming equal yellowing of the habutae in all cases, this effect could be interpreted as a dilution of the overall colour due to the whiteness of the interleaved polyester crepeline. Since silk crepeline is similar in colour to the yellowed habutae, colour dilution did not affect the colour change of silk-backed laminates.

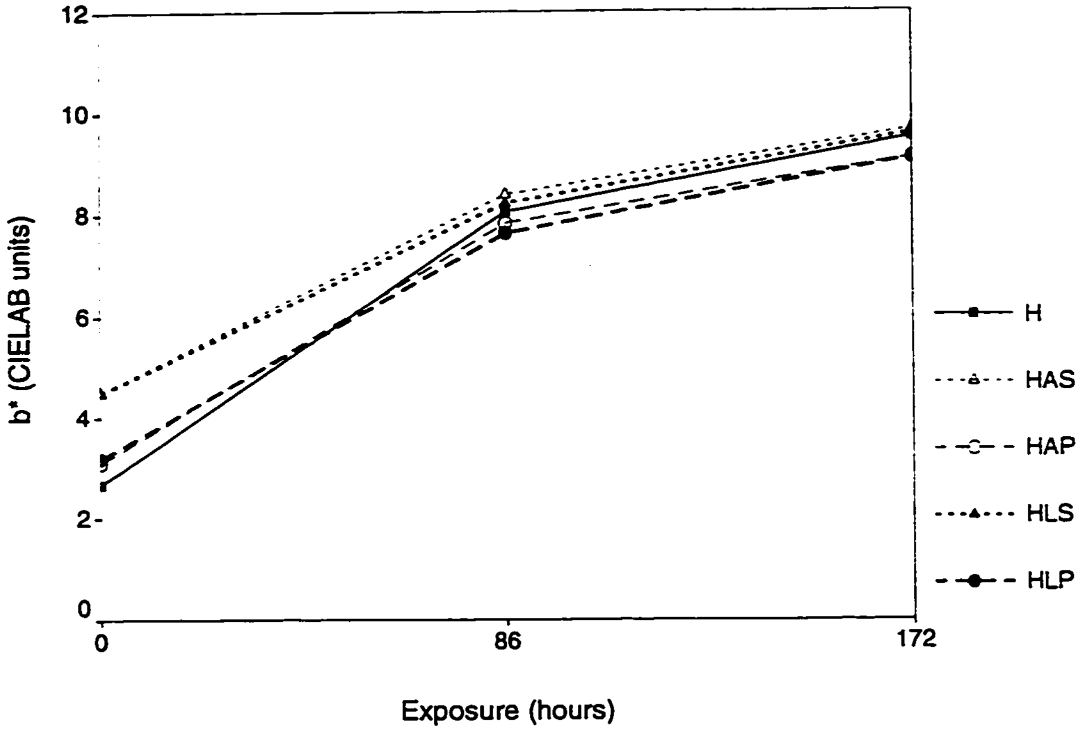

Figure 6. Change in b* of plain and backed silk habutae on exposure to light.

Despite support for this interpretation of the colour change values, the data gathered by this study do not conclusively show that the habutae in the laminated and unlaminated samples yellowed to the same degree or that the backing materials in the laminates did not discolour, as visual observation suggests. Minor differences resulting from the treatment may have been obscured by the complex manner in which the backing fabric colour affected the colour of the laminates as the habutae yellowed. The interpretation that the differences in colour between the exposed laminates and exposed plain silk were due predominantly to the mere presence of the backing fabrics was confirmed tentatively by measuring the colour of a few samples of exposed plain habutae (172 hours) interleaved with unexposed, Appretan-coated backing fabrics and calculating the ΔE_{CIELAB} values for these "samples" against the appropriate laminate standard. The results compared favorably with average ΔE_{CIELAB} values for corresponding laminates from the same exposure run (Karsten & Kerr, 1998). Further experimentation of this sort would be required to examine more precisely the effect of adhesive backing on the colour change of silk due to light exposure.

Stiffness

Of primary interest, when comparing the stiffness of plain and laminated silk, was the huge initial increase in stiffness of the habutae when an adhesive backing was attached (Figure 7). Flexural rigidity values for the various laminates were on average 12 to 18 times that of plain silk (Table 15). The difference was significant at the .05 level and easily noticeable. Once backed, habutae became much more resistant to shear distortion as well. Most of the increase in flexural rigidity in the laminates was due to overhang values that were at least double that of plain silk (Appendix B, Tables B1a, B2a, B3a, B4a, and B5a). Although the mass of the laminates was higher than plain silk (and approximately equal to the sum of the masses of habutae and the corresponding backing fabrics), this increase was much more modest (Table 15). Moreover, mass is given lower weighting than overhang in the calculation of flexural rigidity. Since maintaining the flexibility of the artifact is almost always cited as a requirement for appropriate textile

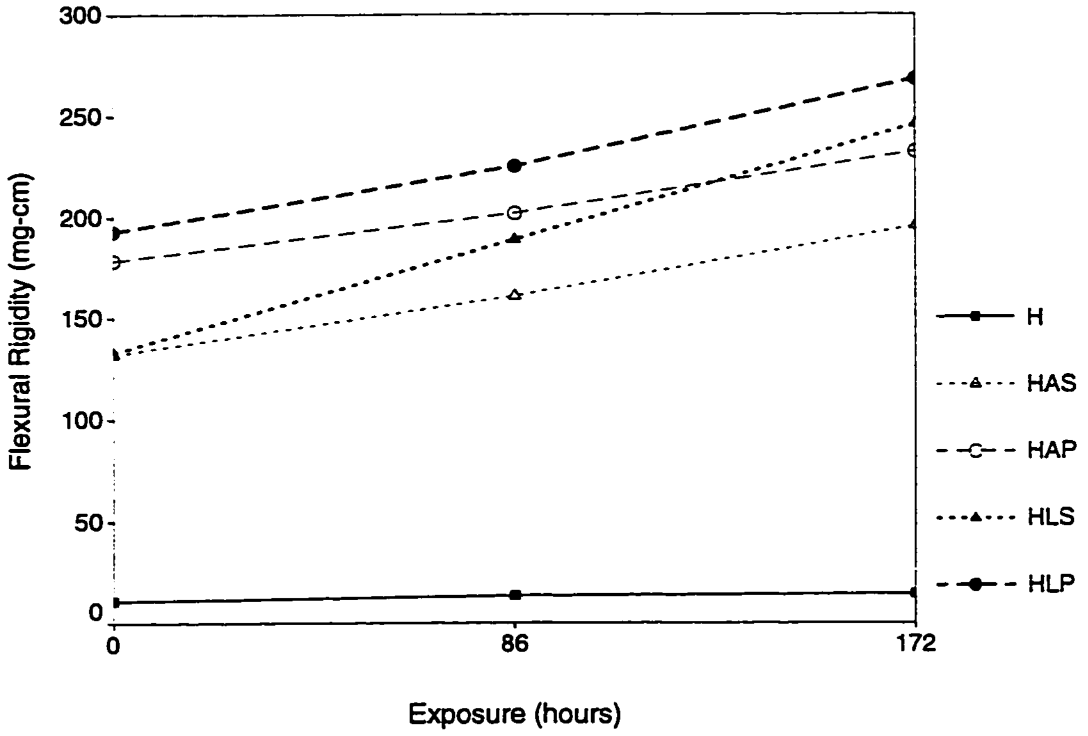

Figure 7. Change in stiffness of plain and backed habutae on exposure to light.

Table 15. Flexural Rigidity (mg-cm) of Plain and Backed Habutae by Level of Light Exposure

Sample Type	Mass (g/m^2)	Exposure Level					
		0 hours		86 hours		172 hours	
		Mean†	Std. Dev.	Mean†	Std. Dev.	Mean†	Std. Dev.
Plain Silk							
habutae	3.59	11^{a}	1	$14^{a,b}$	2	15^{b}	3
Laminates							
habutae - Appretan - silk	4.74	132^{c}	12	$161^{c,d}$	32	$196^{d,e,f,g}$	53
habutae - Appretan - polyester	5.11	$179^{d,e}$	32	$202^{d,e,f,g}$	43	$233^{e,f,g}$	57
habutae - Lascaux - silk	4.84	133^{c}	22	$189^{c,d,e,f}$	51	$246^{e,f,g}$	58
habutae - Lascaux - polyester	5.22	$193^{d,e,f}$	32	$226^{e,f,g}$	31	268^{g}	53

†n =15

^{a,b,etc}means with the same letter are not significantly different as determined by Tamhane's T2 test at $\alpha = .05$.

treatments, this change should be noted by conservators. The laminate samples were, however, still quite flexible.

Stiffness increased due to light exposure. All sample types, except Appretan-polyester laminates, exhibited a significant increase in flexural rigidity after 172 hours of exposure, tested at an alpha level of .05 (Table 15). This increase was not particularly noticeable by touch, even though, in the case of the Lascaux-silk laminates, the change was as high as 85%. Nevertheless, as Figure 7 and the values in Table 16 indicate, the rate of stiffening of the laminates increased during the second exposure period. Thus, continued exposure under the same conditions would probably cause further stiffening. By contrast, the values for plain habutae indicate a reduction of the stiffening effect with increased exposure.

The rates at which the sample types stiffened were significantly different, as indicated by the significance of the interaction effect, $F\,(8, 210) = 4.154$, $p = .000$. Plain habutae stiffened at a very slow rate compared to the laminates. This suggests that the backing fabric or adhesive, alone or in combination, are predominantly responsible for the stiffening of the laminates. The adhesive, softened due to the elevated temperatures in the Weather-Ometer, may have been able to penetrate the habutae yarns somewhat, increasing the stiffness of the upper layer. Differences among the laminates themselves point to more specific effects of backing fabric and adhesive types. The analysis of this data suggest at least a significant effect of backing fabric type. Before light exposure,

Table 16. Change in Flexural Rigidity of Plain and Backed Habutae due to Light Exposure

Sample Type	Code	Rate of Change [a] (mg-cm/hr) 0 - 86 hours	Rate of Change [a] (mg-cm/hr) 86-172 hours	% Change [b] 86 hours	% Change [b] 172 hours
Plain Silk					
habutae	H	0.03	0.01	+27	+36
Laminates					
habutae - Appretan - silk	HAS	0.34	0.40	+22	+49
habutae - Appretan - polyester	HAP	0.27	0.35	+13	+30
habutae - Lascaux - silk	HLS	0.65	0.66	+42	+85
habutae - Lascaux - polyester	HLP	0.38	0.50	+17	+39

[a] first period: (mean 86 hours - mean 0 hours) / 86; second period: (mean 172 hours - mean 86 hours) / 86
[b] (mean 86 or 172 hours - mean 0 hours) / mean 0 hours x 100

polyester-backed laminates were significantly stiffer than silk-backed ones ($\alpha = .05$). This effect was no longer distinguishable after 172 hours of light exposure (Table 15). The effect of backing fabric and adhesive on the stiffness of the laminates will be analysed in more detail in the Part II.

Tensile Properties

Adhesive backing also altered the tensile properties of silk. Unlike the changes in stiffness, which proceeded at different rates for plain silk and the various types of laminates, however, the tensile properties tended to decrease at almost identical rates for all sample types.

Tensile strength. Adhesive backing treatment resulted in silk laminates of greater tensile strength than plain silk. The mean tensile strengths of plain silk and the various laminates are listed in Table 17. Before light exposure, the laminates were on average stronger than plain silk--from about 10% stronger for Appretan-silk crepeline laminates to about 28% for Lascaux-polyester crepeline laminates. Only the difference between plain silk and Appretan-silk laminates was not significant at the .05 level due to the degree of variation in the values for the laminate samples. The increase in strength in the laminates was less than the combined strengths of plain silk (63.3 N) and the corresponding coated backing fabrics: Appretan-silk (15.4 N), Lascaux-silk (14.7 N), and Appretan-polyester or Lascaux-polyester (28.8 N). Thus some of the strength of the adhered fabrics was lost in the adhesion process. Partial immobilisation of the yarns due

Table 17. Tensile Strength (N) of Plain and Backed Habutae by Level of Light Exposure

		Exposure Level					
		0 hours		86 hours		172 hours	
Sample Type	Code	Mean†	Std. Dev.	Mean†	Std. Dev.	Mean†	Std. Dev.
Plain Silk							
habutae	H	63.3^{c}	1.8	45.5^{e}	2.4	29.0^{g}	4.4
Laminates							
habutae - Appretan - silk	HAS	$69.5^{b,c}$	6.6	51.0^{d}	4.0	$32.1^{f,g}$	3.0
habutae - Appretan - polyester	HAP	$77.1^{a,b}$	7.4	$55.4^{c,d}$	8.3	$35.9^{f,g}$	6.8
habutae - Lascaux - silk	HLS	71.1^{b}	5.1	$49.9^{d,e}$	4.7	$33.5^{f,g}$	2.7
habutae - Lascaux - polyester	HLP	80.8^{a}	5.5	54.3^{d}	7.3	36.3^{f}	4.0

†n =15

a, b, etc. means with the same letter are not significantly different as determined by Tamhane's T2 test at $\alpha = .05$.

to adhesion restricts the warp yarns from straightening out in the direction of the applied force as they do in plain fabric in order to better carry the load. In addition, slight differences in grain alignment between the habutae and the backing fabric may leave only one fabric supporting the load in the most effective direction, parallel to the warp. Although care was taken to align the fabrics, perfect alignment was difficult to achieve. The lack of alignment was visible as slight moiré patterns on the backing side of the laminated silk.

Exposure to xenon arc radiation for 172 hours resulted in significant ($\alpha = .05$) losses of over 50% in tensile strength of all samples, as was expected (Tables 17, 18). Figure 8 shows that the losses were almost linear with time. The similar values for rate of strength loss for the two exposure periods confirm this linearity (Table 18). The slight dip for almost every sample type in the second exposure period, however, is an indication that this loss probably follows first-order kinetics, and its rate will decrease over time, as expected from the literature on silk degradation (Hansen & Ginell, 1989; Hersh, et al., 1989; Kuruppillai, et al., 1986). The percentage loss values in Table 18 support this interpretation. Slightly more than half of the total amount was lost in the first 86 hour period. A similar almost linear decrease in the strength of silk habutae exposed to xenon arc radiation under slightly differing conditions was reported by Lemiski (1996).

All sample types lost tensile strength at approximately the same rate (Figure 8, Table 18). The interaction between the factors *sample type* and *exposure* is significant, $F(8, 210) = 2.573$, $p = .011$, but only moderately so (at the .05 level but not at the .01

Table 18. Change in Tensile Strength of Plain and Backed Habutae due to Light Exposure

		Rate of Change [a] (N/hr)		% Change [b]	
Sample Type	Code	0 - 86 hours	86-172 hours	86 hours	172 hours
Plain Silk					
habutae	H	-0.21	-0.19	-28	-54
Laminates					
habutae - Appretan - silk	HAS	-0.22	-0.22	-27	-54
habutae - Appretan - polyester	HAP	-0.25	-0.23	-28	-53
habutae - Lascaux - silk	HLS	-0.25	-0.19	-30	-53
habutae - Lascaux - polyester	HLP	-0.31	-0.21	-32	-55

[a] first period: (mean 86 hours - mean 0 hours) / 86; second period: (mean 172 hours - mean 86 hours) / 86
[b] (mean 86 or 172 hours - mean 0 hours) / mean 0 hours x 100

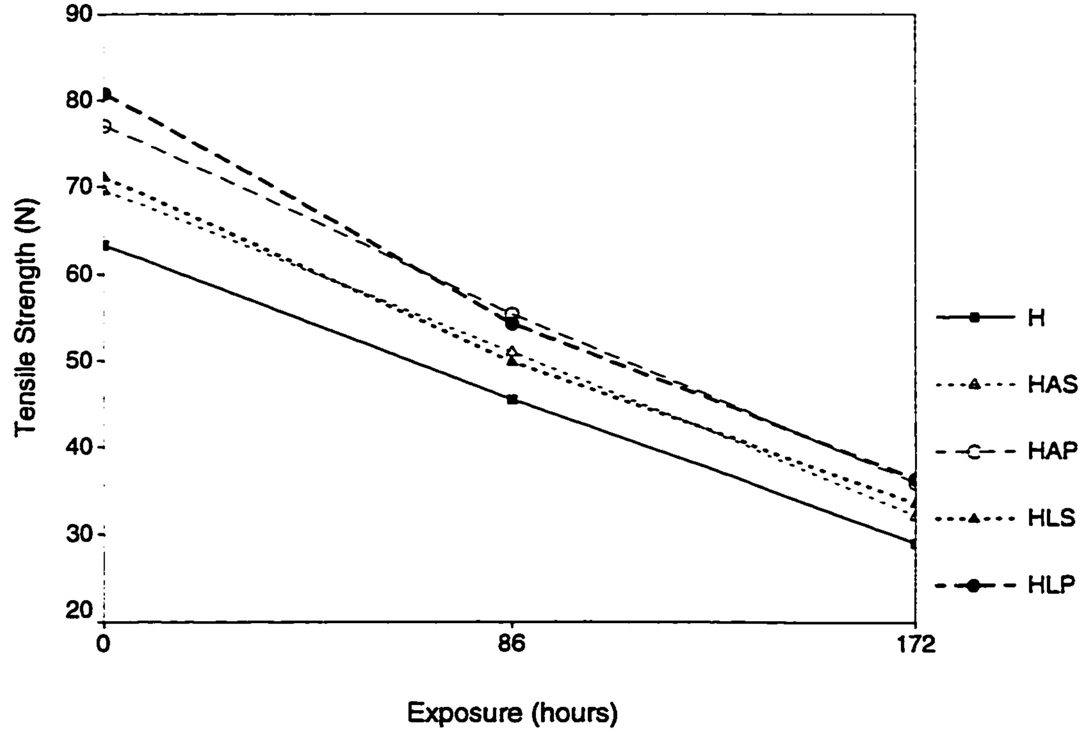

Figure 8. Change in tensile strength of plain and backed habutae on exposure to light.

level). The slight variation in the rates, which resulted in both Lascaux laminates being weaker on average than their Appretan counterparts after 86 hours but not at 0 or 172 hours (Figure 8), accounts for this interaction. As a result of this similarity in rate of strength loss, all laminates remained stronger than plain habutae after exposure to light. After 172 hours of light exposure, however, this difference is only significant for the Lascaux-polyester laminates ($\alpha = .05$; Table 17).

These results apply to laminates wherein the silk facing is stronger than the backing fabric. A textile artifact needing adhesive backing will almost always have a tensile strength less than that of silk crepeline. Halvorson (1991) measured mean tensile strengths for historic silk fabrics as low as 4.12 N (*SD* = 1.85) on specimens 2.5 times the width of those used here. In this study, the silk habutae representing the artifact was still as strong as unexposed polyester crepeline after 172 hours of light exposure. Thus the point where the strength of the silk facing drops below that of the backing fabric and the resultant effect on the change in tensile strength as the backing begins to carry most of the load was not reached. How the tensile strength of laminates changes with continued exposure when the backing fabric, which is not directly exposed to the light, is the stronger component cannot be determined from this study.

Extension at break. The extension at break of the laminates was far less different from that of plain habutae than was their tensile strength, as is clear from the means summarized in Table 19 and from the closely spaced lines in Figure 9. Extension values for the laminates varied from that of plain silk by only 1 to 6% before light exposure, compared to 10 to 28% for tensile strength. After exposure to light for 172 hours the laminates were still only 6 to 16% less extensible than exposed plain habutae. Although the effect of *sample type* is significant, $F(4, 210) = 13.683$, $p = .000$, only the mean extension at break for the silk-backed samples is significantly lower than that of plain habutae ($\alpha = .05$). This reflects the slightly lower extensibility of coated silk crepeline which breaks when stretched to approximately 20% of its original length as compared to 22% for plain habutae. The extension values for the silk crepeline laminates are approximately equal to the average of the values for the components, 21%. Although the greater extensibility of the polyester backing fabrics, approximately 27% for either adhesive, contributed to laminate extension values that were very slightly (but not significantly) higher than that of plain habutae, the extension at break values of the polyester-backed laminates were much lower than the average of those of their component fabrics.

Lamination also resulted in no significant change in the rate at which extension to

Table 19. Extension at Break (%) of Plain and Backed Habutae by Level of Light Exposure

		Exposure Level					
		0 hours		86 hours		172 hours	
Sample Type	Code	Mean[†]	Std. Dev.	Mean[†]	Std. Dev.	Mean[†]	Std. Dev.
Plain Silk							
habutae	H[a]	21.7	0.5	14.2	1.2	9.7	0.9
Laminates							
habutae - Appretan - silk	HAS[b]	20.7	0.9	13.0	0.9	8.1	0.9
habutae - Appretan - polyester	HAP[a,b]	21.9	1.4	13.8	2.0	9.1	1.5
habutae - Lascaux - silk	HLS[b]	20.3	1.9	12.5	1.3	8.3	0.9
habutae - Lascaux - polyester	HLP[a]	22.4	1.8	14.0	1.7	9.1	0.9

[†] n =15

[a, b, etc] types with the same letter are not significantly different as determined by Tamhane's T2 test at α = .05 using values averaged over the three exposure levels.

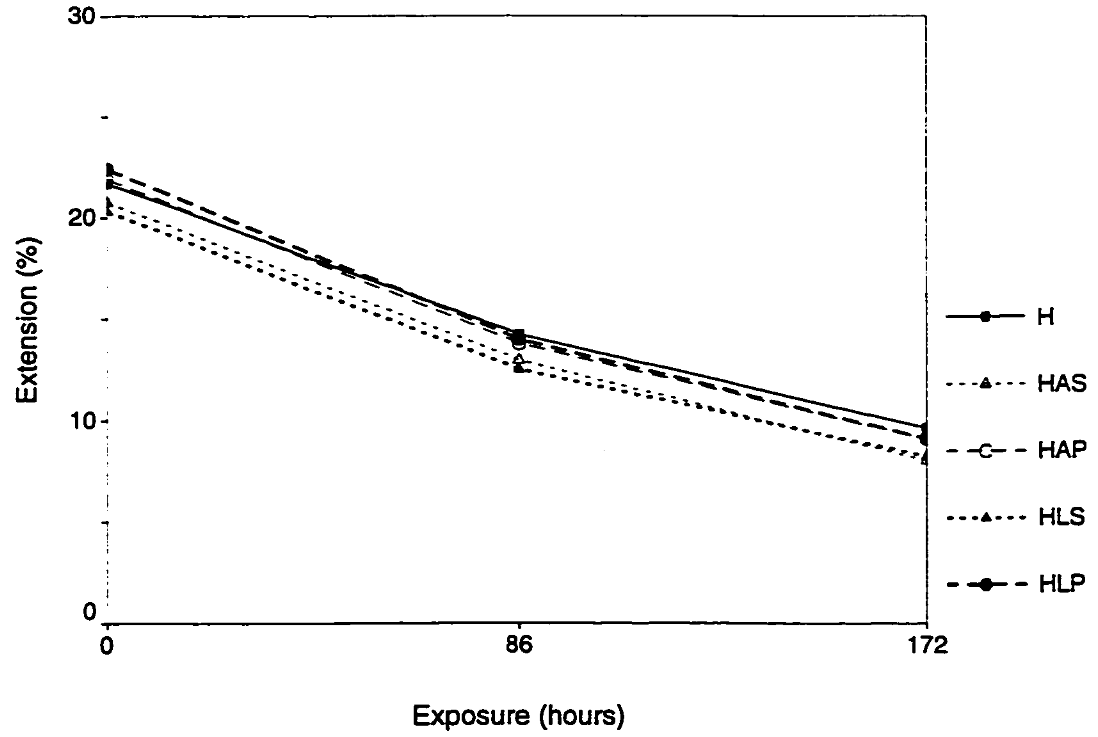

Figure 9. Change in extension at break of plain and backed habutae on exposure to light.

break of habutae decreased due to light exposure. The exposure level had a significant effect on loss of extensibility, *F* (2, 210) = 1764.739, *p* = .000, but the interaction between the factors *sample type* and *exposure* was not significant, *F* (8, 210) = .695, *p* = .696. The similarity of the rates of loss of extensibility during each exposure period for all sample types accounts for this lack of interaction (Table 20, Figure 9). The total percent lost of extensibility after 172 hours was also very similar for all sample types (56-61%). The slight differences can be partially accounted for by the differences in extension at 0 hours, against which these percentages were calculated and by slight increases in spot welding of yarns and fibres of the laminates due to softening of the adhesive during exposure at elevated temperatures.

Energy to rupture. The results obtained for energy to rupture, a measure of fabric toughness that is equal to the area under the load/elongation curve, reveal similar patterns as those for extension at break (Table 21). Exposure to light resulted in significant decreases in energy to rupture for both plain silk and the laminates, *F* (2, 210) = 1559.235, *p* = .000. These decreases are to be expected, given that both tensile strength and elongation decreased due to light exposure. However, the lack of significant interaction between *sample type* and *exposure*, *F* (8, 210) = 1.259, *p* = .267, indicates that this property too changed at the same rate whether or not the habutae was backed using adhesives. The similarity in the rates of change can be seen in the slopes of the lines in Figure 10 and the values in Table 22. All samples showed the greatest decrease in toughness during the first 86 hours (58 to 63%) followed by continued but slower

Table 20. Change in Extension at Break of Plain and Backed Habutae due to Light Exposure

		Rate of Change [a] (%/hr)		% Change [b]	
Sample Type	Code	0 - 86 hours	86-172 hours	86 hours	172 hours
Plain Silk					
habutae	H	-0.09	-0.05	-34	-56
Laminates					
habutae - Appretan - silk	HAS	-0.09	-0.06	-37	-61
habutae - Appretan - polyester	HAP	-0.09	-0.05	-37	-58
habutae - Lascaux - silk	HLS	-0.09	-0.05	-38	-59
habutae - Lascaux - polyester	HLP	-0.10	-0.06	-38	-59

[a] first period: (mean 86 hours - mean 0 hours) / 86; second period: (mean 172 hours - mean 86 hours) / 86
[b] (mean 86 or 172 hours - mean 0 hours) / mean 0 hours x 100

Table 21. Energy to Rupture (N-m) of Plain and Backed Habutae by Level of Light Exposure

		Exposure Level					
		0 hours		86 hours		172 hours	
Sample Type	Code	Mean†	Std. Dev.	Mean†	Std. Dev.	Mean†	Std. Dev.
Plain Silk							
habutae	H^{a}	0.618	0.050	0.228	0.027	0.071	0.026
Laminates							
habutae - Appretan - silk	HAS^{a,b}	0.660	0.087	0.249	0.036	0.085	0.016
habutae - Appretan - polyester	HAP^{b,c}	0.731	0.106	0.307	0.079	0.141	0.052
habutae - Lascaux - silk	HLS^{a}	0.626	0.099	0.237	0.045	0.092	0.013
habutae - Lascaux - polyester	HLP^{c}	0.747	0.113	0.288	0.069	0.126	0.018

†n =15

^{a,b,etc}means with the same letter are not significantly different as determined by Tamhane's T2 test at $\alpha = .05$ using values averaged over the three exposure levels.

decreases in the next 86 hours (22 to 26%). Lemiski (1996) reported a similar pattern of decreasing rate of loss of energy to rupture over time in silk exposed to light. Overall, 172 hours of light exposure resulted in very high losses of energy to rupture for all sample types (81 to 89%).

Although the energy to rupture changed at the same rate for the different sample types, the mean values for these types are not equivalent, $F(4, 210) = 17.335$, $p = .000$. The average energy to rupture was higher for all laminates than for plain silk. However, the values for habutae backed with silk crepeline were not significantly different from that of plain silk while those for polyester-backed habutae were ($\alpha = .05$). This again reflects the relative toughness of the coated backing fabrics, polyester crepeline being about twice as tough as silk crepeline (0.36-0.38 N-m versus 0.16-0.18 N-m respectively). The values for the two Appretan laminates were also not significantly different ($\alpha = .05$). Thus the addition of a polyester backing will significantly increase the toughness of silk habutae, although it will not reduce the rate at which its toughness is reduced due to light exposure.

Summary

The comparison of the properties and of the light stability of plain and backed habutae reveals that while the properties of the laminates may vary significantly from those of plain habutae, the manner in which these two groups of materials change when

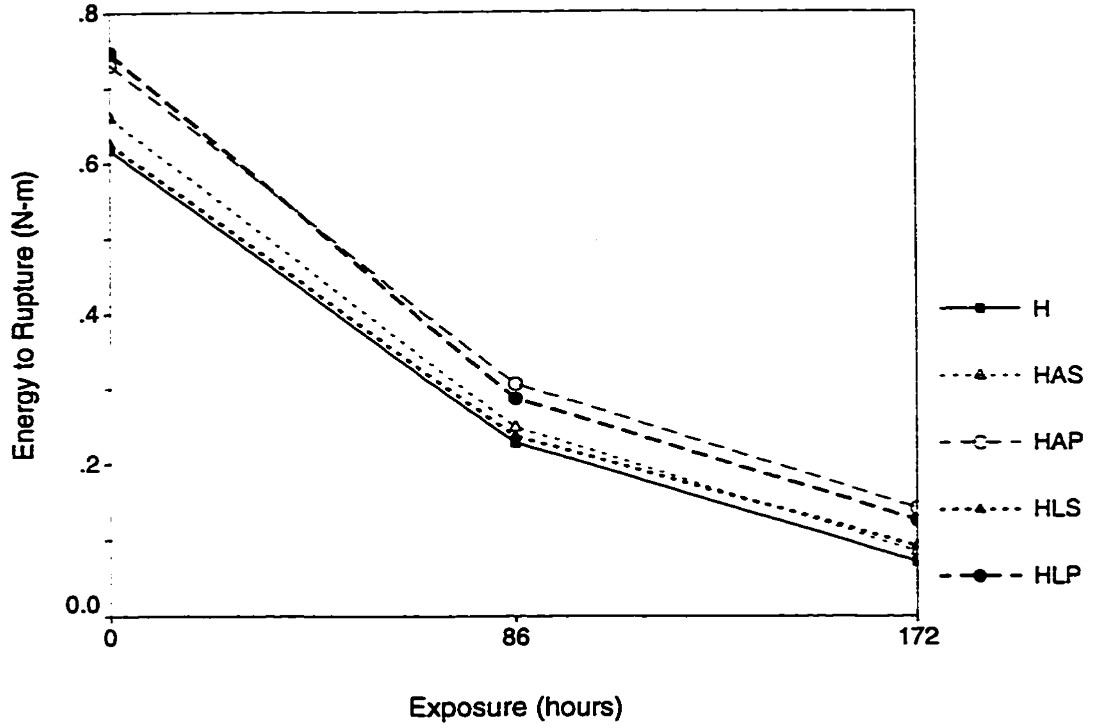

Figure 10. Change in energy to rupture of plain and backed habutae on exposure to light.

Table 22. Change in Energy to Rupture of Plain and Backed Habutae due to Light Exposure

Sample Type	Code	Rate of Change [a] (N-m/hr)		% Change [b]	
		0 - 86 hours	86-172 hours	86 hours	172 hours
Plain Silk					
habutae	H	-0.005	-0.002	-63	-89
Laminates					
habutae - Appretan - silk	HAS	-0.005	-0.002	-62	-87
habutae - Appretan - polyester	HAP	-0.005	-0.002	-58	-81
habutae - Lascaux - silk	HLS	-0.005	-0.002	-62	-85
habutae - Lascaux - polyester	HLP	-0.005	-0.002	-61	-83

[a] first period: (mean 86 hours - mean 0 hours) / 86; second period: (mean 172 hours - mean 86 hours) / 86
[b] (mean 86 or 172 hours - mean 0 hours) / mean 0 hours x 100

exposed to light is remarkably similar, except in terms of stiffness. The null hypothesis of no significant difference between the colour, stiffness, and tensile properties of plain habutae and silk habutae-adhesive-backing fabric laminates before and after light exposure is rejected. Adhesive backing did increase the tensile properties of silk habutae, but it also increased its stiffness significantly and caused visible differences in the colour of the translucent habutae. The null hypothesis of no significant difference in the rate of change of these properties due to light exposure is rejected for stiffness but not for the tensile properties. Change in tensile properties proceeded at the same rate for both plain silk and the laminates. The rate of stiffening, on the other hand, was higher for the laminates. Although both plain and backed silk yellowed similarly, the precise effect of adhesive backing on the rate of colour change could not be determined from this study.

Laminates versus their Corresponding Coated Backing Fabrics

Attention will now turn to the relationship of the properties of silk laminates to those of their second component: the adhesive-coated backing. The results presented in the preceding section suggest that the light stability of the laminate might be dominated to a large degree by the properties of the habutae facing. Before reaching such a conclusion, the properties of the laminates must be compared to those of their corresponding backing fabrics. If the backing fabrics degraded at rates similar to those of the laminates and plain habutae, then neither component could be said to influence the light stability of the laminates more than the other. If, however, the laminates and backing fabrics degraded at different rates, the dominance of the properties of the exposed habutae component in determining the properties of the laminates would be corroborated.

This section will concentrate on a comparison of the rates of degradation of the laminates and their backing fabrics. Although the analyses revealed significant differences in the properties per se, these were not unexpected given the substantial differences between the backing fabrics and silk habutae. The experimental design was also intended to produce significant changes in properties due to exposure. Thus the focus is on the significance of the interaction of the factors, *lamination* and *exposure*, rather than on the significance of those factors individually.

Colour Change

Differences in the colour change of the laminates and their corresponding backing fabrics will only be discussed qualitatively. The difficulty in interpreting the ΔE_{CIELAB} values of the laminates has already been discussed. That the white tile showed through the sheer backing fabrics during colour reading also invalidates comparison of backing fabric and laminate results. Moreover, strong deviations from the assumptions required for ANOVA and nonparametric analyses made statistical hypothesis testing inadvisable. Nevertheless a few observations are noteworthy.

Visible colour change was evident for three of the four types of coated backing fabrics that was not apparent in the laminates. Both silk backing fabrics and the Lascaux-coated polyester crepeline exhibited visible yellowing. Coated silk crepeline backing fabrics had clearly yellowed after 172 hours of light exposure (ΔE_{CIELAB} = 2.4 to 3.2). The colour change of the Lascaux-coated polyester crepeline samples was just visible at a ΔE_{CIELAB} value of 1.4 CIELAB units. Yet the corresponding laminates were not visibly distinct from plain habutae or habutae backed with Appretan-coated polyester after 172 hours of light exposure, although the difficulty in showing this conclusively has already been described. This provides some support for the view that backing materials that discolour when exposed to light, will not do so when covered by the artifact (Keyserlingk, 1990, 1993), even when the covering is as translucent a fabric as silk habutae. Duffy (1989) observed a similar lack of discoloration of adhesives when sandwiched between polyester sailcloth.

Stiffness

The laminates and the unlaminated coated backing fabrics varied distinctly in terms of the effect of light exposure on stiffness (Table 23). The flexural rigidity values for the laminates increased at much higher rates (0.27-0.66 mg-cm/hour) than those for the coated backing fabrics (0.01-0.12 mg-cm/hour). Two-way analysis of variance showed significant interaction between the factors *lamination* and *exposure* for three of the four pairs: HAS/AS, $F(2, 84) = 10.807$, $p = .000$, HLS/LS, $F(2, 84) = 20.717$, $p = .000$, and HLP/LP, $F(2, 84) = 9.260$, $p = .000$. Interaction for the exception, the Appretan-polyester samples, was not significant at the .05 level but moderately so at the 0.10 level, $F(2, 84) = 2.670$, $p = .075$.

When the change in stiffness is calculated as percent increase from the flexural rigidity before exposure, additional patterns emerge. The increase in stiffness is greater for the laminates than the coated backing fabrics only when the backing fabric is silk crepeline. The percentage increase in flexural rigidity of adhesive-coated silk crepeline backing fabrics after 172 hours of light exposure (7%-15%) remains much lower than that of the corresponding laminates (49-85%). By contrast, coated polyester backing fabrics

Table 23. Change in Flexural Rigidity of Laminates and their Corresponding Backing Fabrics due to Light Exposure

		Rate of Change [a] (mg-cm/hr)		% Change [b]	
Sample Type	Code	0 - 86 hours	86-172 hours	86 hours	172 hours
habutae - Appretan - silk	HAS	0.34	0.40	+22	+49
Appretan - silk	AS	0.01	0.01	+ 4	+ 7
habutae - Appretan - polyester	HAP	0.27	0.35	+13	+30
Appretan - polyester	AP	0.12	0.07	+33	+57
habutae - Lascaux - silk	HLS	0.65	0.66	+42	+85
Lascaux - silk	LS	0.04	0.01	+12	+15
habutae - Lascaux - polyester	HLP	0.38	0.50	+17	+39
Lascaux - polyester	LP	0.05	0.05	+30	+48

[a] first period: (mean 86 hours - mean 0 hours) / 86; second period: (mean 172 hours - mean 86 hours) / 86
[b] (mean 86 or 172 hours - mean 0 hours) / mean 0 hours x 100

showed percent increases in stiffness after light exposure for 172 hours (48-57%) that exceeded those of polyester-backed laminates (30-39%). These same values indicate, moreover, that the polyester backing fabrics exhibited higher percent increases in flexural rigidity than silk crepeline backings when not laminated but lower percent increases when laminated. Thus, the factors that affect the stiffening of the laminates and the coated backing fabrics must be distinct. The increases in stiffness of the coated polyester crepeline are due to the effects of light on the polyester fibre, since uncoated polyester crepeline stiffened in a similar manner (see p. 152). By shielding the backing fabric from the light, the habutae may have prevented the polyester from stiffening in the laminates, just as it appears to have prevented the yellowing of the silk crepeline and Lascaux 371. The higher rates of stiffening of the laminates in comparison to their unlaminated coated backing fabrics may also be contingent on the presence of the habutae. The adhesives, softened slightly by the elevated temperatures in the Weather-Ometer, may have penetrated further around the silk yarns of the habutae to weld them together more firmly. Adhesive penetration is regarded as a major cause of fabric laminate stiffness by those who work with bonded fabrics in the textile industry (Allewet & Bauer, 1974; Holker, 1975). Shishoo, et al.(1971) also showed that the stiffness of fabric laminates is more highly dependent on the adhesion of the laminates than on the properties of the fabric components.

The importance of adhesion to the stiffness of laminates was demonstrated by a few trial overhang measurements on the stiffness tester of plain habutae laid upon but not adhered to the coated backing fabrics. The overhang measurements of the unexposed coated backing fabrics were similar to those of the laminates: an average of 5.5 cm for the backing fabrics versus 6.3 cm for the laminates (see Appendix B). Nevertheless, not all of this stiffness is transferred to the laminate. When the backing fabrics were covered with but not adhered to a layer of habutae, the overhang measurements dropped to an average of 4.3 cm. Although this latter value reflects measurements from only one side of the layered samples (the habutae fell independent of the backing fabric when it was on the bottom), it corresponds very well to the expected relationship between components and laminate reported by Shishoo, et al. (1971): that the overhang equals half the sum of the overhangs for the two components. The calculated average of this value for layered samples made from the four backing types is 4.2 cm. The actual values of the overhangs for the laminates were much higher, by contrast, but were not equal to the sum of those of the components, as Shishoo, et al. found in their study. Thus the interaction of the backing fabric and habutae due to adhesion plays a crucial but complex role in the stiffness of the resulting laminates.

Tensile Properties

The comparison of the laminates and their corresponding unlaminated backing fabrics in terms of tensile properties yielded the same basic pattern as that seen for stiffness. The interaction between the factors, *lamination* and *exposure*, was significant at the 0.01 level for every pair (Appendix C, Tables C3, C4, and C5). This indicates significant differences in the rates at which the tensile properties decreased due to exposure to light, which is borne out by the values listed in Table 24. In terms of loss per hour, the backing fabrics deteriorated more slowly than their laminate counterparts. The difference in rate between the two exposure periods was also larger in general for the backing fabrics, which degraded more quickly during the first period. These differences support the theory suggested by the comparison of the properties of the laminates and plain habutae: that the behaviour of the laminates is to a large degree determined by the properties of the exposed face fabric, the habutae, and not by those of the backing materials.

Examination of the differences in the tensile properties of the laminates and unlaminated coated backing fabrics, expressed as percent changes, provides further support for this theory (Table 24). For all three properties, tensile strength, extension at break, and energy to rupture, the percent loss after 172 hours of light exposure was

Table 24. Change in Tensile Properties of Laminates and their Corresponding Backing Fabrics due to Light Exposure

		Rate of Change[a]		% Change[b]	
Sample Type	Code	0 - 86 hours	86-172 hours	86 hours	172 hours
	Tensile Strength	(N/hour)			
habutae - Appretan - silk	HAS	-0.22	-0.22	-27	-54
Appretan - silk	AS	-0.08	-0.03	-45	-64
habutae - Appretan - polyester	HAP	-0.25	-0.23	-28	-53
Appretan - polyester	AP	-0.07	-0.04	-21	-33
habutae - Lascaux - silk	HLS	-0.25	-0.19	-30	-53
Lascaux - silk	LS	-0.07	-0.04	-41	-63
habutae - Lascaux - polyester	HLP	-0.31	-0.21	-32	-55
Lascaux - polyester	LP	-0.11	-0.04	-32	-43
	Extension at Break	(%/hour)			
habutae - Appretan - silk	HAS	-0.09	-0.06	-37	-61
Appretan - silk	AS	-0.16	-0.04	-66	-84
habutae - Appretan - polyester	HAP	-0.09	-0.05	-37	-58
Appretan - polyester	AP	-0.09	-0.03	-30	-38
habutae - Lascaux - silk	HLS	-0.09	-0.05	-38	-59
Lascaux - silk	LS	-0.14	-0.05	-61	-83
habutae - Lascaux - polyester	HLP	-0.10	-0.06	-38	-59
Lascaux - polyester	LP	-0.11	-0.03	-34	-46
	Energy to Rupture	(N-m/hour)			
habutae - Appretan - silk	HAS	-0.005	-0.002	-62	-87
Appretan - silk	AS	-0.002	<0.000	-82	-96
habutae - Appretan - polyester	HAP	-0.005	-0.002	-58	-81
Appretan - polyester	AP	-0.002	-0.001	-54	-65
habutae - Lascaux - silk	HLS	-0.005	-0.002	-62	-85
Lascaux - silk	LS	-0.002	<0.000	-79	-95
habutae - Lascaux - polyester	HLP	-0.005	-0.002	-61	-83
Lascaux - polyester	LP	-0.003	<0.000	-62	-71

[a] first period: (mean 86 hours - mean 0 hours) / 86; second period: (mean 172 hours - mean 86 hours) / 86

[b] (mean 86 or 172 hours - mean 0 hours) / mean 0 hours x 100

always higher for unlaminated silk crepeline backing fabrics than for the corresponding laminates. If the backing fabric was polyester crepeline, on the other hand the opposite was true: the percent loss was lower for the unlaminated backing fabric than for the laminate. Yet the percent losses in tensile properties for laminates with different backing fabrics were remarkably similar. If the relative deterioration rates of the backing fabrics had a significant effect on the rate of degradation of laminates made with them, then the laminates should show similar differences. This provides additional support for the conclusion that the degradation of the backing fabrics due to light exposure is modified or prevented by the presence of the habutae in front of them.

Summary

The analyses in this section show that unlike the habutae component, which deteriorated in much the same way as the laminates for all the properties studied except stiffness, the backing fabric components degraded differently from their laminate counterparts. The null hypothesis of no significant difference in the rate of change of stiffness and tensile properties of the laminates and their corresponding backing fabrics is thus rejected. The light stability of laminates composed of new silk habutae may not be highly affected by the stability of the backing fabric, when the backing fabric is entirely shielded from the light by the habutae.

Part II: Effects of Adhesive and Backing Fabric Type on Laminate Properties

The previous comparisons revealed some significant differences related to the materials used to produce the laminates. If adhesive backing treatment is considered an acceptable treatment for historic textiles, then knowing the effects of different backing fabrics and adhesives would aid conservators in choosing materials suitable for specific treatment problems. The discussion will now address the effects of the various materials more closely.

Laminates

Statistical analyses of the effects of the factors *adhesive*, *backing fabric*, and *exposure* on laminate properties revealed very straightforward results in all cases. Almost no two-way or three-way interactions were significant for stiffness, any of the tensile properties, or peel strength (Appendix C, Table C6). Thus these three factors affected the properties of the laminates relatively independently. The significance of the main effects differed by property, and will be discussed separately. The effects of exposure level, which were included in the analyses due to the possibility of interaction effects, will be discussed only when the results add to what has been presented in Part I. Given the problems in interpreting the results for colour change, which have been discussed at the beginning of Part I, this property will not be considered in comparing the effects of materials.

Stiffness

The stiffness of laminates made with Appretan MB Extra and Lascaux 371 differed significantly, *F* (1, 168) = 16.388, *p* = .000. Lascaux laminates were stiffer than the Appretan laminates (Figure 11), although the difference was not noticeable by touch. Several factors may have contributed to this difference. Higher amounts of adhesive cause increased stiffness in fabric laminates (Shishoo, et al., 1971). This could not be a factor in this study since the adhesive add-on achieved for the two adhesives did not vary significantly, *F* (1, 356) = .320, *p* = .572. Inherent differences in the flexibility of the two adhesive could affect laminate stiffness. Ethylene vinyl acetate copolymer adhesives like Lascaux 371, however, are generally more flexible than vinyl acetate-dibutyl maleate copolymers like Appretan MB extra because of the efficacy of ethylene as a plasticiser for poly(vinyl acetate) (Jaffe et al., 1990). Comparison of the similar adhesives Mowilith DMC2 and Beva 371 have shown that, though both are very flexible, Beva 371, the Lascaux equivalent, is more so (Blackshaw & Ward, 1982). Measurements by Down, et al. (1992, 1996) showed that Beva 371 has a lower modulus (58.1 MPa) than Mowilith DMC2 (305 MPa), indicating that the former is more flexible. Differences in adhesive flexibility, therefore, cannot account for the differences in the flexibility of the laminates.

The manner in which the adhesives were applied may affect the stiffness. Whether this is so cannot be ascertained from this study since the two application techniques were not used on both adhesives. Theoretically, the tiny particles of Lascaux 371, with their more intermittent and irregular spot bonding along the yarns, should produce more flexible laminates than the continuous yarn coating of Appretan MB extra (see p. 144 for more complete descriptions of the adhesive coatings). Dot coatings have been found to cause less stiffening than continuous films (Selm, 1991). However, no research has studied the effects of more minor differences. Samples from the research conducted on adhesive backing treatments at the Victoria and Albert Museum (Hillyer,

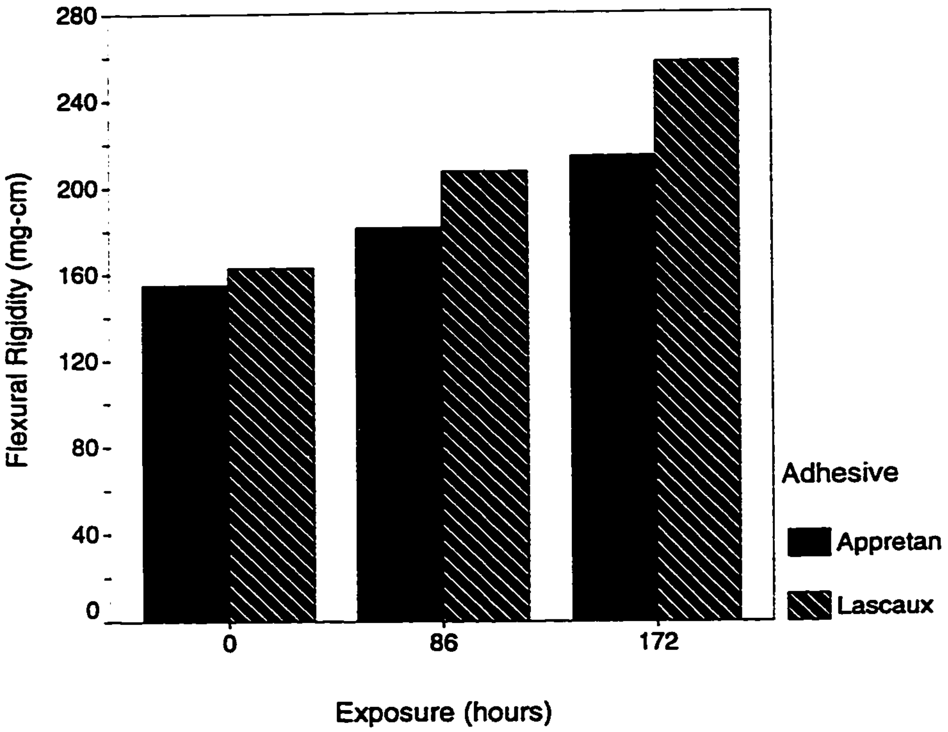

Figure 11. Effect of adhesive type on the stiffness of silk habutae-adhesive-backing fabric laminates.

1993; Pretzel, 1993, 1997a, 1997b)[2] provide tentative evidence that such minor differences may be important. Adhesive-coated silk crepeline backing fabric samples showed that a 20% solution (by volume) of Vinamul 3252 coated only the yarns while a 20% solution of Mowilith DMC2 produced a continuous film filling the interstices between the yarns (see also Hillyer, et al., 1997). A Vinamul 3252 laminate was noticeably more flexible than one prepared with Mowilith DMC2. If the polyester crepeline backings used on these laminates had the same differences in coating as the silk crepeline samples, this difference in flexibility may be due to differences in the continuity of the adhesive film rather than differences in the flexibility of the adhesives. Microscopic examination of the reverse of the two laminate samples, however, revealed residues of adhesive between the backing fabric yarns in both cases. Thus further research is necessary to test for the effect of adhesive distribution on stiffness more rigorously.

The effect of heat on the adhesives may also contribute to differences in stiffness.

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[2] Samples were provided by Linda Hillyer, Textile Conservation Department, Victoria and Albert Museum, London, UK

If Lascaux 371 becomes more fluid during heat-sealing, it may penetrate the habutae yarns more at the points of adhesion, increasing stiffness. Images of adhesive residue on the habutae faces of peeled laminates provide some support for this hypothesis. Lascaux droplets appear to have melted around the silk fibres (Figure 12). In contrast, even after 172 hours of light exposure, residues of Appretan MB extra still seemed to sit on the surface of the fibres (Figure 13). Slight staining of the outer silk face of the Beva laminate sample from the Victoria and Albert Museum lends further support to possible problems of penetration with this type of adhesive. Microscopic examination of the reverse of this sample suggested that adhesive had migrated into the silk between the backing fabric yarns. Unlike the Mowilith and Vinamul samples, almost no adhesive was observed around the polyester yarns, although the bond of the laminate was strong. The sample was at least as stiff as the Mowilith sample, if not more so. Textiles stained by high concentrations of Beva 371 and Beva film have been reported (M. Keyserlingk, personal communication, 1995; Landi, 1992; Lochhead, 1995; Muir & Yates, 1987), but infrequently. As in this study, the adhesive usually penetrates enough to increase stiffness, but not to cause staining.

The elevated temperature during light exposure may have contributed to further adhesive penetration of the yarns and thus to the significant increases in stiffness due to exposure to light, $F(2, 168) = 49.717$, $p = .000$ (see Figures 7 and 11). The black panel temperature of the the Weather-Ometer (50°C) was closer to the suggested heat-sealing temperature of Lascaux 371 (60-65°C) than to that of Appretan MB extra (80°C) (Keyserlingk & Down, 1995). The temperature of the samples was probably lower than 50°C. Hansen and Ginell (1989) recorded values of 35°C at the surface of silk samples exposed to similar conditions. But both adhesives soften sufficently for bonding at temperatures below those recommended for heat-sealing. Pretesting showed that laminates could be produced at 55°C with Lascaux 371 and at 75°C with Appretan MB extra. Beva 371 softens sufficiently at 50°C to produce measurable peel strengths on samples simulating lined canvas paintings (Hardy, 1992). Mowilith DMC2 has been found to soften at 68°C (Blackshaw & Ward, 1982). In general, Lascaux 371, like Beva 371, is more sensitive to heat and thus more likely to soften due to the heat levels in the Weather-Ometer than Appretan MB extra or Mowilith DMC2. That the difference in the stiffness of Lascaux and Appretan laminates increased with increased exposure (Figure 11) is consistent with the interpretation that Lascaux laminates are stiffer due to the greater heat-sensitivity of Lascaux 371.

The flexibility of Appretan laminates in this study was further affected by the

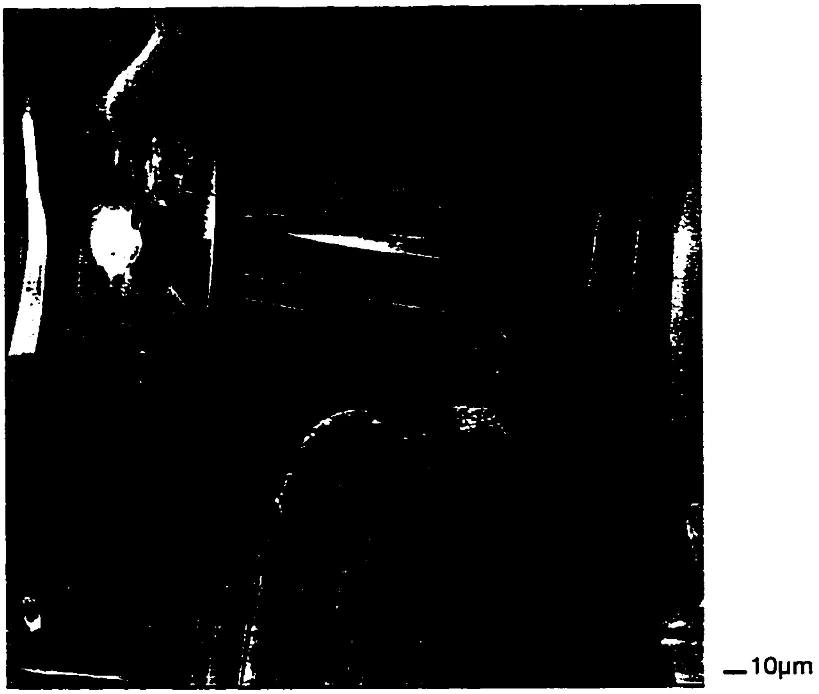

Figure 12. Adhesive residue on the surface of silk habutae after peeling an unexposed habutae-Lascaux 371-silk crepeline laminate (HLS4-0A).

Figure 13. Adhesive residue on the surface of silk habutae after peeling an exposed habutae-Appretan MB extra-silk crepeline laminate (HAS4-172A).

environmental conditions in the laboratory during adhesive application to the backing fabric samples. As already described, the first block of samples was prepared during a period of relatively high humidity. Attempts to replicate these conditions with a portable humidifier for subsequent batches did not succeed in preventing significant differences in the laminate stiffness for the first and the last two blocks, ($\alpha = .05$, Figure 14). Furthermore, significant interaction between *block* and *exposure*, $F(4, 72) = 6.161$, $p = .000$, indicates that the greater increases in stiffness due to light exposure for blocks B and C versus block A are also significant. The increases for block A are, in fact, not significant at the .05 level. The overhang measurements were also clearly dependent on the orientation of the laminate (face up or face down) for blocks B and C, but not for block A, an effect that was not examined closely in this study. These differences may be due to

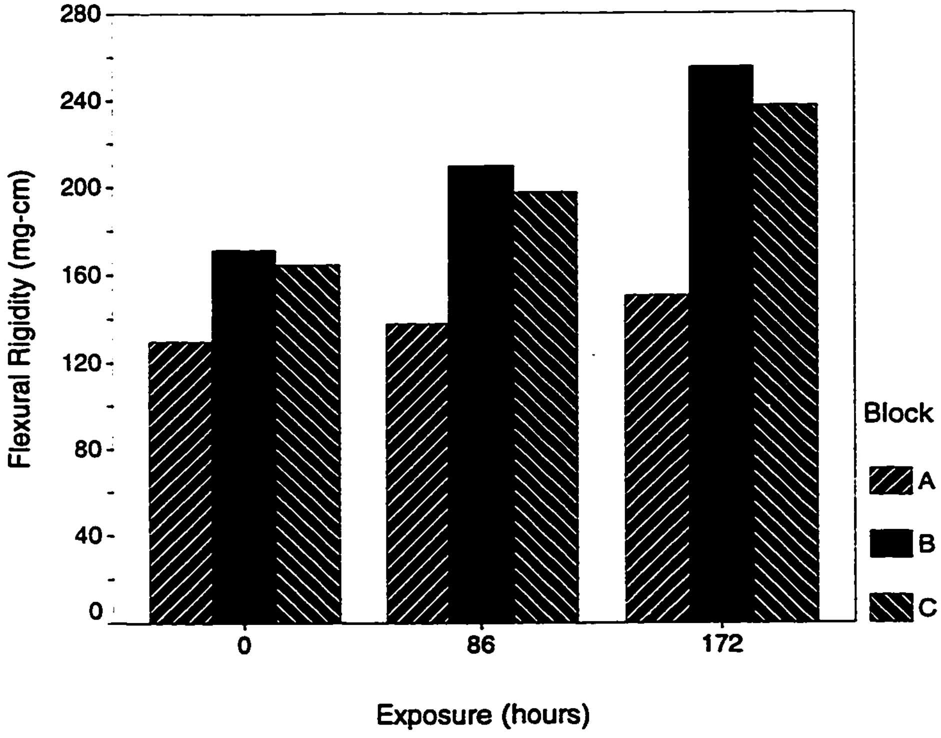

Figure 14. Effect of environmental conditions during the application of Appretan MB extra onto backing fabrics on the subsequent stiffness of laminates made with these coated fabrics. The relative humidity and temperature during application of the adhesive for Block A on a humid day were 58% and 22°C. The conditions during adhesive application for Blocks B and C were similar (55%, 20°C), but were produced using an ultrasonic humidifier.

the effect of humidity levels on the setting of the adhesive films. When the humidity is high, as it was during the coating of block A samples, the dispersion particles in the adhesive would have had more time to coalesce and form a more cohesive film while drying. The humidity provided by the ultrasonic humidifier did not have the same effect, perhaps because of the accompanying draught, the slightly lower temperatures, or the more mist-like delivery. Heat provided during heat-sealing and light exposure may have allowed further coalescence of the particles in a manner that increased stiffness. According to Feller (1971), the coalescence of dispersion adhesives and a resultant increase in toughness continues over time in ambient conditions as long as the temperature is above the minimum film forming temperature. Sperry, et al. (1994) also showed that heat was sufficient to induce coalescence of a dispersion dried below its minimum film forming temperature. The effect in this case is dependent on adhesion to the habutae since the same patterns are not apparent in the coated backing fabrics (Appendix B, Tables B6a, B7a, B8a, and B9a).

The type of backing fabric used for the laminates also significantly affected their stiffness, *F* (1, 168) = 41.766, *p* = .000. Polyester crepeline produced stiffer laminates than silk crepeline (Figure 15), despite very little difference in the flexural rigidity of these fabrics, coated or uncoated, before exposure (see Table 29).[3] This supports further the theory that the adhesion of the materials, rather than materials alone, is the more important factor affecting laminate stiffness. Further study is needed to differentiate more precisely between the contributions of adhesion versus material properties towards laminate stiffness.

Tensile Properties

The three tensile properties, tensile strength, extension at break, and energy to rupture, were affected by the adhesives and backing fabrics in similar ways. The type of adhesive did not affect tensile strength, *F* (1, 168) = .906, *p* = .343, extension at break, *F* (1, 168) = .001, *p* = .979, or energy to rupture, *F* (1, 168) = .894, *p* = .346. Moreover, the environmental conditions during Appretan MB extra application did not have a highly significant effect on tensile properties. Thus, the tensile properties of laminates made with new habutae were independent of the adhesive used. The type of backing fabric, on

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[3] The stiffness of the silk crepeline may depend on the degree to which sizes applied by the manufacturer are removed during prewashing.

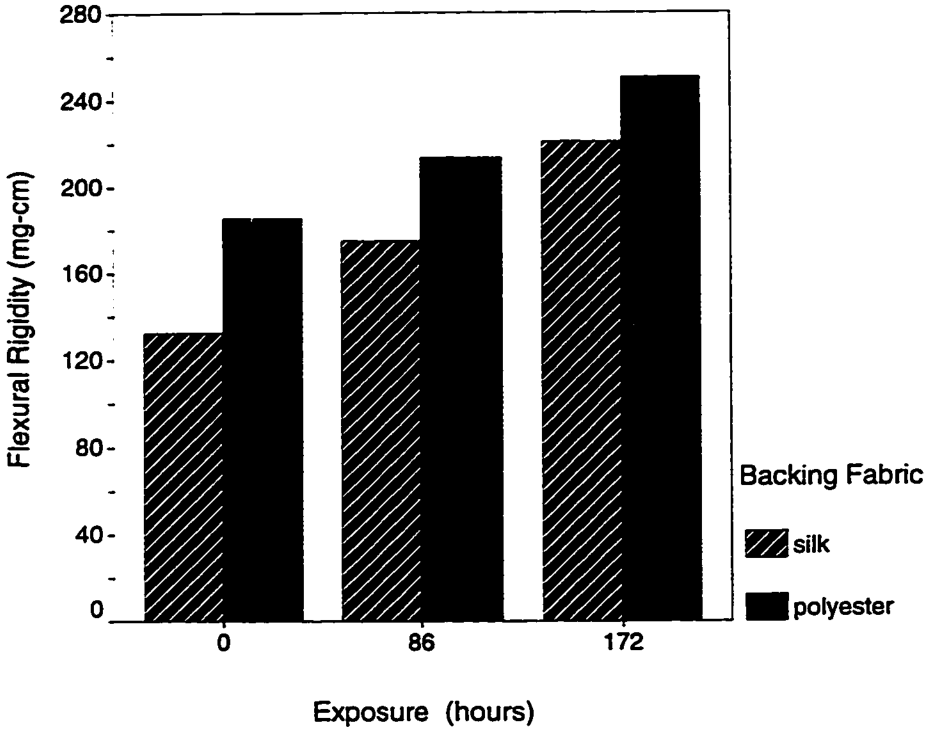

Figure 15. Effect of backing fabric type on the stiffness of silk habutae-adhesive-backing fabric laminates.

the other hand, affected all three properties significantly: tensile strength, *F* (1, 168) = 40.751, *p* = .000; extension at break, *F* (1, 168) = 36.555, *p* = .000; and energy to rupture, *F* (1, 168) = 38.838, *p* = .000. Polyester crepeline laminates were significantly stronger, tougher, and more extensible than silk crepeline ones. As for stiffness, the differences reflect the properties of the backing fabrics themselves (see pp. 160-161).

Peel Strength

The peel strength of the laminates, like their stiffness, was significantly affected by adhesive type, *F* (1, 168) = 661.579, *p* = .000. The bonds of Lascaux laminates were three to four times as strong as their Appretan counterparts before exposure, and remained over twice as strong after exposure, regardless of backing fabric (Table 25). Peeling often caused cohesive failure in the Lascaux laminates: the tiny droplets of adhesive were torn apart as well as pulled from the fibres (Figure 16). In contrast, peeling the Appretan laminates apparently resulted in adhesive failure: the habutae fibres pulled cleanly away, leaving their impressions in the adhesive (Figure 17). As a result,

Table 25. Peel Strength (mN/mm) of Laminates by Level of Light Exposure

		Exposure Level					
		0 hours		86 hours		172 hours	
Sample Type	Code	Mean*	Std. Dev.	Mean*	Std. Dev.	Mean*	Std. Dev.
habutae - Appretan - silk	HAS	11.3	4.9	20.0	8.0	20.4	5.8
habutae - Appretan - polyester	HAP	17.9	7.3	25.7	7.9	26.4	7.3
habutae - Lascaux - silk	HLS	48.1	7.6	49.6	10.6	52.0	11.1
habutae - Lascaux - polyester	HLP	51.9	11.5	57.9	10.4	58.8	7.3

*n =15

adhesive residue was more likely to be left on the habutae surface from the peeling of Lascaux laminates than from Appretan ones (Figures 18 and 19). Where Appretan residue was transferred to the habutae, it appears to have peeled cleanly away from yarns of the backing fabric. This occurred more frequently on laminates with silk crepeline backing fabrics, where irregularities in the yarns created an adhesive coating that was susceptible to losses from the beginning (see Figure 22, left edge).

Several factors may contribute to this difference in peel strength. Physico-chemical forces of adhesion between the two adhesives and silk habutae may not be the same. Such a conclusion cannot be based solely on peel tests, however, since other properties of the sample materials affect the results. For example, the moduli of the adhesives, one factor influencing peel strength (Wake, 1982), are distinctly different. Down, et al. (1996) recorded values of 58.1 MPa and 305 MPa for the equivalent adhesives, Beva 371 and Mowilith DMC2, respectively. Given that Beva 371 is the more flexible adhesive, surfaces coated with it should require less force to be bent back during peeling, if both adhesives achieved similar degrees of wetting. Evidence from peeled strips suggests that Lascaux 371 wetted the habutae fibres to a greater degree than Appretan MB extra during heat-sealing, as already described in the discussion of the higher stiffness of the Lascaux laminates (p. 131). Thus, a greater degree of mechanical adhesion may have contributed to the strength of the Lascaux bonds. Further study would be required to distinguish between the effects of these factors on peel strength.

These results replicate to a certain extent those reported by Pretzel (1993, 1997a, 1997b). In his study, the peel strength of Beva 371 (120 mN/mm) was twice that of Mowilith DMC2 (60 mN/mm) for laminates with polyester crepeline backing fabrics. The values from this study are considerably lower than Pretzel's, despite the use of equivalent

Figure 16. Detail of adhesive coating after peeling a habutae-Lascaux 371-silk crepeline laminate showing cohesive and adhesive failure of the bond (HLS4-172A).

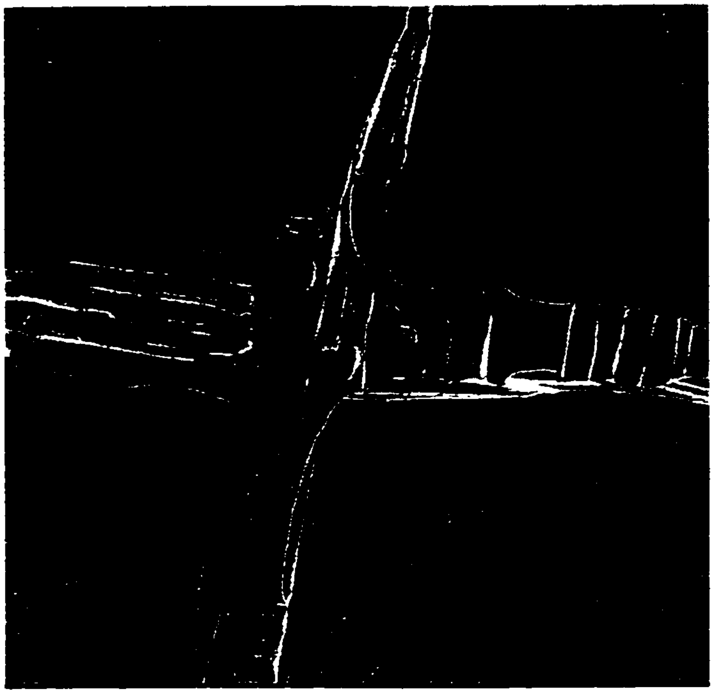

Figure 17. Detail of adhesive coating after peeling a habutae-Appretan MB extra-silk crepeline laminate showing adhesive failure of the bond (HAS2-0A).

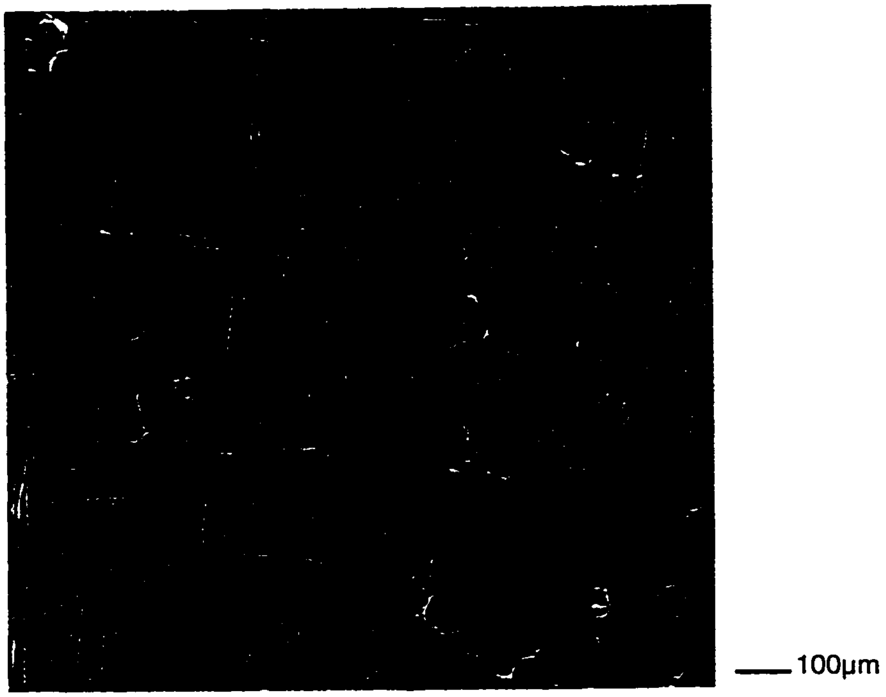

Figure 18. Adhesive residue left on the surface of silk habutae after peeling an exposed habutae-Lascaux 371-silk crepeline laminate (HLS4-172A).

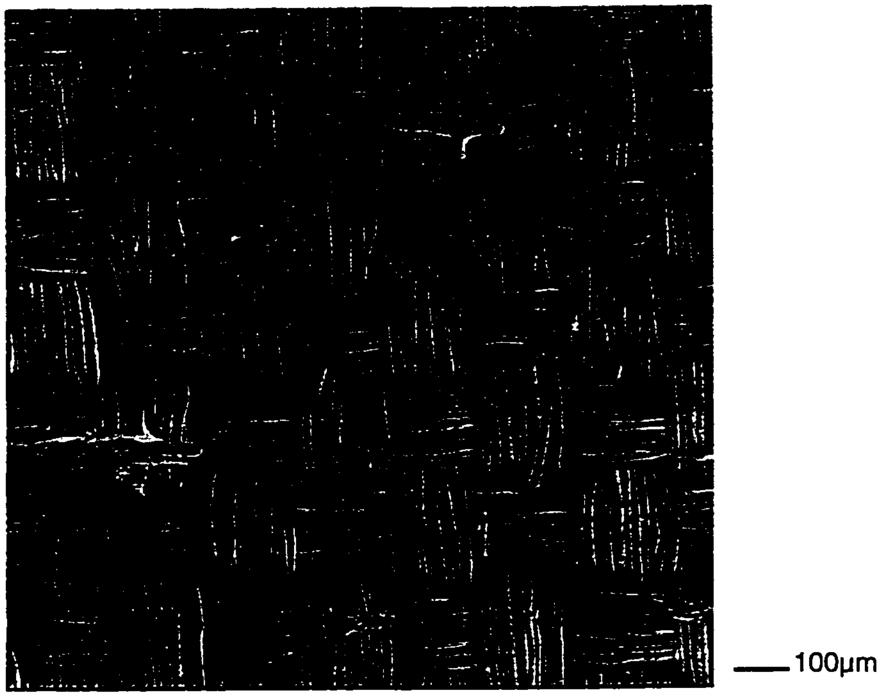

Figure 19. Adhesive residue left on the surface of silk habutae after peeling an exposed habutae-Appretan MB extra-silk crepeline laminate (HAS4-172A).

adhesives and similar procedures. This probably reflects differences in adhesive application. In the Pretzel study, Mowilith DMC2 was applied as a 20% solution (by volume), resulting in a continuous adhesive film on the surface of the backing fabric, whereas in this study a 10% solution (by volume) only coated the yarns. The Beva 371 was brushed on as a 20% solution rather than sprayed like the Lascaux 371. Adhesive add-ons were not reported for that study so more precise comparisons are not possible. None of the peel strengths recorded in this study were as strong as what Pretzel considered as the minimum strength for a good bond in non-conservation testing (100 mN/mm). In fact, three of the four types of laminates had mean peel strengths that fell in the poor category (< 50 mN/mm). Yet all laminates had sufficiently effective bonds that the layers could not be separated for the peel tests without wetting them to release the bond. Whether such low peel strengths are sufficient for textile conservation purposes has not been studied.

The results for peel strength of the Appretan samples were, like stiffness, affected by the conditions during adhesive application. The peel strength of the laminates was significantly affected by *block*, $F(2, 72) = 233.677$, $p = .000$, with the mean from block A being higher than those of blocks B and C ($\alpha = .05$, Figure 20). This distinction is true for both backing fabrics ($\alpha = .05$), even though there was a moderately significant interaction between *block* and *backing fabric*, $F(2, 72) = 3.464$, $p = .037$. This lower bond strength for blocks B and C can be accounted for by the relative lack of coalescence of the dispersion particles caused by too rapid drying due to the environmental conditions. The cohesive strength of the adhesive film was weaker as a result. The failure of the humidification system is especially clear in terms of peel strength. A few test samples prepared in the dry environment of the lab (RH < 25%) produced laminates with peel strengths of a similar magnitude to those given the benefit of a humidification. Pretest samples prepared in non-humid summer conditions (details not recorded), also had similarly low peel strengths.

The results for these subsets of the Appretan samples present an interesting challenge to understanding how bond strength might be related to stiffness. The overall comparison of Lascaux 371 and Appretan MB extra suggests that the higher the peel strength of the laminates, the stiffer they will be. Since greater adhesive penetration probably accounts for the stronger bonds of the Lascaux 371 laminates and is known to cause increased stiffness, this pattern makes sense. However, for the Appretan subsets the opposite is true: samples having high peel strengths are less stiff on average (block A) than those with low peel strengths (blocks B and C). In this case the degree of film

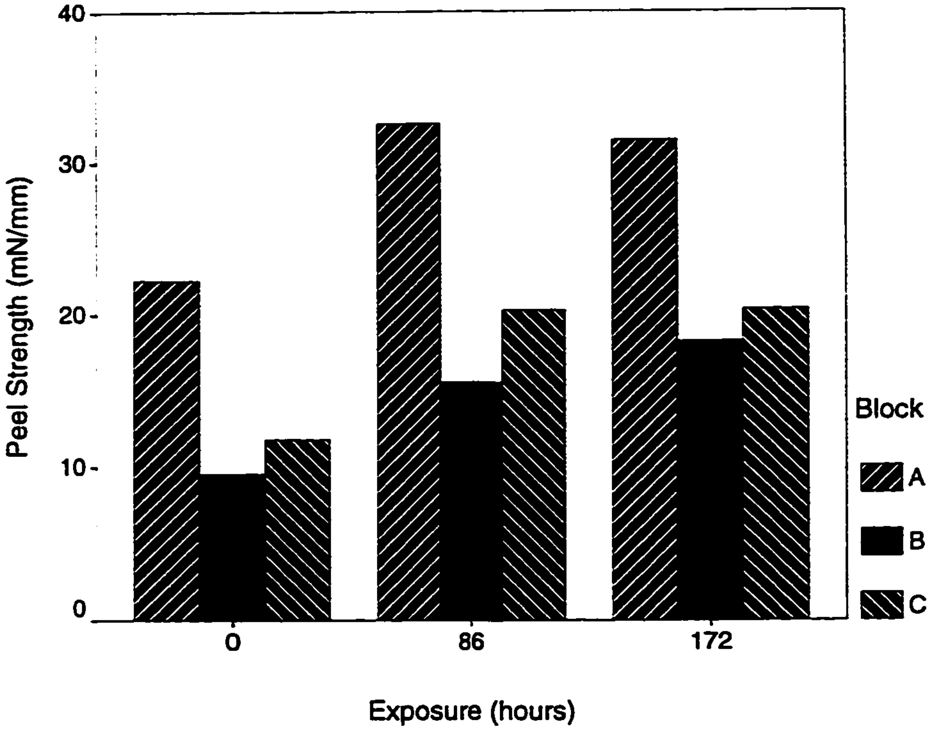

Figure 20. Effect of environmental conditions during the application of Appretan MB extra onto backing fabrics on the subsequent peel strength of laminates made with these coated fabrics. The relative humidity and temperature during application of the adhesive for Block A on a humid day were 58% and 22°C. The conditions during adhesive application for Blocks B and C were similar (55%, 20°C), but were produced using an ultrasonic humidifier.

coalescence is possibly the critical factor: the more fully dispersion polymer particles coalesce during drying and before heat-sealing, the stronger and more flexible the laminates made from the adhesive will be.

If the relationship between peel strength and flexural rigidity or stiffness is complex, that between peel strength and tensile properties may be nonexistent. Since adhesive type does not significantly affect the tensile properties, neither could the differing bond strengths. The lack of significant effect of the conditions during Appretan application on tensile properties further supports this interpretation. Although the peel strength of laminates from blocks B and C was significantly less than that of laminates from block A, their tensile properties did not vary greatly (Appendix B, Tables B2b and B3b).

The main effect of *backing fabric* was also significant with regards to peel strength, *F* (1, 168) = 23.523, *p* = .000. Not surprisingly, the peel strength of polyester crepeline laminates was higher than that of the silk crepeline ones (Figure 21). This is probably because the initial moduli of the two fabrics affects the peel strength values (Wake, 1982). The modulus of polyester, 10.6 N/tex, is slightly higher than that of silk,7.3 N/tex (Morton & Hearle, 1993). Thus more force would be required simply to bend back the polyester backings. The difference in the diameter of the yarns in silk and polyester crepeline may also have influenced the results. When peel tests are conducted at speeds as slow as 50 mm/min on samples with discontinuous coatings, the highest peaks recorded correspond to the force required to separate the laminates at the weft yarns of the backing fabric where the amount of adhesive was the greatest across the width of the fabric. This was especially apparent on Appretan samples where the bulk of the adhesive was concentrated at yarn intersections. Since the polyester weft yarns were wider than their silk counterparts (63 μm versus 53 μm respectively), each carried more

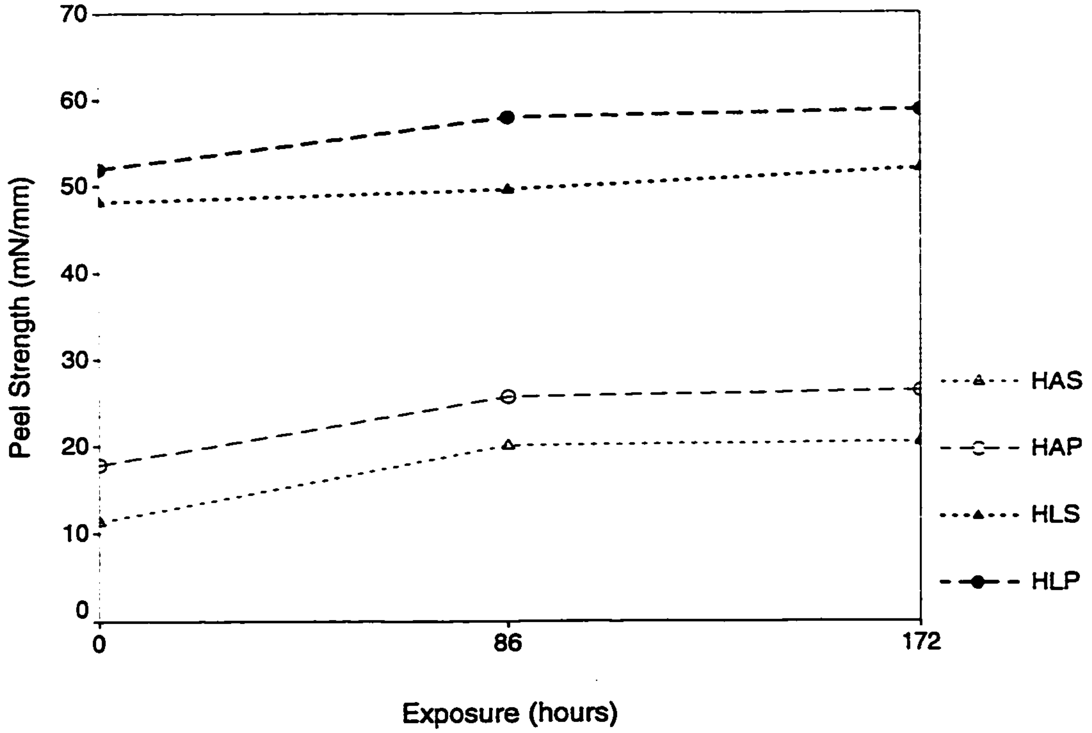

Figure 21. Change in peel strength of silk habutae-adhesive-backing fabric laminates on exposure to light.

adhesive (compare Figures 22 and 23). With a larger area of adhesive (Appretan laminates) or larger number of adhesive particles (Lascaux laminates) concentrated along the polyester weft yarns, the force required to overcome the bond at these points would have been higher.

The interpretation of the significant effect of *exposure*, *F* (2, 168) = 11.965, *p* = .000, is more problematic. A one-way ANOVA of the values averaged over adhesive and backing fabric types, performed since the interaction between these factors is not significant, showed that *exposure* does not have a significant effect on peel strength, *F* (2, 177) = 2.472, *p* = .087. Tukey's test for homogeneous subsets similarly reported no significant differences among the peel strengths for exposures of 0, 86, and 172 hours (α = .05). This contradiction appears to be due to slight differences in how the length of exposure affected the two different adhesives. Separate one-way ANOVAs of the effect of *exposure* on the peel strength of each adhesive-backing fabric combination revealed significant effects for Appretan-silk (*F* (2, 42) = 9.874, *p* = .000) and Appretan-polyester (*F* (2, 42) = 5.987, *p* = .005) laminates, but not for Lascaux-silk (*F* (2, 42) = .581, *p* = .564) and Lascaux-polyester (*F* (2, 42) = 2.130, *p* = .132) laminates. The unexposed and exposed treatment groups for the Appretan laminates were significantly different (α = .05). If this were a reliable finding, however, the interaction between the factors *adhesive* and *exposure* should have been significant in the original three-way ANOVA. It was not significant, *F* (2, 168) = 1.178, *p* = .311.

These discrepancies in the results of the statistical analyses cast doubt on the significance of the increase in peel strength due to light exposure that was recorded for all sample types. Since values for peel strength increase much more rapidly than the increase in adhesion they represent (Wake, 1982, p. 146), these small changes may not be very important. Unlike the results for stiffness, moreover, the increases in peel strength are limited to the first 86-hour exposure period (Table 25, Figure 21). Further increase due to continued exposure under the same conditions is not likely, given these results.

The possible insignificance of the changes in laminate peel strength due to light exposure raises questions about the interpretation or significance of the corresponding changes in stiffness. High levels of laminate stiffness and peel strength have both been interpreted as resulting from adhesive penetration into the yarns (pp. 131 and 137). If the significant increases in stiffness due to light exposure were caused by such penetration due to the elevated temperature in the Weather-Ometer as proposed (p. 131), similar increases in peel strength would be expected. Given that the recorded increases in peel strength may not be significant, this simple explanation for these two properties may not hold under all circumstances. The results for the three different blocks of Appretan laminates have already shown that stiffness and peel strength do not always increase together (p. 139). Identifying precisely what factors affect the stiffness and peel strength of the laminates in order to explain these discrepancies would require further analysis of the data and probably further testing. The ANOVA results do suggest, however, which factor needs closer attention. Comparing the sum of squares for *model* and *total* for the variables *stiffness* and *peel strength* (Appendix C, Table C6) shows that the model comprising the independent variables *adhesive*, *backing*, and *exposure* accounts for only about 50% of the stiffness data (294622.8 of 592499.8) but accounts for just over 80% of the peel strength data (52117.110 of 64405.130). Further study, therefore, should concentrate on analysing factors contributing to laminate stiffness.

Summary

Although the type of backing fabric, silk or polyester crepeline, significantly affected all the properties studied, the type of adhesive only affected the stiffness and peel strength of the laminates. Thus the null hypothesis of no significant difference between the properties of the laminates having silk versus polyester crepeline backing fabrics is rejected. The null hypothesis that the presence of Appretan MB extra versus Lascaux 371 results in no significant difference in laminate properties is rejected only for stiffness and peel strength.

Coated and Uncoated Backing Fabrics

Comparison of coated and uncoated backing fabrics clarifies two aspects of the results of the preceding sections of this study. The backing materials often affect the properties of laminates and unlaminated backing fabrics in similar ways. Thus the results for coated and uncoated backing fabrics confirm and elucidate the results for the laminates. On the other hand, the backing materials sometimes affect the laminates and unlaminated samples differently. This divergence corresponds to the differences in rate of change due to light exposure found in Part I of this study. Whether adhesive coating significantly alters the properties and light stability of the backing fabrics, as has been suggested (Bede, 1993; Keyserlingk, 1990, 1993), can also be examined in this comparison. The two backing fabrics included in this study, silk and polyester crepeline, are used extensively in textile conservation for stitching as well as adhesive treatments.

Thus, the light stability of these fabrics deserves more thorough examination than is possible here. This analysis will focus on aspects of the properties and light stability of these materials that add to an understanding of the properties of the laminates.

Characteristics of Coated Backing Fabrics

Visual characteristics. Both fabric and adhesive type produce visually distinct coated backing fabrics. Silk crepeline is woven from finer, more irregular, 2-ply yarns that are spaced more closely together than the 4-ply yarns of polyester crepeline. Further differences between these two fabrics were listed in detail in Table 10 (p. 95). The adhesive layers produced by the two adhesives were also distinct due to the way in which each was applied. Brushed on, the Appretan MB extra solution dried to form a continuous coating of adhesive along the yarns (Figures 22 and 23). The coatings on the two backing fabrics differed slightly. The adhesive on the polyester formed a much more regular grid, mirroring the more even yarns below. The coating on silk crepeline was also more likely to have adhesive missing at some yarn intersections. The sprayed Lascaux 371 formed a random splattering of tiny adhesive droplets of various sizes along the entire length of the yarns of both fabrics (Figures 24 and 25). At places, conglomerations of droplets projected into the spaces between the yarns, both towards the front and the back of the fabric. After nine months of storage, the droplets were seen to be pierced with numerous tiny pin holes (Figure 24). These are probably the result of continued evaporation of the toluene, which tends to be retained by adhesive films (Hansen, et al., 1991). Initially the evaporation of the toluene and 1,1,1 trichloroethylene caused the adhesive droplets to collapse during spraying (Masters, 1985). The remaining toluene evaporated much more slowly, resulting in pinholes that are most apparent on the surface of larger droplets, which would be more likely to retain solvent. The coated samples continued to smell distinctly of solvent long after adhesive application.

Hand. The two coating methods produced backing fabrics of very different hand immediately after application. A brushed coating of Appretan MB extra eliminated all interyarn and interfibre movement in the fabrics. The adhesive penetrated the interstices between the fibres through to the reverse (Figures 26 and 27) . Although insufficient to form a heat-sealed bond, a surprising amount of adhesive coated the reverse of the yarns, especially the rougher surface of the silk fibres. The bumpy texture of the adhesive reveals the particles of the original dispersion, still not fully coalesced. As a result of this adhesive penetration, fibres and yarns are welded together. Although still flexible, the coated fabric has a much higher resistance to shear distortion than it did

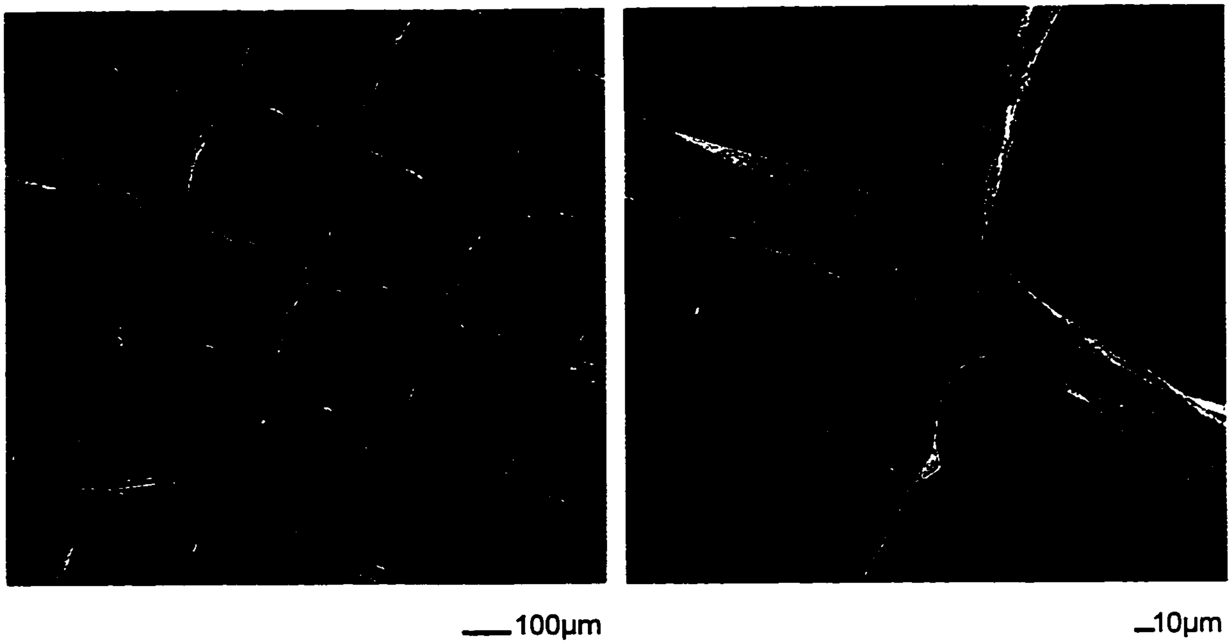

Figure 22. Silk crepeline coated with Appretan MB extra (unexposed, not heat-sealed).

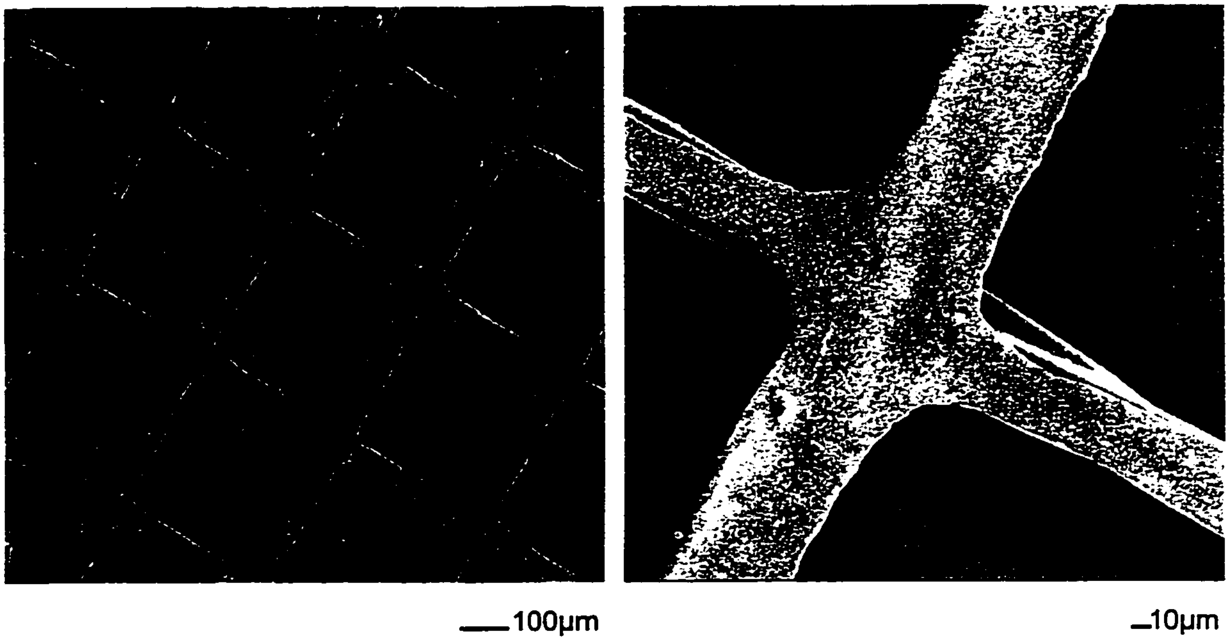

Figure 23. Polyester crepeline coated with Appretan MB extra (unexposed, not heat-sealed).

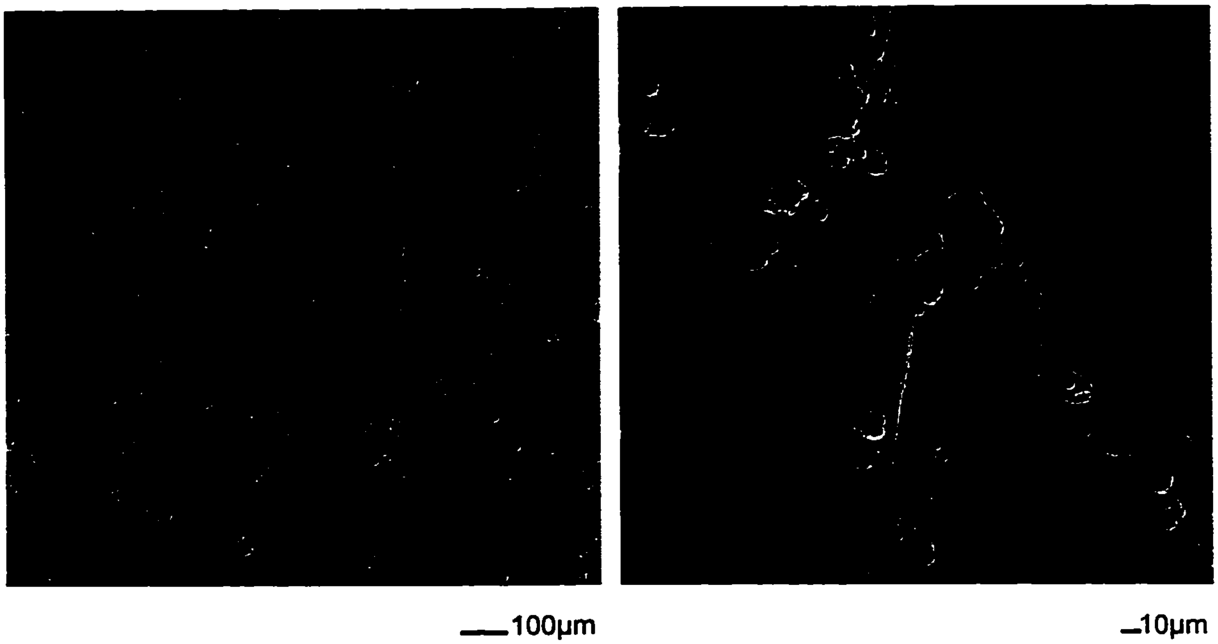

Figure 24. Silk crepeline coated with Lascaux 371 (unexposed, not heat-sealed).

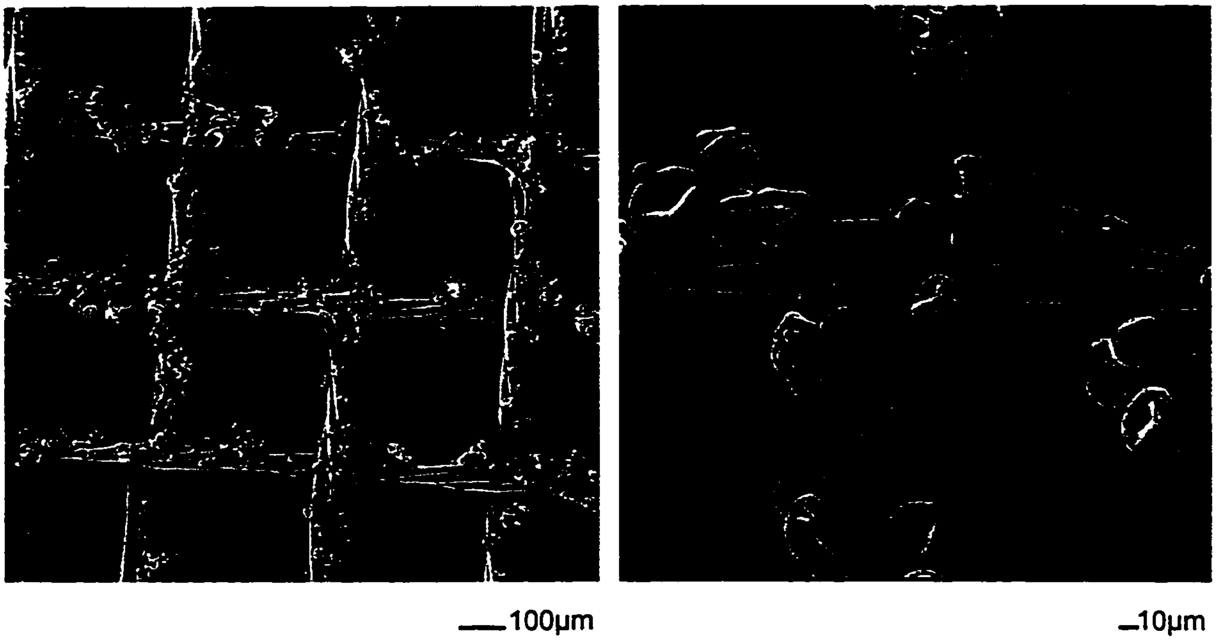

Figure 25. Polyester crepeline coated with Lascaux 371 (unexposed, not heat-sealed).

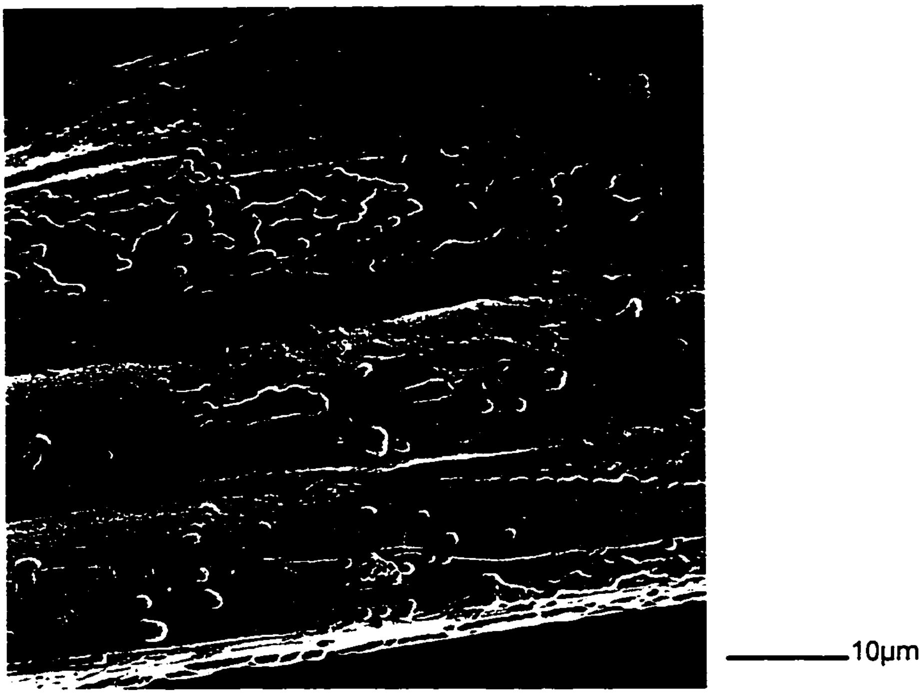

Figure 26. Reverse side of silk crepeline showing Appretan MB extra residues (unexposed, not heat-sealed).

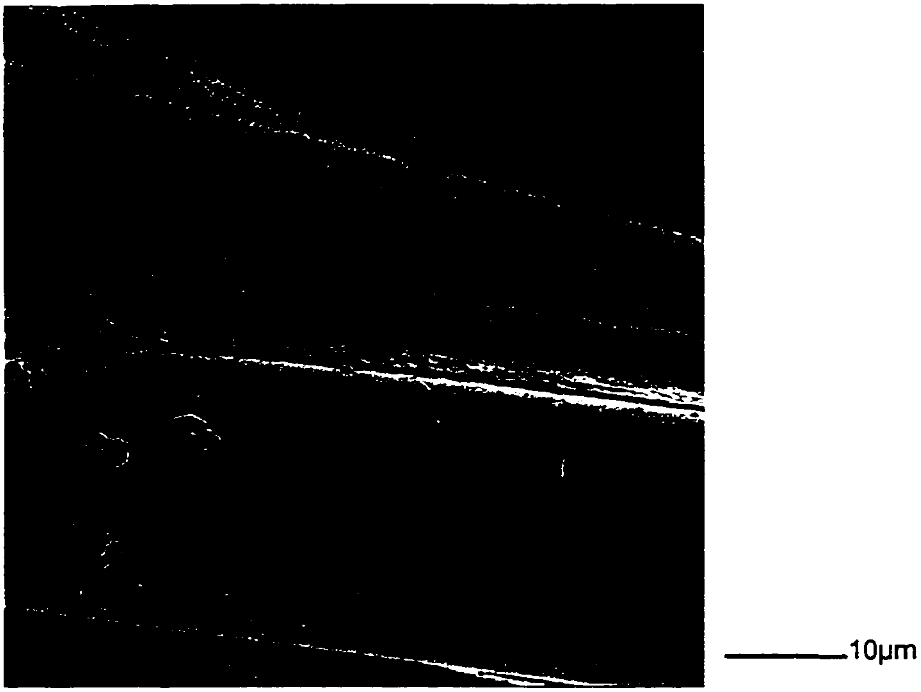

Figure 27. Reverse side of polyester crepeline showing Appretan MB extra adhesive residues (unexposed, not heat-sealed).

before coating. The samples were also highly charged with static electricity when peeled off the Teflon-coated glass fabric.

The movement of individual yarns was barely affected by the dust-like coating of Lascaux 371. A shear force could still skew the fabric (Figure 24), although not as easily as uncoated fabric. Similarly, fibres were not fully welded together, despite a more fluid coating of adhesive that was seen to penetrate between them in a few spots. Once heat-sealed, however, the samples lost this characteristic and became almost as shear resistant as the Appretan-coated samples. The samples did not exhibit a static charge but were noticeably tacky, especially when conditioned at 65% RH.

Add-on. Virtually identical adhesive coatings by weight (approximately 3 g/m^2) were achieved for all fabric-adhesive combinations (Table 26). Nevertheless, the same techniques produced a significantly lower average add-on for polyester crepeline (2.9 g/m^2) than for silk crepeline (3.1 g/m^2), $F(1, 356) = 35.507$, $p = .000$. This may be due to the relatively larger spaces between the yarns of the polyester fabric.

Colour Change

Visible colour change noted for some of the coated and uncoated backing fabric groups were all due to light exposure. The application of the adhesive coatings caused no visible differences in the colour of the backing fabrics. Measured differences were minor, the total colour change (ΔE_{CIELAB}) being less than 1 CIELAB unit (Table 27). Much of this may be due to dust sticking to the adhesive coatings, especially the Lascaux ones. Differences due to light exposure were clearly visible in some cases (Table 28, Figure 28). The silk crepeline backing fabrics all showed a colour change of 2 to 3 CIELAB units after 172 hours of light exposure. The colour change of the Lascaux-coated polyester

Table 26. Average Adhesive Add-on (g/m^2) by Adhesive and Backing Fabric

	Backing Fabric					
	silk crepeline		polyester crepeline		Average	
Adhesive	Mean[a]	Std. Dev.	Mean[a]	Std. Dev.	Mean[b]	Std. Dev.
Appretan MB extra	3.13[a]	0.33	2.91[a]	0.32	3.02[b]	0.35
Lascaux 371	3.10[a]	0.38	2.89[a]	0.31	3.00[b]	0.36
Average	3.11[b]	0.36	2.90[b]	0.31	3.01[c]	0.35

[a] n = 90 [b] n = 180 [c] n=360

Table 27. Colour Difference of Coated Backing Fabrics from Uncoated Counterparts[a]

	ΔL^* (light-dark)		Δa^* (red-green)		Δb^* (yellow-blue)		ΔE_{CIELAB} [b] (total change)	
Coated Backing Fabric	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
Appretan - silk[c]	-0.34	0.09	-0.20	0.04	0.57	0.09	0.70	0.11
Lascaux - silk[c]	-0.30	0.25	-0.17	0.10	0.85	0.06	0.96	0.03
Appretan -polyester[d]	-0.24	0.10	-0.01	0.02	0.41	0.09	0.48	0.10
Lascaux - polyester[d]	-0.14	0.05	0.00	0.05	0.46	0.05	0.49	0.05

[a] unexposed samples

[b] $\Delta E_{CIELAB} = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{0.5}$

[c] calculated against a plain silk crepeline standard (mean of 15 samples)

[d] calculated against a plain polyester crepeline standard (mean of 15 samples)

Table 28. Colour Change (ΔE_{CIELAB})[a] of Coated and Uncoated Backing Fabrics by Level of Light Exposure

	Exposure Level			
	86 hours		172 hours	
Sample Type	Mean	Std.Dev.	Mean	Std.Dev.
Uncoated Backing Fabrics				
silk	1.41[b]	0.56	2.66[c]	0.58
polyester	0.43	0.32	0.56	0.41
Coated Backing Fabrics				
Appretan - silk	1.35[b]	0.25	2.40[c]	0.37
Appretan - polyester	0.32	0.19	0.30	0.23
Lascaux - silk	1.74[b]	0.45	3.16[c]	0.82
Lascaux - polyester	1.12[b]	0.32	1.41[b]	0.25

[a] calculated against standard from unexposed samples of type from the same ageing run (n =15)

[b] barely visible [c] visible

crepeline was just visible at approximately 1.5 CIELAB units. The results were not analysed statistically because of strong deviations from the assumptions required for either an ANOVA or a nonparametric test. Furthermore, readings were affected to differing degrees by the white tile showing through, depending on the openness of the weave and on the particular way in which samples were stacked.

The yellowing of the silk crepeline was expected and parallelled the yellowing of the habutae. The visible yellowing of the Appretan-coated silk crepeline suggests that the adhesive coating does not prevent transmission of the light through to the fibre and subsequent degradation. Further testing would be required to determine whether the

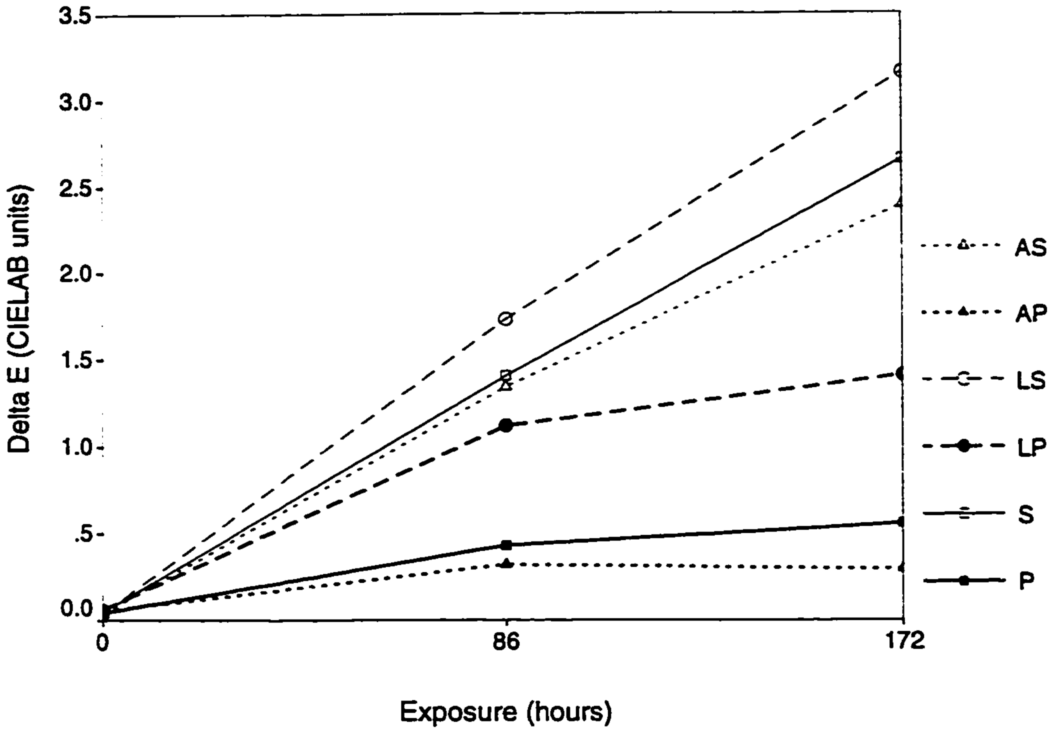

Figure 28. Change in colour of coated and uncoated backing fabrics on exposure to light.

consistently lower values for the Appretan-coated silk crepeline, as compared to uncoated and Lascaux-coated silk crepeline, represent a significant reduction in the rate of colour change. If so, the adhesive may be absorbing some of the ultraviolet radiation that causes most of the silk degradation.

The yellowing of the Lascaux-coated polyester must be due to yellowing of the adhesive, since the plain and Appretan-coated polyesters showed no visible yellowing. The yellowing of Lascaux 371 would also account for the greater ΔE_{CIELAB} values for the Lascaux-coated silk crepeline compared to plain silk. That this adhesive yellowed was not surprising, since its equivalent, Beva 371, has been shown to yellow upon light exposure, even when most ultraviolet light is filtered (Down, et al., 1992, 1996; Horton-James, et al., 1984). That it was visible, given such a fine layer of adhesive, was unexpected. The visibility of the colour change was observed on piles of five stacked samples, which intensifies colours somewhat. Most of the yellowing occurred in the first ageing period, after which the rate of change dropped substantially (Figure 28). Thus the adhesive may not yellow much beyond the amount produced by this exposure, which is only just visible. As well, this discoloration did not appear to affect the laminates, where the adhesive was not directly exposed to light. Nevertheless, it may be a concern with regards to facing treatments. The tendency for this type of adhesive to yellow requires further attention, since it has not yet been explained. It may be related to the effects of light on components of the adhesive formulation other than the polymer, since other vinyl acetate-ethylene copolymer adhesives have been shown to be resistant to yellowing (Down, et al.). Yellowing is often related to other forms of deterioration, as is the case for silk. To this point, however, the testing of Beva 371 has not revealed significant stability problems related to other properties (Down, et al.).

Stiffness

All three main effects, *backing, adhesive*, and *exposure*, significantly affected the stiffness of the backing fabric samples, but in ways dependent on the levels of the other factors. Although the three-way interaction between the factors was not significant, *F* (4, 252) = 1.369, *p* = .245, all two-way interactions were significant at the .05 level.

The type of backing fabric had a predominant effect on the stiffness of the samples (Table 29, Figure 29). Although the two fabrics had essentially the same flexural rigidity before exposure, silk fabrics retained their flexibility, while the polyesters stiffened significantly over the two exposure periods (α = .05). This accounts for the significant interaction between *backing fabric* and *exposure*, *F* (2,252) = 53.934, *p* = .000. The

Table 29. Flexural Rigidity (mg-cm) of Coated and Uncoated Backing Fabrics by Level of Light Exposure

		Exposure Level					
		0 hours		86 hours		172 hours	
Sample Type	Code	Mean[†]	Std. Dev.	Mean[†]	Std. Dev.	Mean[†]	Std. Dev.
Uncoated Backing Fabrics							
silk	S[a]	28	4	27	2	27	2
polyester	P[c]	27	2	34	7	38	6
Coated Backing Fabrics							
Appretan - silk	AS[b]	28	3	29	1	30	2
Appretan - polyester	AP[d]	30	4	40	3	47	3
Lascaux - silk	LS[a,b]	26	3	29	2	30	3
Lascaux - polyester	LP[c]	27	3	35	6	40	5

[†] n =15

[a, b, etc] types with the same letter are not significantly different as determined by Tamhane's T2 test at α = .05 using values averaged over the three exposure levels.

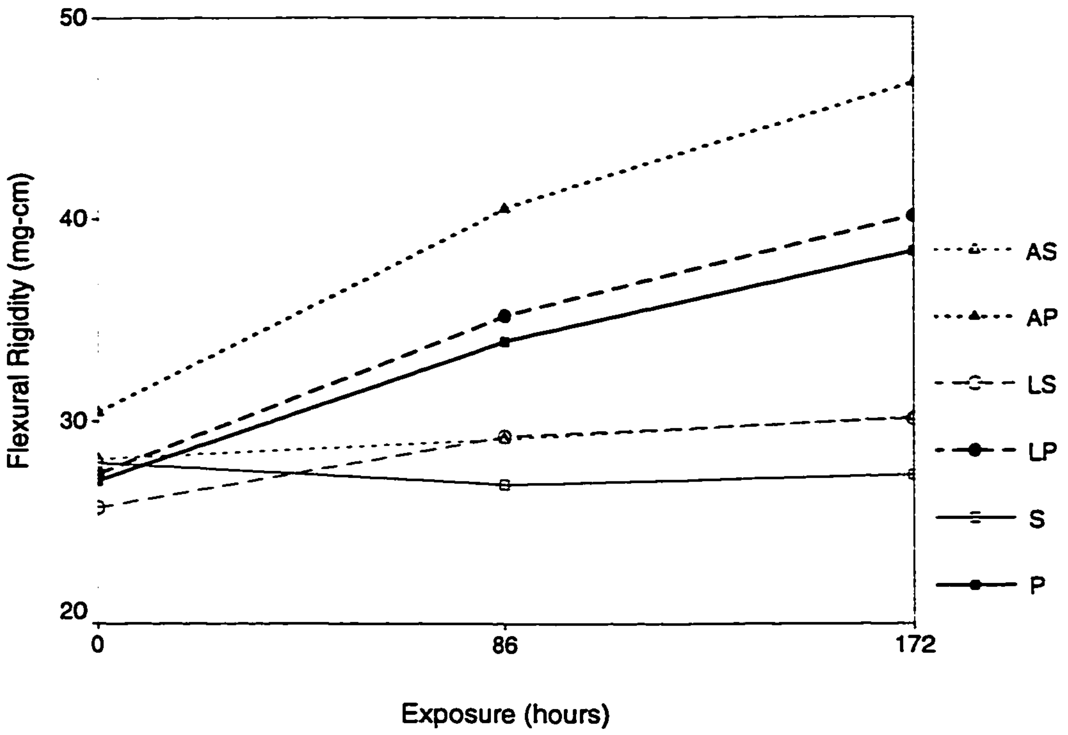

Figure 29. Change in stiffness of coated and uncoated backing fabrics on exposure to light.

stiffening of the polyester crepelines must have been due to the fibre and not the adhesives since increases in flexural rigidity of both coated and uncoated samples occurred at very similar rates (Table 30). The degradative effects of light on the polyester aggravated by the presence of a delustering pigment in the fibres is probably responsible for this change. The delustrant was visible under magnification as fine speckling throughout the fibres. Polyester is usually resistant to light degradation when shielded by window glass, which absorbs much of the range of ultraviolet radiation that is especially damaging to this polymer (Wall & Frank, 1971; Wall, et al., 1971). The borosilicate-soda lime filters in the Weather-Ometer provide equivalent protection. Because the pigment absorbs radiation in the near UV and visible range, however, degradation still occurs (Allen & McKellar, 1980; Wall & Frank; Wall, et al.). The stiffening of the polyesters was barely noticeable to touch.

By contrast, the silk crepelines exhibited little tendency to stiffen, and the changes that did occur proceeded at different rates (Table 30). Uncoated silk crepeline actually decreased in stiffness after exposure. Lascaux-coated silk stiffened more than its

Table 30. Change in Flexural Rigidity of Coated and Uncoated Backing Fabrics due to Light Exposure

		Rate of Change [a] (%/hr)		% Change [b]	
Sample Type	Code	0 - 86 hours	86-172 hours	86 hours	172 hours
Uncoated Backing Fabrics					
silk	S	-0.01	0.01	- 4	- 4
polyester	P	0.08	0.05	+26	+41
Coated Backing Fabrics					
Appretan - silk	AS	0.01	0.01	+ 4	+ 7
Appretan - polyester	AP	0.12	0.07	+33	+57
Lascaux - silk	LS	0.04	0.01	+12	+15
Lascaux - polyester	LP	0.09	0.05	+30	+48

[a] first period: (mean 86 hours - mean 0 hours) / 86; second period: (mean 172 hours - mean 86 hours) / 86
[b] (mean 86 or 172 hours - mean 0 hours) / mean 0 hours x 100

Appretan counterpart, although both had the same average values for flexural rigidity after 172 hours of exposure. These differences account for the moderately significant interaction of *adhesive* and *exposure*, *F* (4, 252) = 2.476, *p* = .045.

Adhesive type also influenced stiffness (Table 29). Averaged over exposure level, Appretan-coated samples were stiffer than both Lascaux-coated or uncoated samples of the same backing fabric, which were not significantly different ($\alpha = .05$).[4] The distinction was especially apparent on polyester-backed samples, which explains the significant *adhesive-backing fabric* interaction, *F* (2, 252) = 9.683 , *p* = .000. The Appretan coating imparted greater stiffness to the backing fabrics since, unlike Lascaux 371, it welded the filaments and yarns together (Figures 26 and 27). By contrast, the yarns in Lascaux-coated backing fabrics were never fully impregnated even after heat-sealing and 172 hours of light exposure (Figure 30).

Comparison of the stiffness measurements for the coated and uncoated backing fabrics reinforces the conclusions already drawn regarding the differences in the properties of laminates and their corresponding backing fabrics. The increased stiffness of the polyester fabrics versus the relatively low stiffening of the silk crepelines due to

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[4] The values for the silk crepeline backing fabrics in Table 29 seem to suggest that the difference in stiffness between the Appretan- and Lascaux-coated backing fabrics is non-existent after exposure and that the Appretan-coated silk crepeline is no stiffer than uncoated silk crepeline before exposure. Nevertheless, the lack of significant three-way interaction between the factors, *adhesive*, *backing fabric*, and *exposure*, suggests that these patterns are not significant.

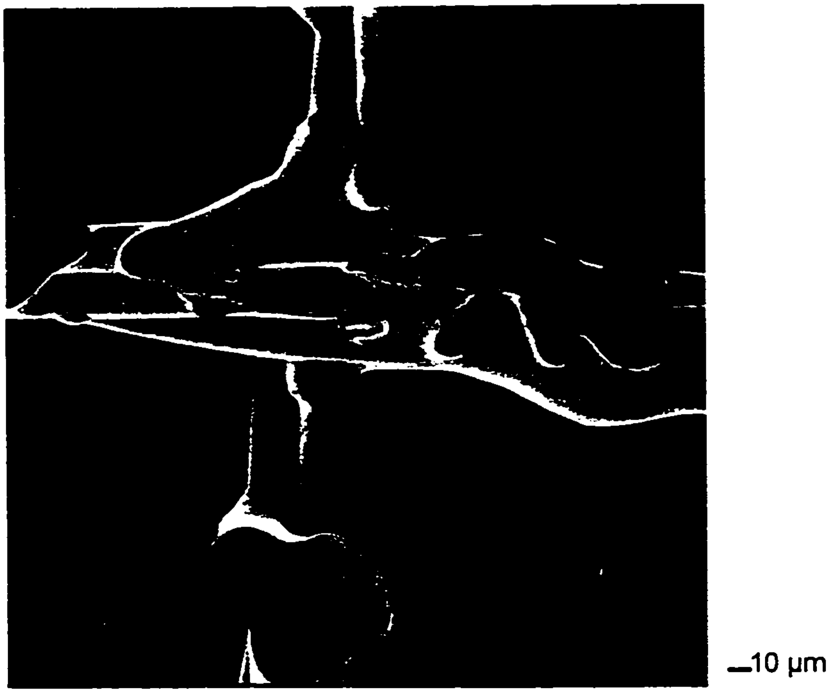

Figure 30. Detail of polyester crepeline sample coated with Lascaux 371 showing the degree to which the adhesive has not entirely penetrated all the spaces between the filaments. The sample has been "heat-sealed" and exposed to light for 172 hours (LP1-172C).

exposure was not reflected in the results for the laminates, where silk-backed samples stiffened more rapidly than polyester-backed samples. The relative effect of the adhesives was also reversed. Lascaux-coated backing fabrics were more flexible than Appretan-coated ones, but produced stiffer laminates.

Tensile Properties

The tensile properties tensile strength, extension at break, and energy to rupture of all coated and uncoated backing fabrics were adversely affected by exposure to light (Tables 31 and 32). The manner in which this occurred with regards to each of the three properties depended on a complex relationship between the three factors *adhesive*, *backing fabric*, and *exposure*. The three-way interaction of these factors was significant for all three properties: tensile strength, $F\,(4,252) = 36.957$, $p = .000$; extension at break, $F\,(4,252) = 10.251$, $p = .000$; and energy to rupture, $F\,(4,252) = 18.120$, $p = .000$. Two-way analyses of the data at each level of the third factor, *adhesive* or *backing fabric*,

Table 31. Tensile Properties of Coated and Uncoated Backing Fabrics by Level of Light Exposure

		Exposure Level					
		0 hours		86 hours		172 hours	
Sample Type	Code	Mean[†]	Std. Dev.	Mean[†]	Std. Dev.	Mean[†]	Std. Dev.
		Tensile Strength (N)					
Uncoated Backing Fabrics							
silk	S	14.4[a]	0.4	8.8[c]	0.7	5.6[d]	1.0
polyester	P	29.1[A]	0.3	25.1[B]	0.6	22.3[C]	0.6
Coated Backing Fabrics							
Appretan - silk	AS	15.4[b]	0.5	8.5[c]	0.8	5.6[d]	0.8
Appretan - polyester	AP	28.8[A]	0.7	22.7[C]	0.8	19.3[D]	0.7
Lascaux - silk	LS	14.7[a]	0.4	8.7[c]	0.5	5.5[d]	0.4
Lascaux - polyester	LP	28.8[A]	1.0	19.7[D]	0.8	16.5[E]	0.4
		Extension at Break (%)					
Uncoated Backing Fabrics							
silk	S	19.1[a]	0.8	8.4[b]	1.1	3.6[d]	1.0
polyester	P	27.4[A]	0.8	22.0[B]	0.6	19.4[C]	0.6
Coated Backing Fabrics							
Appretan - silk	AS	20.1[a]	0.8	6.8[c]	1.3	3.3[d]	0.8
Appretan - polyester	AP	26.9[A]	1.2	18.9[C]	0.7	16.7[D]	0.6
Lascaux - silk	LS	19.5[a]	0.8	7.7[b]	0.6	3.3[d]	0.3
Lascaux - polyester	LP	26.5[A]	2.1	16.7[D]	0.4	14.4[E]	0.4
		Energy to Rupture (N-m)					
Uncoated Backing Fabrics							
silk	S	0.175[a]	0.007	0.044[c]	0.011	0.010[d]	0.005
polyester	P	0.400[A]	0.015	0.256[C]	0.013	0.195[D]	0.011
Coated Backing Fabrics							
Appretan - silk	AS	0.179[a]	0.011	0.032[c]	0.007	0.008[d]	0.003
Appretan - polyester	AP	0.375[B]	0.021	0.173[E]	0.013	0.132[F]	0.008
Lascaux - silk	LS	0.161[b]	0.008	0.034[c]	0.005	0.008[d]	0.001
Lascaux - polyester	LP	0.357[B]	0.041	0.137[F]	0.007	0.103[G]	0.004

[†] n =15

[a, b, etc] silk crepeline samples with the same letter for each property are not significantly different as determined by Tamhane's T2 test at $\alpha = .05$.

[A, B, etc] polyester crepeline samples with the same letter for each property are not significantly different as determined by Tamhane's T2 test at $\alpha = .05$.

Table 32. Change in Tensile Properties of Coated and Uncoated Backing Fabrics due to Light Exposure

Sample Type	Code	Rate of Change [a]		% Change [b]	
		0 - 86 hours	86-172 hours	86 hours	172 hours
	Tensile Strength	(N/hr)			
Uncoated Backing Fabrics					
silk	S	-0.07	-0.04	-39	-61
polyester	P	-0.05	-0.03	-14	-23
Coated Backing Fabrics					
Appretan - silk	AS	-0.08	-0.03	-45	-64
Appretan - polyester	AP	-0.07	-0.04	-21	-33
Lascaux - silk	LS	-0.07	-0.04	-41	-63
Lascaux - polyester	LP	-0.11	-0.04	-32	-43
	Extension at Break	(%/hr)			
Uncoated Backing Fabrics					
silk	S	-0.13	-0.06	-56	-81
polyester	P	-0.06	-0.03	-20	-29
Coated Backing Fabrics					
Appretan - silk	AS	-0.16	-0.04	-66	-84
Appretan - polyester	AP	-0.09	-0.03	-30	-38
Lascaux - silk	LS	-0.14	-0.05	-61	-83
Lascaux - polyester	LP	-0.11	-0.03	-34	-46
	Energy to Rupture	(N-m/hr)			
Uncoated Backing Fabrics					
silk	S	-0.002	<0.000	-75	-94
polyester	P	-0.002	-0.001	-36	-51
Coated Backing Fabrics					
Appretan - silk	AS	-0.002	<0.000	-82	-96
Appretan - polyester	AP	-0.002	-0.001	-54	-65
Lascaux - silk	LS	-0.002	<0.000	-79	-95
Lascaux - polyester	LP	-0.003	<0.000	-62	-71

[a] first period: (mean 86 hours - mean 0 hours) / 86; second period: (mean 172 hours - mean 86 hours) / 86

[b] (mean 86 or 172 hours - mean 0 hours) / mean 0 hours x 100

yielded several significant trends (Appendix C, Tables C8-C12).

The type of adhesive affected the rate of deterioration of the coated and uncoated backing fabrics, but in a manner specific to each backing fabric. Two-way analyses of the factors *adhesive* and *exposure* for just the silk crepeline samples indicate significant interaction of the variables for tensile strength, *F* (4,126) = 4.399, *p* = .002, extension at break, *F* (4,126) = 8.342, *p* = .000, and energy to rupture, *F* (4,126) = 12.004, *p* = .000.

For tensile strength and energy to rupture, this interaction is due to differences among the samples before exposure. The tensile strength of Appretan-coated silk crepeline (15.4 N) was significantly higher than that of Lascaux-coated (14.7 N) and uncoated silk crepeline (14.4 N), which were essentially equal ($\alpha = .05$). For energy to rupture, the Lascaux-coated samples had significantly lower values (mean = 0.161 N-m) than the other two ($\alpha = .05$). The values for Appretan-coated silk crepeline (0.179 N-m) and uncoated silk crepeline (0.175) were not significantly different ($\alpha = .05$). After 86 and 172 hours of light exposure, the tensile strength and energy to rupture of the three types of silk crepeline samples were not significantly different ($\alpha = .05$). The interaction for extension at break is due to differences among the samples after 86 hours of light exposure. Appretan-coated silk crepeline exposed for 86 hours was significantly less extensible (6.8%) than Lascaux-coated (7.7 %) and uncoated silk crepeline (8.8%) ($\alpha = .05$). The latter two types were not significantly different ($\alpha = .05$). All types were statistically identical at exposures of 0 and 172 hours ($\alpha = .05$). As the graphs for tensile strength (Figure 31), extension at break (Figure 32), and energy to rupture (Figure 33) well illustrate, the differences among Appretan-coated, Lascaux-coated, and uncoated silk crepeline are small. After 172 hours of light exposure, all samples exhibited high losses in tensile strength (61-64%), extensibility (81-84%), and toughness (94-96%). These values correspond well to percent losses of plain silk habutae recorded in this study (tensile strength, 54%, extension at break, 56%, and energy to rupture, 89%) and to values obtained by Lemiski (1996) for silk habutae exposed to 160 hours of xenon arc radiation under similar conditions (tensile strength, 67%, extension at break, 71%, and energy to rupture, 95%). Adhesive coating, therefore, does not affect the light stability of silk.

By contrast, the polyester crepelines deteriorated to varying degrees in the following order of increasing severity: uncoated, Appretan-coated, Lascaux-coated. The samples had equivalent tensile strength and extensibility at 0 hours, but the energy to rupture of uncoated polyester crepeline (0.400 N-m) was significantly higher than that of Appretan-coated (0.375 N-m) and Lascaux-coated (0.357 N-m) polyester crepeline ($\alpha = .05$). At 86 hours, however, all samples were significantly different ($\alpha = .05$) for each tensile property and remained so after 172 hours of exposure to light (Table 31). For example, uncoated polyester lost 23% of its initial strength due to 172 hours of light exposure, while Appretan-coated polyester lost 33% and Lascaux-coated polyester lost 43% during the same exposure period. The differences are clearly apparent from the graphs of the tensile properties (Figures 31-33). Because the rates at which these

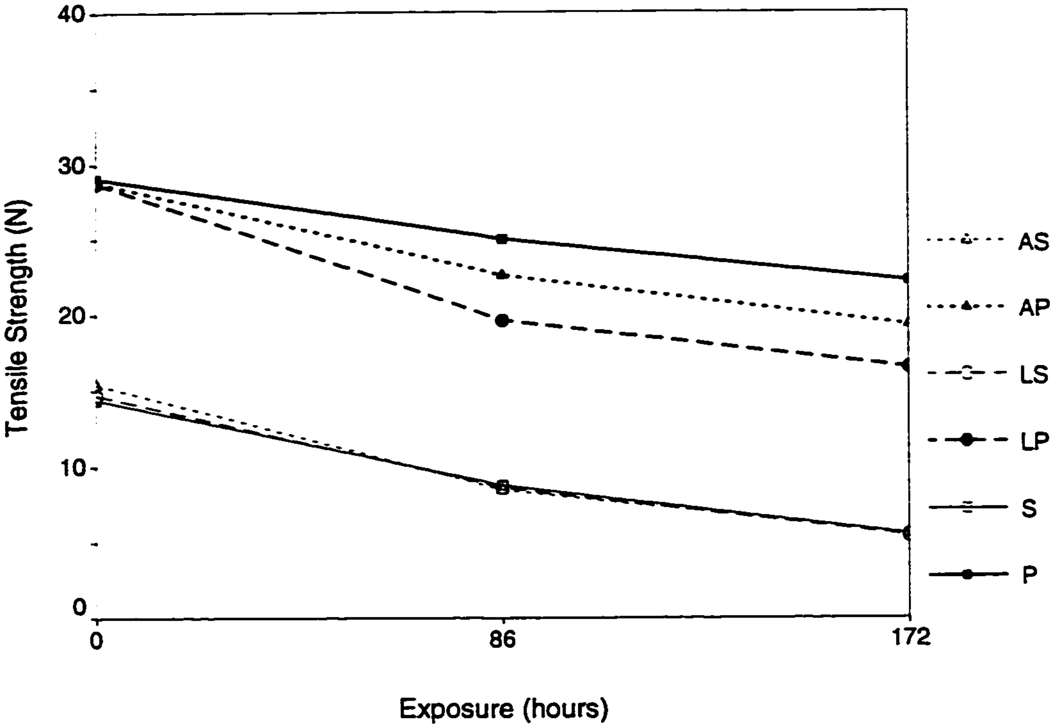

Figure 31. Change in tensile strength of coated and uncoated backing fabrics on exposure to light.

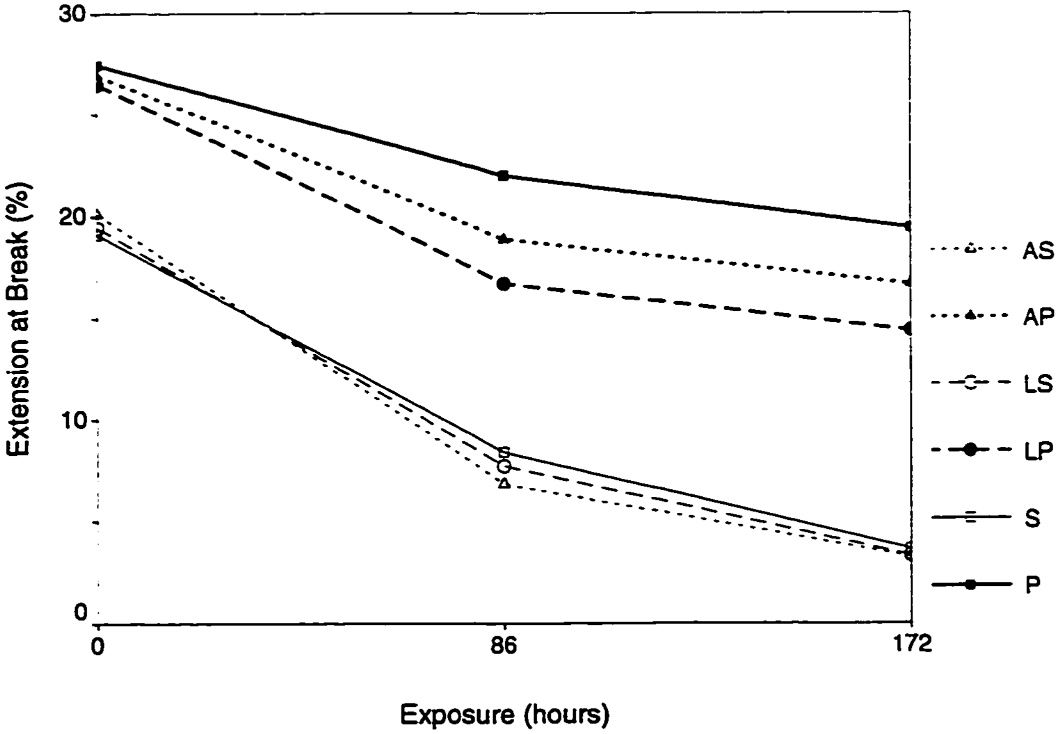

Figure 32. Change in extension at break of coated and uncoated backing fabrics on exposure to light.

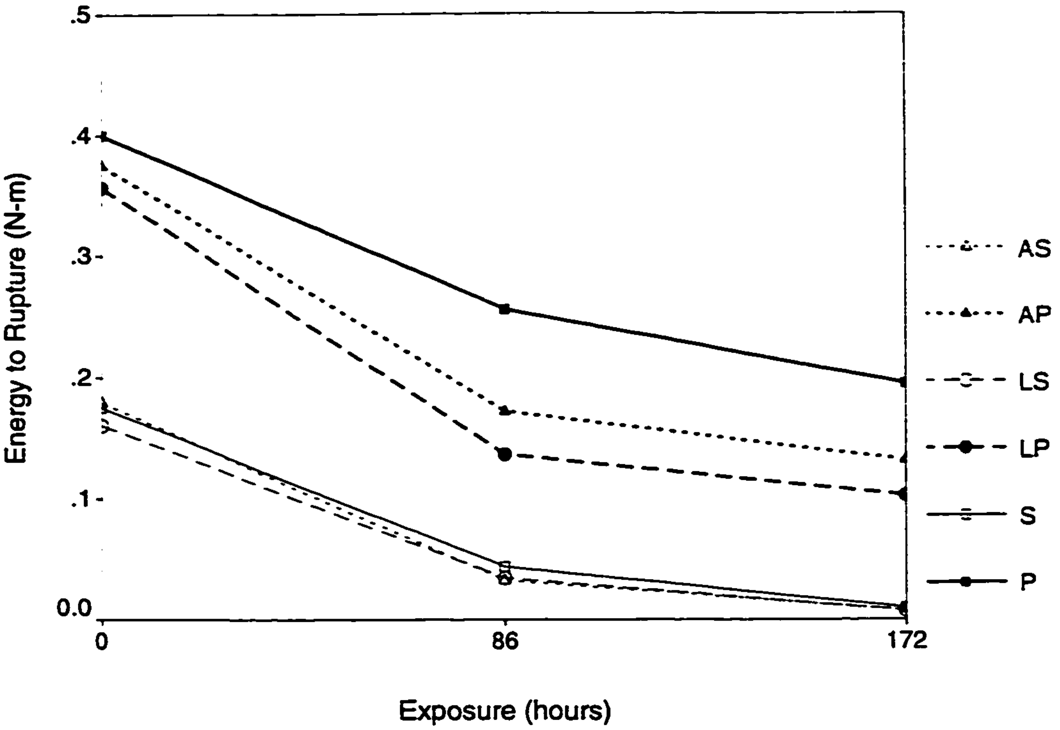

Figure 33. Change in energy to rupture of coated and uncoated backing fabrics on exposure to light.

polyester samples deteriorated were distinct, the two-way interaction of *adhesive* and *exposure* for these samples was significant for tensile strength, F (4,126) = 73.102, p = .000, extension at break, F (4,126) = 23.971, p = .000, and energy to rupture, F (4,126) = 18.815, p = .000. Given that the adhesive coatings did not affect the light stability of silk crepeline, these differences in rate are perplexing. The effects of increased welding together of the crepeline yarns on exposure may account for these differences. As has already been suggested, Lascaux coatings could cause greater increases in fibre welding since they had not penetrated the yarns before exposure, and since they were more likely to soften at the temperatures in the Weather-Ometer, which were close to the heat-sealing temperature of that adhesive. Increased welding would restrain the fibres from fully extending during the tensile test, which would result in lower values for tensile strength and elongation and therefore for energy to rupture as well. If this were the only factor, however, the same differences should be apparent on both polyester and silk crepeline samples. Moreover, the effect is dependent on the backing fabrics and adhesive coatings being exposed to the light. These different patterns of deterioration did not affect laminate samples containing the two types of coated polyester backing fabrics, which deteriorated at the same rate. Further research would be necessary to elucidate the precise cause of this effect of adhesive coating on the light stability of polyester crepeline. Clearly, as for silk crepeline, adhesive coating does not prevent tensile deterioration of polyester crepeline. According to these results, both Appretan MB extra and Lascaux 371 coatings accelerate the light degradation of polyester.

When compared directly, the two different backing fabrics have distinctly different tensile properties, but they do not degrade at such different rates when exposed to light. Polyester crepeline consistently exhibited tensile properties superior to those of silk crepeline (Table 31, Figures 31-33). Before exposure, the tensile strength, extension at break, and energy to rupture of uncoated polyester crepeline were 29.1 N, 27.4%, and 0.400 N-m respectively. By contrast, the corresponding values for silk crepeline were 14.4 N, 19.1%, and 0.175 N-m. Similar differences were maintained after 86 and 172 hours of light exposure. These results support the observations of textile conservators that polyester crepeline is stronger than silk crepeline (Bede, 1993; Ellis, 1997; Fischer & Rothhaar, 1987; de Groot, 1994; Hillyer, et al., 1997; Keyserlingk, 1990. 1993; Lodewijks, 1980).

Nevertheless, the rates of loss of the tensile properties do not vary greatly for the two backing fabrics (Table 32). Thus the lines for polyester and silk crepeline samples are often almost parallel in Figures 31, 32, and 33. The degree of similarity in the rates of loss of tensile properties between silk and polyester depends on the adhesive coating, as indicated by the significance of the three way interaction. For example, both fabrics lost tensile strength at statistically identical rates when they were coated with Appretan MB extra: the interaction between *backing* and *exposure* for the Appretan samples was not significant, $F(2, 84) = 2.039$, $p = .136$. During the first exposure period, tensile strength was lost at a rate of 0.08 N/hour and 0.07 N/hour for silk and polyester respectively. By contrast, during the same period the loss of tensile strength for Lascaux-coated silk and polyester crepeline was 0.07 N/hour and 0.11 N/hour respectively. The interaction between *backing* and *exposure* for the Lascaux samples was significant, $F(2, 84) = 58.919$, $p = .000$. Similarly, differences in the rate of loss of energy to rupture for corresponding silk and polyester backing fabrics can be clearly seen in Figure 33. Although the lines representing uncoated silk and polyester are almost parallel, those for Appretan-coated and Lascaux-coated samples clearly are not. Surprisingly, the coated polyester samples showed larger decreases in energy to rupture than the silk ones during the first exposure period. Polyester is generally considered to be more stable to light than silk (Cook, 1984a; Hatch, 1993). Silk crepeline yarns have been found to exhibit significant loss in tensile strength when exposed to intense UV-filtered fluorescent light, while polyester crepeline yarns did not (Ellis, 1997). The degradation of the polyester under the light ageing conditions of this study is probably due to phototendering initiated by the delustering pigment in the fibres. Titanium dioxide, the most common delustrant, has an absorption maximum at 350 nm (Allen & McKellar, 1980). Thus the emission of near UV radiation from the xenon arc light source was probably an important contributing factor. Because they were significantly stronger, more extensible, and tougher than the silk crepelines to begin with ($\alpha = .05$), however, the polyester crepeline samples retained a much higher percentage of their original tensile properties after light exposure (Table 32). The contrast is especially evident for the uncoated samples. After 172 hours of exposure, polyester crepeline had lost 23% of its initial tensile strength, 29% of its initial extension at break, and 51% of its initial energy to rupture. The corresponding values for silk crepeline are 61% (tensile strength), 81% (extension at break), and 94% (energy to rupture).

Summary

The three factors, *adhesive*, *backing fabric,* and *exposure*, significantly affected the properties of coated and uncoated backing fabrics in a complex manner. The influence of the two adhesives and backing fabrics depended on how they were combined and on how long the samples were exposed to light. Thus the null hypothesis of no significant difference between the changes in the properties of coated and uncoated backing fabrics due to the presence of Appretan MB extra versus Lascaux 371 or silk versus polyester crepeline can be rejected. Similarly the null hypothesis of no difference in rate of change (no interaction between *exposure* and *adhesive* or *backing fabric*) is rejected for most of the properties of the coated and uncoated backing fabrics. The significance of the interaction between these three factors in affecting the properties of the coated and uncoated backing fabrics contrasts with the virtual lack of interaction in the analyses for the laminates. This provides further evidence to support the theory that the properties of the backing materials affect the light stability of silk habutae-adhesive-backing fabric laminates to a lesser degree than the properties of silk habutae.

CHAPTER V   CONCLUSIONS AND RECOMMENDATIONS

Summary of the Study

This study examined aspects of adhesive backing treatments used on historical textiles. When a degraded silk textile is adhered to a new silk or polyester backing fabric, a new laminated fabric is produced. Because the properties and stability of this laminated fabric are not well understood, textile conservators are hesitant to use adhesive backing treatments even if no alternative is available. This research focussed on the light stability of the laminated fabric produced from adhesive backing treatments. Two aspects were of particular concern. First, the study compared the properties of the laminated fabrics with those of their components, the silk "artifact" and the coated backing fabric, on exposure to light. Secondly, the effects of the type of adhesive and backing fabric on the properties and light stability of the laminates were studied.

The light stability of silk-adhesive-backing fabric laminates was examined by subjecting laminated and unlaminated samples to three levels of accelerated light ageing and then measuring selected physical properties. Laminates were produced from silk habutae, as the artifact, adhered to silk or polyester crepeline backing fabrics with one of two poly(vinyl acetate) copolymer adhesives, Appretan MB extra or Lascaux Heat-seal Adhesive 371. Samples of the corresponding coated and uncoated backing fabrics and plain habutae were also prepared. These were exposed to 0, 86, or 172 hours of xenon arc radiation in an Altas Ci35W Weather-Ometer at approximately 50 ±1 °C and 50 ±10% RH. The colour change, flexural rigidity or stiffness, and tensile properties (tensile strength, extension at break, and energy to rupture) of all the samples and the peel strength of the laminates were compared and analysed statistically.

Conclusions

If using adhesives to attach a new backing fabric to a brittle, historic silk is to be considered acceptable, the treatment must improve the mechanical properties of the fragile silk while altering other properties, such as colour and stiffness, as little as possible. Furthermore, the silks given adhesive backings should not be more susceptible to degradation than they would have been had they been left untreated. The results of this study lead to the following conclusions about the effects of adhesive backing treatments on silk.

Adhering silk or polyester crepeline backings to silk habutae creates fabric laminates that are stronger, tougher, stiffer, and possibly of a different colour than plain silk habutae. The laminated silk habutae samples in this study often had significantly different properties than the plain habutae (Table 33). Lamination resulted in fabrics of greater tensile properties than plain silk habutae. The laminates were 10 to 28% stronger, up to 21% tougher, and of a similar extensibility as plain habutae. These increases are desirable, given that the aim of the treatment is to improve the mechanical properties of degraded artifacts. The changes were more often significant if the backing fabric was polyester crepeline than if it was silk crepeline.

Lamination also resulted in potentially undesirable changes in stiffness and colour (Table 33). Adhesive-backed silk was 12 to 18 times stiffer than plain silk. The degree of stiffness appears to depend at least partially on how much the adhesive penetrated the silk habutae face of the laminates. The backing fabrics caused changes to the colour of the translucent habutae, although the difference was visible only on unexposed silk crepeline laminates. The colour change was not affected by the adhesives.

Table 33. Significant Differences between the Properties of Plain Silk Habutae and Habutae-Adhesive-Backing Fabric Laminates

	Exposure Level	Laminates			
		Appretan MB extra		Lascaux 371	
Property	(hours)	silk	polyester	silk	polyester
colour change	0, 86, 172	H ≠ HAS	H ≠ HAP	H ≠ HLS	H ≠ HLP
flexural rigidity	0, 86, 172	H < HAS	H< HAP	H < HLS	H < HLP
tensile strength	0	H ~ HAS	H <HAP	H ~ HLS	H < HLP
	86	H < HAS	H <HAP	H ~ HLS	H < HLP
	172	H ~ HAS	H ~HAP	H ~ HLS	H < HLP
extension at break	averaged[a]	H > HAS	H ~HAP	H > HLS	H ~ HLP
energy to rupture	averaged[a]	H ~HAS	H <HAP	H ~ HLS	H < HLP

shaded = significant difference at the .05 level between plain habutae (H) and the habutae laminates (HAS, HAP, HLS, HLP) composed of the adhesive, Appretan MB extra (A) or Lascaux 371 (L) and the backing fabric, silk (S) or polyester (P) crepeline

[a] Significant differences were determined after averaging over the effects of exposure level since the interaction between *sample type* and *exposure* was not significant.

The tensile properties and colour of silk habutae-adhesive-backing fabric laminates appear to be affected by light exposure in much the same way as plain silk habutae. However, the laminates stiffen more than plain habutae when exposed to light. The laminates in this study lost tensile properties at the same rate as plain silk on exposure to light. After 172 hours of exposure, the tensile strength, extension at break, and energy to rupture of the laminates and plain habutae had dropped by about 54%, 59%, and 85% respectively. This result may pertain only to laminates in which the silk facing is stronger than the backing fabric. Laminated silk also appeared to yellow in a manner similar to that of plain silk. Because the backing fabrics altered the colour of the translucent habutae before and after ageing, however, the methods used to compare colour change in this study could not demonstrate conclusively that the yellowing of the habutae was not affected by the presence of adhered backings. The results for these two properties suggest that the properties of the silk habutae facing, the strongest component and the only one exposed directly to light, may be dominant in influencing the properties of the laminates.

In contrast, laminated silk habutae stiffened at a greater rate than plain habutae when exposed to light, although none of the increases in stiffness were very noticeable to touch. If the adhesive plays an important role in the stiffness of laminated fabric, as suggested, this difference is not surprising. It is, however, disquieting, since increased stiffness is generally considered to be unacceptable in the treatment of historic textiles. The cause of this stiffening may be related to increased penetration of the adhesive into the fabric yarns due to elevated temperatures in the Weather-Ometer. However, results for the Appretan laminates and for peel strength, which may also be dependent on adhesive penetration, do not always support this interpretation.

The properties of the laminates do not change at the same rate when exposed to light as those of their corresponding coated backing fabrics. The interaction between the factors *lamination* and *exposure* for laminated and unlaminated backing fabric pairs was almost always significant, indicating differences in the rates at which stiffness and tensile properties changed due to light exposure. These results further support the interpretation that the properties of the silk habutae largely determined those of the laminates.

The type of backing fabric significantly affects the stiffness, tensile properties, and peel strength of silk habutae-adhesive-backing fabric laminates. Laminate stiffness, tensile properties, and peel strength were significantly affected by the type of backing fabric (Table 34). Laminates backed with polyester crepeline were 36 to 45% stiffer, 11 to 14 % stronger, and 11 to 20% tougher than those backed with silk crepeline before exposure. Since light exposure resulted in changes that proceeded at mostly similar rates for all laminate types, these differences largely remained after accelerated light ageing. Similarly, the peel strength of the polyester laminates was always higher than that of the silk crepeline laminates.

The type of adhesive significantly affects the stiffness and peel strength of silk habutae-adhesive-backing fabric laminates, but not their tensile properties. Only the stiffness and peel strength of the laminates were significantly influenced by the type of adhesive (Table 34). The Lascaux 371 adhesive produced slightly stiffer laminates with bonds 3 to 4 times stronger than Appretan MB extra. Exposure to light altered only the magnitude of these differences. In contrast, the tensile properties of the laminated fabrics and changes in these properties upon light exposure appeared to be independent of the type of adhesive used.

The environmental conditions during the application of Appretan MB extra onto the backing fabrics significantly affect the stiffness and peel strength of laminates produced from these backing fabrics. Laminates produced from backing fabrics that had been coated during humid summer conditions (58% RH) were approximately 25% more flexible and had peel strengths almost twice as high as those whose backings were coated in an environment humidified to a similar RH using an ultrasonic humidifier. Furthermore, the latter laminates stiffened at a greater rate when exposed to light than

Table 34. Significance of Effects of Adhesive and Backing Fabric on the Properties of Silk Habutae-Adhesive-Backing Fabric Laminates

	Property				
Factor	Flexural Rigidity	Tensile Strength	Extension at Break	Energy to Rupture	Peel Strength
Backing Fabric	S<P	S<P	S<P	S<P	S<P
Adhesive	A<L	A~L	A~L	A~L	A<L

shaded = significant difference at the .05 level between Appretan MB extra (A) and Lascaux 371 (L) or between silk (S) and polyester (P) crepeline the former ones. These differences may be due to the effect of relative humidity on the degree of adhesive particle coalescence during the drying of the dispersion adhesive.

The effects of the type of adhesive and backing fabric on the properties of unlaminated coated and uncoated backing fabrics differed from the effects on the properties of the laminates. The changes in properties due to light exposure of unlaminated backing fabrics, both coated and uncoated, were distinct from those of the laminates in several ways. Although the silk crepeline backing fabrics and the Lascaux 371 adhesive yellowed visibly when directly exposed to light, the laminates appeared to yellow due to light exposure to the same degree regardless of type of adhesive or backing fabric. The Appretan-coated backing fabrics--especially polyester crepeline--tended to be slightly stiffer than Lascaux-coated ones, whereas the Lascaux laminates were stiffer than the Appretan ones. The differences in tensile properties of silk and polyester-backed laminates did reflect the relative properties of the plain backing fabrics: the polyesters were stronger and tougher in both cases. Nevertheless, the type of adhesive did affect the tensile properties of the coated backing fabrics to a certain degree, although it did not influence these properties in the laminates. Appretan-coated silk crepeline samples were significantly stronger and tougher than their Lascaux 371 counterparts before exposure to light. Appretan-coated polyester crepeline samples were significantly stronger, tougher and more extensible than their Lascaux counterparts after exposure. Neither of these patterns appeared to influence the change in tensile properties of the laminates. The apparent independence of the light stability of the laminates from that of the unlaminated backing materials explains the differences in the rates of degradation of the laminates and their corresponding backing fabrics. Thus the light stability of unlaminated backing materials may not necessarily affect the stability of laminates in which the backing materials are shielded from the light.

Recommendations for Further Research

The results of this study point to several key areas in which further research would be beneficial. Each addresses issues that concern understanding the mechanics of the fabric laminates that result from this treatment and the effects of environmental conditions on their stability. There are numerous variables related to adhesive backing methods that this study has only begun to consider or has not examined at all. These include several factors related to the adhesive, such as add-on, application technique, and solution concentration, as well as the heat-sealing variables of temperature, pressure, time in contact, and delivery system (iron versus vacuum table). Other adhesives and backing fabrics also deserve attention. Nevertheless, a better understanding of how the components interrelate to produce the properties of the adhered laminate will permit more focussed and profitable comparative testing of materials and techniques. Research related to such an understanding is, therefore, a priority.

Knowledge about the effects of light on the tensile properties of laminated fabrics needs to be expanded to fabric structures in which the exposed component is the weaker fabric. Such laminates would more closely resemble the structures produced when a historic artifact is treated. This study suggests that the stronger fabric dominates the tensile properties of the laminate. If so, the backing fabric properties should be dominant in laminates in which they are the strongest component. Studying the light stability of such laminates will more precisely clarify whether the degradation of coated backing fabrics is indeed retarded when shielded from the light. It would also reveal the effects of further light degradation of already fragile silk that is restrained by an adhesive support. The testing of woven structures such as satins and brocades is especially needed in this regard. Although this study showed that the type of adhesive did not significantly affect the tensile properties of the laminates, testing a wider range of adhesive formulations and polymers, such as acrylics and starch pastes, could confirm whether this is a general property of laminated fabrics, or whether other factors might influence the relationship between adhesive and tensile properties.

Because adhesive backing resulted in significant decreases in flexibility--a very important characteristic of textile artifacts--further research should characterize more precisely the factors affecting the stiffness of silk laminates. The hypothesis that these changes in stiffness are largely due to adhesive penetration into the silk habutae yarns could be tested using microscopic analyses of laminate cross-sections. The role of heat in producing changes in stiffness both during heat-sealing and after treatment needs to be examined more closely. Methods for determining fabric flexibility that are less affected by tacky surfaces and static electricity than the cantilever method used in this study would facilitate such research.

Several issues regarding the bond strength of fabric laminates should be addressed. Precise characterization of the effects of such factors as temperature, relative humidity, surface contamination, and mechanical stress of the sort encountered during handling on the bond strength of the silk-adhesive-backing fabric laminates would enhance understanding of the properties of the treated artifact. The role of the weave structures of the artifact and backing fabrics, the type of adhesive coating, and the interrelationship between fabrics and adhesive also need attention. Microscopic analysis and research techniques that directly measure adhesive forces would clarify the relative importance of mechanical interlocking and physico-chemical forces in the adhesion of the fabric layers.

The bond strength of silk-adhesive-backing fabric laminates also needs to be considered in terms of the requirements for treated artifacts and in terms of testing techniques that best measure performance given these requirements. Although conservators have found that less adhesive and lower heat-sealing pressures than have been used in the past are sufficient to support an artifact, the precise requirements for bond strength have not been clarified. As Wake (1982, p. 148) has noted, nothing is necessarily gained from a stronger adhesive or stronger adhesion between the adhesive and substrate if the substrate fails under stress. Given the fragility of the artifacts that are treated with adhesive backings, they will be the weakest component in the treated structure. What this means in terms of properties required of the treatment materials must yet be determined. Only when the objectives of this treatment are more clearly characterized, can a test method for measuring bond strength that addresses the factors of interest be chosen or developed. Measures such as peel strength may not be ideal for comparative research regarding the bond strength of laminates unless the influence of factors such as the moduli of the fabric and the adhesive can be isolated.

The effects of relative humidity during application of dispersion adhesives on the subsequent stiffness and peel strength of the laminates especially deserves study since most conservators use such adhesives. Scanning electron microscopy could be used to examine the degree of coalescence of adhesive coatings dried under different relative humidity levels. Systematic microscopic examination of the surfaces and cross-sections of laminates and peeled strips may clarify how adhesive coatings of differing degrees of coalescence result in the differences in stiffness and peel strength observed in this study. The effects of post-drying coalescence of the adhesive on the properties of laminates needs to be elucidated, with particular attention to the role played by heat.

Finally, the effects of adhesive backing on colour changes when exposed to light should be examined more thoroughly. Since both silk crepeline and Lascaux 371 exhibited visible yellowing on exposure to light, further study designed to distinguish discoloration of the silk face fabric from effects of the adhered backing is warranted. Such research would provide an ideal way of determining to what degree degradation of the backing materials is reduced or prevented when covered by the silk artifact.

Implications for Textile Conservation

Because this study only begins to clarify the properties of the type of fabric laminate that results when degraded silk is adhered to sheer fabric backings for support, no definitive advice can be given regarding the suitability of adhesive backing treatments for historic artifacts. The results of this study provide some support for the judgement of textile conservators who have continued to use adhered backings to treat fragile silk artifacts over the last four decades despite problems with particular materials and techniques. Nothing in these results is especially surprising given the experience of conservators, including the effect of the treatment on the flexibility of silk. Moreover, the light to which samples were exposed in this study, xenon arc radiation including near UV wavelengths, is much more severe than the light levels to which historic artifacts would normally be exposed. That silk laminates exposed to such conditions should degrade in a manner so similar to plain silk suggests that this treatment merits further study.

How such study would eventually benefit the textile conservator deserves comment. The better understood the properties of the laminated fabric that results from adhesive backing, the more control the conservator can exercise in both the decision whether to use adhesive techniques and the choice of materials for the treatment. This study suggests, for example, that if the tensile properties of the treated artifact are most important, the type of adhesive may not matter and could be chosen for such reasons as ease or safety in use. If the flexibility of an artifact is of utmost importance and the backing fabric will be completely obscured by the artifact, silk crepeline, which produces more flexible laminates than polyester crepeline, might be chosen. If dispersion adhesive coatings produce stronger bonds and more flexible laminates the more fully they are allowed to coalesce before heat-sealing, these desired properties could be maximized by controlling environmental conditions during application of the adhesive. Although the colour changes caused by the presence of the backing fabric in this study may not be a problem when the backing is dyed to match the colour of the artifact, further fading of fugitive dyes on translucent artifacts due to subsequent exposure to light may result in unanticipated colour interference. An adhesive treatment, if considered not sufficiently reversible for the artifact, might be avoided in such a case. With sufficient knowledge of this sort, the textile conservator would be able to use and adapt adhesive backing treatments much more skillfully to respond to the needs of particular artifacts.

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APPENDIX A: Settings and Operating Conditions of the Atlas Ci35W Weather-Ometer

Table A1. Atlas Ci35W Weather-Ometer Settings and Operating Conditions

Block	Adhesive	Settings			Operating Conditions	
		Black Panel Temperature (°C)	Wet Bulb Depression (°C)	Conditioning Water Temperature (°C)	Dry Bulb Temperature (°C)	Relative Humidity (%)
A	Appretan	50±1	8±1	50	30±1	50±5
	Lascaux	50±1	8±1	50	30±1	50±5
B	Appretan	50±1	7.5±1.5	50	29.5±2.5	48±6
	Lascaux	50±1	7.5±1	50	30±2	52±7
C	Appretan	50±1	8±1.5	50	29±2	48±8
	Lascaux	50±1	8±1.5	50	29±1.5	48±8

Table A2. Atlas Ci35W Weather-Ometer Burner and Filter Age

		Age (operating hours)		
Block	Adhesive	xenon burner	soda lime outer filter	borosilicate inner filter
A	Appretan	1195.80 - 1367.75	1761.05 - 1933.00	0.00 - 171.95
	Lascaux	1367.75 - 1539.70	1933.00 - 2104.95	171.95 - 343.90
B	Appretan	1711.80 - 1883.75	172.10 - 344.05	4.95 - 176.90
	Lascaux	1883.75 - 2055.65	344.05 - 515.95	176.90 - 348.80
C	Appretan	127.05 - 299.00	643.00 - 814.95	84.50 - 256.45
	Lascaux	299.00 - 470.95	814.95 - 986.90	256.45 - 428.40

APPENDIX B: Raw Data

Table B1a. Colour Change and Stiffness Data for Habutae Samples

Specimen	Colour Change				Overhang(cm)		Flex. Rigidity (mg-cm)		
	DL*	Da*	Db*	DE	a	b	a	b	ave
H1-0A	0.14	-0.01	0.00	0.14	2.90	2.95	11	12	11
H2-0A	-0.07	0.01	0.02	0.07	2.73	2.78	9	10	9
H3-0A	0.01	-0.01	0.01	0.02	2.88	2.98	11	12	11
H4-0A	-0.08	0.00	0.02	0.08	2.93	2.93	11	11	11
H5-0A	-0.09	0.04	-0.02	0.10	2.80	2.80	10	10	10
H1-0B	0.06	-0.02	0.00	0.06	2.88	2.90	11	11	11
H2-0B	0.05	0.03	-0.03	0.07	2.95	2.90	12	11	11
H3-0B	0.13	-0.01	-0.01	0.13	2.93	2.95	11	12	11
H4-0B	-0.09	0.03	0.05	0.11	2.78	2.80	10	10	10
H5-0B	0.31	0.01	-0.01	0.31	3.05	2.93	13	11	12
H1-0C	0.22	-0.04	-0.06	0.23	3.10	3.20	13	15	14
H2-0C	0.00	-0.07	-0.08	0.11	2.88	2.90	11	11	11
H3-0C	0.01	-0.08	-0.01	0.08	2.90	2.90	11	11	11
H4-0C	-0.09	-0.10	-0.05	0.14	3.08	2.98	13	12	12
H5-0C	-0.08	-0.09	-0.04	0.13	2.80	2.85	10	10	10
MEAN	0.03	-0.02	-0.01	0.12	2.90	2.92	11	11	11
ST.DEV.	0.12	0.05	0.03	0.07	0.11	0.10	1	1	1
H1-86A	-2.08	-0.25	5.48	5.87	3.03	3.18	12	14	13
H2-86A	-2.13	-0.25	5.50	5.90	3.00	3.03	12	12	12
H3-86A	-2.34	-0.24	5.47	5.95	2.75	2.90	9	11	10
H4-86A	-2.28	-0.20	5.31	5.78	2.93	3.00	11	12	12
H5-86A	-2.23	-0.22	5.36	5.81	2.83	3.03	10	12	11
H1-86B	-3.11	0.06	6.29	7.02	3.08	3.15	13	14	14
H2-86B	-2.58	0.13	5.56	6.13	2.90	2.83	11	10	11
H3-86B	-2.76	0.18	5.59	6.24	3.08	3.10	13	13	13
H4-86B	-2.66	0.06	5.91	6.48	3.15	3.48	14	19	16
H5-86B	-2.81	0.00	6.27	6.87	3.20	3.33	15	17	16
H1-86C	-1.87	0.07	4.83	5.18	3.13	3.10	14	13	14
H2-86C	-1.81	0.07	4.77	5.10	3.05	3.23	13	15	14
H3-86C	-1.81	0.07	4.79	5.12	3.35	3.43	17	18	17
H4-86C	-1.90	0.06	4.87	5.23	3.30	3.38	16	17	17
H5-86C	-1.95	0.07	4.65	5.04	3.15	3.03	14	12	13
MEAN	-2.29	-0.03	5.38	5.85	3.06	3.14	13	14	14
ST.DEV.	0.41	0.16	0.52	0.63	0.17	0.19	2	3	2
H1-172A	-2.98	0.04	6.23	6.91	3.03	2.98	12	12	12
H2-172A	-2.94	-0.05	6.48	7.12	3.20	3.18	15	14	15
H3-172A	-3.18	-0.03	6.65	7.37	2.98	2.93	12	11	12
H4-172A	-3.00	-0.03	6.41	7.08	2.83	2.98	10	12	11
H5-172A	-2.87	-0.05	6.24	6.87	2.78	2.83	10	10	10
H1-172B	-3.70	0.17	7.83	8.66	3.18	3.28	14	16	15
H2-172B	-3.42	0.09	7.70	8.43	3.45	3.28	18	16	17
H3-172B	-3.41	0.17	7.27	8.03	2.95	3.33	12	17	14
H4-172B	-3.41	0.19	7.25	8.01	3.18	3.25	14	15	15
H5-172B	-3.35	0.23	7.13	7.88	3.05	3.15	13	14	13
H1-172C	-3.01	0.18	6.71	7.36	3.50	3.60	19	21	20
H2-172C	-3.26	0.16	6.57	7.34	3.28	3.28	16	16	16
H3-172C	-3.10	0.18	6.56	7.26	3.55	3.53	20	20	20
H4-172C	-3.20	0.16	6.61	7.35	3.18	3.18	14	14	14
H5-172C	-3.30	0.13	6.74	7.51	3.20	3.35	15	17	16
MEAN	-3.21	0.10	6.83	7.54	3.15	3.21	14	15	15
ST.DEV.	0.23	0.10	0.50	0.54	0.23	0.21	3	3	3

Table B1b. Tensile Data for Habutae Samples

Specimen	Tensile Strength (kg/N)				Elongation (mm)			Extension	Energy to Rupture (kgf-mm/N-m)			
	a	b	ave	ave (N)	a	b	ave	%	a	b	ave	ave (Nm)
H1-0A	6.754	6.897	6.826	66.96	16.19	16.34	16.27	21.69	70.760	72.940	71.850	0.7048
H2-0A	6.260	6.883	6.572	64.47	16.33	16.25	16.29	21.72	61.850	64.430	63.140	0.6194
H3-0A	6.389	6.628	6.509	63.85	15.93	16.18	16.06	21.41	64.420	66.630	65.525	0.6428
H4-0A	6.569	6.639	6.604	64.79	16.41	16.94	16.68	22.23	64.610	67.010	65.810	0.6456
H5-0A	6.631	6.848	6.740	66.11	15.83	16.34	16.09	21.45	63.180	67.060	65.120	0.6388
H1-0B	6.448	6.284	6.366	62.45	16.36	15.71	16.04	21.38	62.660	59.410	61.035	0.5988
H2-0B	6.148	6.309	6.229	61.10	16.79	16.43	16.61	22.15	60.350	62.050	61.200	0.6004
H3-0B	6.523	6.309	6.416	62.94	16.73	16.07	16.40	21.87	63.490	56.940	60.215	0.5907
H4-0B	6.228	6.464	6.346	62.25	17.03	17.26	17.15	22.86	65.940	68.040	66.990	0.6572
H5-0B	6.631	6.601	6.616	64.90	16.43	16.68	16.56	22.07	68.860	67.000	67.930	0.6664
H1-0C	6.255	6.438	6.347	62.26	15.40	15.82	15.61	20.81	35.520	61.910	48.715	0.4779
H2-0C	6.376	6.314	6.345	62.24	16.15	15.80	15.98	21.30	66.190	58.390	62.290	0.6111
H3-0C	6.644	6.158	6.401	62.79	16.30	15.58	15.94	21.25	65.060	58.300	61.680	0.6051
H4-0C	6.212	6.217	6.215	60.96	15.54	16.60	16.07	21.43	60.520	64.570	62.545	0.6136
H5-0C	6.191	6.378	6.285	61.65	15.98	16.69	16.34	21.78	58.010	62.550	60.280	0.5913
MEAN	6.417	6.491	6.454	63.32	16.23	16.31	16.27	21.69	62.095	63.815	62.955	0.6176
ST.DEV.	0.198	0.245	0.183	1.80	0.45	0.47	0.37	0.50	8.039	4.438	5.114	0.0502
H1-86A	4.940	4.824	4.882	47.89	11.19	10.68	10.94	14.58	27.400	25.530	26.465	0.2596
H2-86A	4.964	4.846	4.905	48.12	11.17	11.10	11.14	14.85	27.210	25.430	26.320	0.2582
H3-86A	4.816	4.721	4.769	46.78	11.36	11.09	11.23	14.97	25.280	23.360	24.320	0.2386
H4-86A	5.036	5.133	5.085	49.88	11.55	11.64	11.60	15.46	25.480	27.170	26.325	0.2582
H5-86A	5.042	4.910	4.976	48.81	11.57	11.44	11.51	15.34	28.260	25.770	27.015	0.2650
H1-86B	4.601	4.485	4.543	44.57	12.12	12.41	12.27	16.35	22.220	23.210	22.715	0.2228
H2-86B	4.319	4.289	4.304	42.22	10.10	10.06	10.08	13.44	19.400	19.560	19.480	0.1911
H3-86B	4.819	4.682	4.751	46.60	11.65	11.79	11.72	15.63	25.140	25.310	25.225	0.2475
H4-86B	4.600	4.401	4.501	44.15	10.78	10.24	10.51	14.01	21.980	21.250	21.615	0.2120
H5-86B	4.346	4.444	4.395	43.11	10.53	10.62	10.58	14.10	19.210	21.060	20.135	0.1975
H1-86C	4.336	4.275	4.306	42.24	8.94	9.06	9.00	12.00	18.190	17.700	17.945	0.1760
H2-86C	4.619	4.545	4.582	44.95	10.10	9.87	9.99	13.31	23.370	23.960	23.665	0.2322
H3-86C	4.662	4.592	4.627	45.39	9.78	9.50	9.64	12.85	24.020	23.160	23.590	0.2314
H4-86C	4.499	4.493	4.496	44.11	9.66	9.79	9.73	12.97	21.630	22.060	21.845	0.2143
H5-86C	4.470	4.378	4.424	43.40	10.50	10.21	10.36	13.81	22.820	21.560	22.190	0.2177
MEAN	4.671	4.601	4.636	45.48	10.73	10.63	10.68	14.24	23.441	23.073	23.257	0.2281
ST.DEV.	0.253	0.247	0.247	2.42	0.89	0.94	0.91	1.21	3.082	2.584	2.763	0.0271
H1-172A	3.862	3.887	3.875	38.01	9.00	9.09	9.05	12.06	12.830	14.250	13.540	0.1328
H2-172A	3.627	3.764	3.696	36.25	7.92	8.49	8.21	10.94	11.220	12.570	11.895	0.1167
H3-172A	3.303	3.266	3.285	32.22	7.75	7.83	7.79	10.39	8.538	8.854	8.696	0.0853
H4-172A	3.125	3.360	3.243	31.81	7.69	7.87	7.78	10.37	7.775	9.413	8.594	0.0843
H5-172A	3.361	3.211	3.286	32.24	7.64	7.35	7.50	9.99	9.402	7.416	8.409	0.0825
H1-172B	2.345	2.365	2.355	23.10	6.94	6.77	6.86	9.14	4.557	4.566	4.562	0.0447
H2-172B	2.950	2.863	2.907	28.51	7.10	7.01	7.06	9.41	7.647	6.735	7.191	0.0705
H3-172B	2.640	2.681	2.661	26.10	7.23	7.04	7.14	9.51	5.547	5.884	5.716	0.0561
H4-172B	2.569	2.489	2.529	24.81	6.81	6.73	6.77	9.03	4.855	4.913	4.884	0.0479
H5-172B	2.733	2.675	2.704	26.53	7.09	6.95	7.02	9.36	6.108	5.862	5.985	0.0587
H1-172C	3.052	3.058	3.055	29.97	6.83	6.70	6.77	9.02	7.947	7.273	7.610	0.0747
H2-172C	2.903	2.788	2.846	27.91	6.88	6.75	6.82	9.09	6.178	6.020	6.099	0.0598
H3-172C	2.838	2.854	2.846	27.92	6.95	6.76	6.86	9.14	6.487	6.143	6.315	0.0620
H4-172C	2.632	2.467	2.550	25.01	6.79	6.38	6.59	8.78	5.299	4.573	4.936	0.0484
H5-172C	2.541	2.553	2.547	24.99	6.50	6.40	6.45	8.60	5.140	4.688	4.914	0.0482
MEAN	2.965	2.952	2.959	29.03	7.27	7.21	7.24	9.66	7.302	7.277	7.290	0.0715
ST.DEV.	0.428	0.465	0.443	4.35	0.63	0.78	0.70	0.94	2.409	2.900	2.622	0.0257

Table B2a. Colour Change, Stiffness, and Peel Strength Data for Habutae-Appretan-Silk Crepeline Samples

Specimen	Colour Change				Overhang(cm)		Flex. Rigidity (mg-cm)			Peel Strength(mN/mm)			Add-on
	DL*	Da*	Db*	DE	a	b	a	b	ave	a	b	ave	(g/m2)
HAS1-0A	-0.01	0.03	0.05	0.06	5.75	5.75	113	113	113	17.7	16.4	17.0	3.10
HAS2-0A	0.08	-0.02	0.00	0.08	5.90	5.93	122	123	122	18.0	19.2	18.6	3.55
HAS3-0A	0.05	-0.03	0.00	0.06	5.88	5.88	120	120	120	19.6	17.0	18.3	3.31
HAS4-0A	0.05	-0.01	-0.06	0.08	5.88	5.80	120	116	118	15.3	15.0	15.1	3.21
HAS5-0A	0.22	0.03	-0.13	0.26	5.90	6.20	122	141	131	19.4	18.8	19.1	3.23
HAS1-0B	0.24	-0.02	-0.05	0.25	5.90	6.13	122	136	129	8.3	8.7	8.5	3.16
HAS2-0B	-0.03	0.02	-0.01	0.04	6.20	6.25	141	145	143	6.6	6.3	6.4	2.72
HAS3-0B	-0.17	0.02	0.02	0.17	6.10	6.33	134	150	142	8.0	7.6	7.8	2.77
HAS4-0B	-0.05	0.00	0.02	0.05	6.43	6.45	157	159	158	5.2	4.0	4.6	2.52
HAS5-0B	0.11	-0.01	0.00	0.11	6.00	6.05	128	131	130	8.8	9.9	9.3	3.01
HAS1-0C	-0.06	-0.01	0.05	0.08	6.10	6.05	134	131	133	9.3	9.2	9.3	3.27
HAS2-0C	-0.11	-0.01	0.02	0.11	5.93	5.93	123	123	123	11.0	9.7	10.4	3.08
HAS3-0C	0.08	0.00	-0.04	0.09	6.05	6.35	131	152	141	10.2	8.4	9.3	3.31
HAS4-0C	0.07	0.02	-0.05	0.09	6.15	6.20	138	141	140	7.9	6.9	7.4	3.40
HAS5-0C	-0.03	0.00	-0.01	0.03	6.23	6.03	143	130	136	8.9	7.2	8.0	3.35
MEAN	0.03	0.00	-0.01	0.10	6.03	6.09	130	134	132	11.6	10.9	11.3	3.13
ST.DEV.	0.11	0.02	0.05	0.07	0.18	0.21	12	14	12	4.9	4.9	4.9	0.28
HAS1-86A	-1.60	0.15	3.83	4.15	5.90	5.85	122	119	120	33.7	35.5	34.6	4.07
HAS2-86A	-1.47	0.09	3.83	4.10	5.95	6.05	125	131	128	25.0	29.9	27.5	3.47
HAS3-86A	-1.17	0.15	3.40	3.60	6.13	5.85	136	119	127	32.5	30.7	31.6	3.17
HAS4-86A	-1.31	0.15	3.66	3.89	5.98	5.85	126	119	123	32.2	32.7	32.4	3.98
HAS5-86A	-1.32	0.05	4.00	4.21	6.23	6.05	143	131	137	26.3	26.4	26.4	3.44
HAS1-86B	-1.94	0.37	4.11	4.56	6.78	6.70	184	178	181	16.5	12.8	14.7	3.09
HAS2-86B	-1.96	0.32	4.23	4.67	6.13	6.25	136	145	140	15.0	14.0	14.5	2.88
HAS3-86B	-1.93	0.29	4.45	4.86	6.88	7.15	193	217	205	15.7	13.0	14.4	3.10
HAS4-86B	-2.02	0.33	4.30	4.76	6.90	6.78	195	184	189	13.6	14.3	14.0	2.77
HAS5-86B	-1.96	0.30	4.36	4.79	6.78	6.90	184	195	189	12.0	11.4	11.7	2.82
HAS1-86C	-1.62	0.40	3.58	3.95	6.50	6.30	163	148	155	13.9	14.4	14.2	3.35
HAS2-86C	-1.72	0.40	3.48	3.90	6.38	6.35	154	152	153	16.3	14.0	15.2	3.63
HAS3-86C	-1.79	0.38	3.64	4.07	6.25	6.65	145	174	159	17.5	14.4	16.0	2.98
HAS4-86C	-1.74	0.38	3.80	4.20	6.70	6.95	178	199	189	19.7	17.2	18.5	3.72
HAS5-86C	-1.50	0.44	3.43	3.77	7.35	7.03	235	205	220	13.7	15.3	14.5	2.84
MEAN	-1.67	0.28	3.87	4.23	6.45	6.45	161	161	161	20.2	19.7	20.0	3.29
ST.DEV.	0.27	0.13	0.35	0.40	0.43	0.46	33	34	32	7.6	8.6	8.0	0.42
HAS1-172A	-2.08	0.27	5.27	5.67	6.10	5.80	134	116	125	28.5	28.8	28.6	3.18
HAS2-172A	-2.07	0.32	5.05	5.47	6.25	6.15	145	138	141	32.0	28.7	30.3	3.31
HAS3-172A	-2.13	0.28	5.24	5.66	6.10	5.95	134	125	130	28.2	29.5	28.9	3.41
HAS4-172A	-2.20	0.35	5.03	5.50	6.10	5.98	134	126	130	27.9	24.9	26.4	3.49
HAS5-172A	-2.07	0.26	5.17	5.58	6.05	6.10	131	134	133	24.7	26.4	25.6	2.67
HAS1-172B	-2.70	0.54	5.40	6.06	7.03	7.08	205	210	208	15.8	17.2	16.5	2.90
HAS2-172B	-2.43	0.45	5.55	6.08	7.80	7.93	281	295	288	17.0	19.1	18.0	3.16
HAS3-172B	-2.47	0.50	5.28	5.85	7.53	7.05	252	208	230	15.7	15.4	15.5	3.16
HAS4-172B	-2.46	0.50	5.16	5.74	7.33	7.15	233	217	225	16.4	20.3	18.4	2.64
HAS5-172B	-2.46	0.55	5.08	5.67	6.90	6.95	195	199	197	12.2	14.4	13.3	2.68
HAS1-172C	-2.72	0.56	5.10	5.81	7.10	7.28	212	228	220	17.1	14.8	16.0	3.73
HAS2-172C	-2.39	0.53	5.07	5.63	7.43	7.30	243	231	237	19.3	14.0	16.6	3.19
HAS3-172C	-2.35	0.60	4.65	5.24	6.90	6.85	195	190	193	15.6	17.0	16.3	3.16
HAS4-172C	-2.51	0.60	4.81	5.46	6.98	7.25	201	226	213	20.1	17.1	18.6	3.26
HAS5-172C	-2.69	0.55	5.23	5.91	7.60	7.75	260	276	268	18.4	15.9	17.1	3.11
MEAN	-2.38	0.46	5.14	5.69	6.88	6.84	197	195	196	20.6	20.2	20.4	3.14
ST.DEV.	0.23	0.13	0.22	0.23	0.61	0.68	51	56	53	6.0	5.8	5.8	0.31

Table B2b. Tensile Data for Habutae-Appretan-Silk Crepeline Samples

Specimen	Tensile Strength(kg/N)				Elongation (mm)			Extension	Energy to Rupture (kgf-mm/N-m)			
	a	b	ave	ave (N)	a	b	ave	%	a	b	ave	ave (Nm)
HAS1-0A	7.791	8.180	7.986	78.34	16.87	15.76	16.32	21.75	80.250	71.430	75.840	0.7440
HAS2-0A	7.793	7.503	7.648	75.03	16.02	16.85	16.44	21.91	72.850	77.090	74.970	0.7355
HAS3-0A	7.887	7.401	7.644	74.99	17.52	14.39	15.96	21.27	85.530	57.030	71.280	0.6993
HAS4-0A	7.568	8.078	7.823	76.74	14.57	16.61	15.59	20.79	61.700	81.630	71.665	0.7030
HAS5-0A	7.922	7.884	7.903	77.53	16.00	15.19	15.60	20.79	81.070	74.520	77.795	0.7632
HAS1-0B	6.062	6.526	6.294	61.74	14.35	15.02	14.69	19.58	50.310	58.670	54.490	0.5345
HAS2-0B	6.693	7.071	6.882	67.51	15.65	16.21	15.93	21.24	65.760	69.810	67.785	0.6650
HAS3-0B	6.035	5.656	5.846	57.34	14.49	13.80	14.15	18.86	54.640	50.510	52.575	0.5158
HAS4-0B	6.593	6.419	6.506	63.82	15.26	14.68	14.97	19.96	58.250	55.440	56.845	0.5576
HAS5-0B	6.625	5.855	6.240	61.21	15.47	13.70	14.59	19.45	59.910	48.240	54.075	0.5305
HAS1-0C	7.527	7.444	7.486	73.43	15.71	16.20	15.96	21.27	77.020	73.390	75.205	0.7378
HAS2-0C	6.754	6.424	6.589	64.64	16.49	14.66	15.58	20.77	68.690	59.980	64.335	0.6311
HAS3-0C	7.221	7.337	7.279	71.41	16.35	15.81	16.08	21.44	73.400	74.180	73.790	0.7239
HAS4-0C	7.135	7.135	7.135	69.99	15.51	16.83	16.17	21.56	70.260	77.020	73.640	0.7224
HAS5-0C	7.264	6.872	7.068	69.34	15.55	14.75	15.15	20.20	70.110	60.100	65.105	0.6387
MEAN	7.125	7.052	7.089	69.54	15.72	15.36	15.54	20.72	68.650	65.936	67.293	0.6601
ST.DEV.	0.636	0.759	0.674	6.61	0.88	1.05	0.69	0.92	10.221	10.687	8.866	0.0870
HAS1-86A	5.361	5.278	5.320	52.18	10.32	9.86	10.09	13.45	25.910	24.040	24.975	0.2450
HAS2-86A	5.957	5.366	5.662	55.54	11.67	9.39	10.53	14.04	36.360	24.760	30.560	0.2998
HAS3-86A	6.011	6.220	6.116	59.99	10.56	10.91	10.74	14.31	32.000	35.020	33.510	0.3287
HAS4-86A	5.694	5.340	5.517	54.12	10.27	9.35	9.81	13.08	28.620	25.070	26.845	0.2633
HAS5-86A	4.723	5.729	5.226	51.27	8.49	10.37	9.43	12.57	19.540	28.240	23.890	0.2344
HAS1-86B	5.015	4.921	4.968	48.74	11.01	10.74	10.88	14.50	28.080	25.330	26.705	0.2620
HAS2-86B	4.431	4.589	4.510	44.24	9.25	9.02	9.14	12.18	18.620	19.050	18.835	0.1848
HAS3-86B	4.937	5.208	5.073	49.76	9.45	10.11	9.78	13.04	23.190	27.680	25.435	0.2495
HAS4-86B	5.084	5.152	5.118	50.21	10.05	10.34	10.20	13.59	26.310	26.170	26.240	0.2574
HAS5-86B	4.811	4.730	4.771	46.80	9.80	9.32	9.56	12.75	23.570	20.820	22.195	0.2177
HAS1-86C	4.773	4.510	4.642	45.53	8.34	8.31	8.33	11.10	20.470	18.860	19.665	0.1929
HAS2-86C	4.883	5.318	5.101	50.04	9.26	10.36	9.81	13.08	23.060	27.960	25.510	0.2503
HAS3-86C	5.407	5.203	5.305	52.04	10.13	9.03	9.58	12.77	27.340	23.180	25.260	0.2478
HAS4-86C	5.385	5.256	5.321	52.19	8.93	9.19	9.06	12.08	24.290	26.840	25.565	0.2508
HAS5-86C	5.144	5.503	5.324	52.22	8.87	9.39	9.13	12.17	23.060	27.810	25.435	0.2495
MEAN	5.174	5.222	5.198	50.99	9.76	9.71	9.74	12.98	25.361	25.389	25.375	0.2489
ST.DEV.	0.458	0.433	0.402	3.95	0.94	0.74	0.69	0.92	4.714	4.073	3.642	0.0357
HAS1-172A	3.310	3.793	3.552	34.84	5.96	7.00	6.48	8.64	8.773	10.650	9.712	0.0953
HAS2-172A	3.852	3.699	3.776	37.04	7.27	7.03	7.15	9.53	12.810	10.830	11.820	0.1160
HAS3-172A	3.280	3.255	3.268	32.05	6.47	6.63	6.55	8.73	8.830	9.877	9.354	0.0918
HAS4-172A	3.533	3.710	3.622	35.53	6.97	7.48	7.23	9.63	11.470	10.940	11.205	0.1099
HAS5-172A	3.244	3.542	3.393	33.29	6.05	5.99	6.02	8.03	9.590	8.904	9.247	0.0907
HAS1-172B	3.097	2.689	2.893	28.38	6.33	5.92	6.13	8.17	8.551	6.666	7.609	0.0746
HAS2-172B	3.160	3.178	3.169	31.09	5.70	5.59	5.65	7.53	7.937	7.843	7.890	0.0774
HAS3-172B	2.942	2.577	2.760	27.07	6.10	5.76	5.93	7.91	7.355	6.662	7.009	0.0688
HAS4-172B	3.448	3.031	3.240	31.78	6.06	6.05	6.06	8.07	8.485	7.532	8.009	0.0786
HAS5-172B	3.055	2.917	2.986	29.29	6.23	5.85	6.04	8.05	7.899	7.144	7.522	0.0738
HAS1-172C	3.714	3.838	3.776	37.04	6.49	6.34	6.42	8.55	10.420	10.580	10.500	0.1030
HAS2-172C	3.373	2.811	3.092	30.33	5.32	4.86	5.09	6.79	7.572	6.157	6.865	0.0673
HAS3-172C	3.341	2.910	3.126	30.66	5.55	5.26	5.41	7.21	8.749	7.057	7.903	0.0775
HAS4-172C	3.274	3.247	3.261	31.99	5.12	5.27	5.20	6.93	7.562	7.260	7.411	0.0727
HAS5-172C	3.369	3.025	3.197	31.36	5.50	5.05	5.28	7.03	7.598	6.732	7.165	0.0703
MEAN	3.333	3.215	3.274	32.12	6.07	6.01	6.04	8.05	8.907	8.322	8.615	0.0845
ST.DEV.	0.239	0.415	0.303	2.97	0.59	0.77	0.66	0.87	1.572	1.775	1.592	0.0156

Table B3a. Colour Change, Stiffness, and Peel Strength Data for Habutae-Appretan-Polyester Crepeline Samples

Specimen	Colour Change				Overhang(cm)		Flex. Rigidity (mg-cm)			Peel Strength(mN/mm)			Add-on
	DL*	Da*	Db*	DE	a	b	a	b	ave	a	b	ave	(g/m2)
HAP1-0A	-0.08	0.02	0.00	0.08	5.98	6.03	136	140	138	26.7	21.4	24.1	2.87
HAP2-0A	-0.10	-0.02	0.08	0.13	5.73	5.95	120	135	127	30.0	34.5	32.3	2.91
HAP3-0A	0.05	0.00	-0.04	0.06	5.90	5.95	131	135	133	30.0	29.9	29.9	2.96
HAP4-0A	-0.08	0.01	-0.01	0.08	6.15	6.15	149	149	149	23.8	31.1	27.4	2.93
HAP5-0A	0.13	0.01	-0.02	0.13	6.13	6.10	147	145	146	19.7	21.8	20.7	2.72
HAP1-0B	0.09	-0.01	0.09	0.13	7.00	6.83	219	203	211	10.7	11.8	11.2	2.66
HAP2-0B	0.00	0.01	0.01	0.01	7.30	6.73	249	194	221	14.3	13.7	14.0	2.60
HAP3-0B	0.07	0.02	-0.06	0.09	6.80	6.83	201	203	202	8.4	8.4	8.4	2.94
HAP4-0B	-0.09	0.02	-0.01	0.09	6.45	6.53	171	178	174	11.6	11.2	11.4	2.62
HAP5-0B	-0.03	0.02	0.05	0.06	6.50	7.15	175	234	205	14.6	13.3	14.0	2.36
HAP1-0C	-0.15	-0.04	0.02	0.16	6.33	7.03	162	222	192	17.6	17.0	17.3	3.43
HAP2-0C	0.08	0.02	0.04	0.09	6.78	6.95	199	214	207	14.7	14.1	14.4	2.89
HAP3-0C	-0.09	-0.01	0.04	0.10	6.58	6.73	182	194	188	15.2	12.8	14.0	3.25
HAP4-0C	0.20	0.03	-0.07	0.21	6.78	6.90	199	210	204	15.1	12.9	14.0	2.93
HAP5-0C	-0.02	-0.01	-0.07	0.07	6.63	6.53	186	178	182	14.2	13.7	14.0	3.10
MEAN	0.00	0.00	0.00	0.10	6.47	6.56	175	182	179	17.8	17.8	17.8	2.88
ST.DEV.	0.10	0.02	0.05	0.05	0.44	0.42	35	34	32	6.8	8.1	7.3	0.27
HAP1-86A	-1.94	0.02	4.74	5.12	6.35	6.18	164	150	157	27.0	34.4	30.7	2.67
HAP2-86A	-1.90	0.00	4.75	5.12	6.20	5.88	152	130	141	37.3	42.1	39.7	2.97
HAP3-86A	-1.75	0.03	4.42	4.75	6.20	6.35	152	164	158	36.7	34.9	35.8	2.57
HAP4-86A	-2.05	0.08	4.59	5.03	6.10	5.78	145	123	134	30.0	28.6	29.3	2.58
HAP5-86A	-1.94	-0.04	4.91	5.28	6.20	6.23	152	154	153	42.3	33.0	37.6	3.16
HAP1-86B	-2.37	0.09	5.23	5.74	6.93	7.03	212	222	217	16.1	15.4	15.8	2.25
HAP2-86B	-2.17	0.04	5.31	5.74	7.23	7.18	241	236	238	18.4	14.5	16.5	2.96
HAP3-86B	-2.02	0.01	5.08	5.47	7.05	7.25	224	243	234	19.5	18.4	18.9	2.39
HAP4-86B	-2.15	0.09	4.92	5.37	7.33	7.60	251	280	266	18.7	16.5	17.6	2.71
HAP5-86B	-2.15	0.14	4.84	5.30	7.25	7.15	243	234	239	17.9	17.8	17.9	2.57
HAP1-86C	-1.99	0.21	4.65	5.06	7.13	7.28	231	246	239	27.8	26.9	27.4	3.07
HAP2-86C	-1.94	0.22	4.36	4.78	6.95	6.63	214	186	200	26.6	26.6	26.6	2.96
HAP3-86C	-1.86	0.26	4.28	4.67	7.28	7.08	246	226	236	27.3	24.0	25.6	3.31
HAP4-86C	-2.21	0.26	4.37	4.90	6.53	6.85	178	205	191	20.3	18.8	19.5	3.54
HAP5-86C	-2.00	0.21	4.72	5.13	7.38	6.83	256	203	230	25.0	27.0	26.0	3.33
MEAN	-2.03	0.11	4.74	5.16	6.81	6.75	204	200	202	26.1	25.3	25.7	2.87
ST.DEV.	0.16	0.10	0.31	0.33	0.48	0.55	42	47	43	7.9	8.3	7.9	0.37
HAP1-172A	-2.49	0.13	5.43	5.98	6.28	6.10	158	145	151	36.5	37.7	37.1	3.01
HAP2-172A	-2.47	0.12	5.65	6.17	6.33	6.23	162	154	158	34.6	32.6	33.6	2.91
HAP3-172A	-2.44	0.12	5.68	6.18	6.45	6.48	171	173	172	43.2	40.5	41.9	2.99
HAP4-172A	-2.50	0.13	5.66	6.19	6.75	6.78	197	199	198	26.7	30.5	28.6	2.92
HAP5-172A	-2.67	0.14	5.69	6.29	6.48	6.25	173	156	165	33.8	33.7	33.7	2.96
HAP1-172B	-3.04	0.21	6.43	7.12	7.20	7.28	238	246	242	19.4	22.7	21.0	2.42
HAP2-172B	-2.89	0.20	6.27	6.91	7.03	7.23	222	241	231	21.4	20.6	21.0	2.94
HAP3-172B	-2.91	0.21	6.43	7.06	7.98	7.73	324	295	309	17.7	17.8	17.7	2.36
HAP4-172B	-2.75	0.17	6.42	6.99	7.83	7.93	306	318	312	19.1	20.7	19.9	2.24
HAP5-172B	-2.73	0.13	6.68	7.22	7.73	8.00	295	327	311	20.3	22.8	21.6	2.51
HAP1-172C	-2.78	0.36	5.97	6.60	7.95	7.73	321	295	308	19.9	19.4	19.6	3.55
HAP2-172C	-2.76	0.38	5.79	6.43	7.25	6.98	243	217	230	25.2	26.4	25.8	3.09
HAP3-172C	-2.90	0.36	5.97	6.65	7.48	6.78	267	199	233	19.9	22.5	21.2	3.10
HAP4-172C	-3.07	0.33	6.15	6.88	7.10	7.20	229	238	234	26.1	29.5	27.8	3.11
HAP5-172C	-2.99	0.38	5.88	6.61	7.20	7.15	238	234	236	24.8	24.9	24.8	3.30
MEAN	-2.76	0.22	6.01	6.62	7.13	7.05	236	229	233	25.9	26.8	26.4	2.89
ST.DEV.	0.21	0.11	0.37	0.40	0.59	0.62	57	60	57	7.7	7.0	7.3	0.36

Table B3b. Tensile Data for Habutae-Appretan-Polyester Crepeline Samples

Specimen	Tensile Strength (kg/N)				Elongation (mm)			Extension	Energy to Rupture (kgf-mm/N-m)			
	a	b	ave	ave (N)	a	b	ave	%	a	b	ave	ave (Nm)
HAP1-0A	8.319	9.503	8.911	87.42	17.58	17.75	17.67	23.55	78.500	92.250	85.375	0.8375
HAP2-0A	8.344	8.346	8.345	81.86	17.24	17.01	17.13	22.83	78.350	79.710	79.030	0.7753
HAP3-0A	8.644	8.950	8.797	86.30	17.53	17.11	17.32	23.09	88.200	86.660	87.430	0.8577
HAP4-0A	8.424	9.109	8.767	86.00	16.66	18.95	17.81	23.74	76.520	102.700	89.610	0.8791
HAP5-0A	8.733	9.189	8.961	87.91	17.51	16.61	17.06	22.75	96.700	84.150	90.425	0.8871
HAP1-0B	7.009	7.506	7.258	71.20	14.16	15.40	14.78	19.71	55.250	66.330	60.790	0.5963
HAP2-0B	7.229	6.561	6.895	67.64	15.55	14.69	15.12	20.16	65.030	54.750	59.890	0.5875
HAP3-0B	7.160	7.629	7.395	72.54	15.56	16.54	16.05	21.40	59.970	69.200	64.585	0.6336
HAP4-0B	7.640	6.937	7.289	71.50	17.09	17.32	17.21	22.94	74.500	69.580	72.040	0.7067
HAP5-0B	6.867	6.674	6.771	66.42	16.84	14.98	15.91	21.21	69.470	53.670	61.570	0.6040
HAP1-0C	7.911	7.466	7.689	75.42	17.79	17.16	17.48	23.30	81.420	76.610	79.015	0.7751
HAP2-0C	8.048	7.855	7.952	78.00	15.93	15.01	15.47	20.63	78.270	70.550	74.410	0.7300
HAP3-0C	7.211	7.039	7.125	69.90	14.74	14.65	14.70	19.59	62.910	64.250	63.580	0.6237
HAP4-0C	8.032	8.099	8.066	79.12	17.05	15.83	16.44	21.92	82.370	76.940	79.655	0.7814
HAP5-0C	7.447	7.758	7.603	74.58	17.02	15.60	16.31	21.75	70.740	70.180	70.460	0.6912
MEAN	7.801	7.908	7.855	77.05	16.55	16.31	16.43	21.90	74.547	74.502	74.524	0.7311
ST.DEV.	0.621	0.943	0.754	7.40	1.11	1.27	1.05	1.41	10.969	13.286	10.834	0.1063
HAP1-86A	6.451	6.419	6.435	63.13	11.58	11.64	11.61	15.48	39.930	37.270	38.600	0.3787
HAP2-86A	6.145	6.526	6.336	62.15	10.59	11.58	11.09	14.78	32.840	35.470	34.155	0.3351
HAP3-86A	7.237	7.291	7.264	71.26	13.45	12.56	13.01	17.34	50.560	48.770	49.665	0.4872
HAP4-86A	6.819	6.582	6.701	65.73	12.37	12.24	12.31	16.41	41.550	38.520	40.035	0.3927
HAP5-86A	5.976	6.250	6.113	59.97	10.96	10.84	10.90	14.53	31.120	34.070	32.595	0.3198
HAP1-86B	4.819	5.017	4.918	48.25	9.68	9.37	9.53	12.70	23.470	24.520	23.995	0.2354
HAP2-86B	5.839	5.965	5.902	57.90	11.87	11.34	11.61	15.47	34.240	34.400	34.320	0.3367
HAP3-86B	4.872	4.770	4.821	47.29	9.98	9.12	9.55	12.73	24.180	21.900	23.040	0.2260
HAP4-86B	5.412	5.546	5.479	53.75	11.14	11.23	11.19	14.91	29.620	30.670	30.145	0.2957
HAP5-86B	4.770	4.425	4.598	45.10	9.42	8.92	9.17	12.23	22.950	20.220	21.585	0.2117
HAP1-86C	6.134	5.632	5.883	57.71	11.19	9.77	10.48	13.97	38.090	33.630	35.860	0.3518
HAP2-86C	4.805	4.623	4.714	46.24	9.05	7.99	8.52	11.36	25.320	22.390	23.855	0.2340
HAP3-86C	5.213	5.476	5.345	52.43	8.57	9.22	8.90	11.86	28.680	31.000	29.840	0.2927
HAP4-86C	4.327	4.507	4.417	43.33	7.96	8.00	7.98	10.64	19.490	20.420	19.955	0.1958
HAP5-86C	6.059	5.522	5.791	56.80	9.62	9.55	9.59	12.78	33.210	30.200	31.705	0.3110
MEAN	5.659	5.637	5.648	55.40	10.50	10.22	10.36	13.81	31.683	30.897	31.290	0.3070
ST.DEV.	0.849	0.865	0.845	8.29	1.50	1.49	1.46	1.95	8.348	7.961	8.064	0.0791
HAP1-172A	3.970	3.942	3.956	38.81	7.26	7.56	7.41	9.88	16.420	19.990	18.205	0.1786
HAP2-172A	5.087	4.969	5.028	49.32	8.91	8.90	8.91	11.87	26.110	24.590	25.350	0.2487
HAP3-172A	4.050	4.452	4.251	41.70	7.37	7.48	7.43	9.90	18.970	19.390	19.180	0.1882
HAP4-172A	4.434	4.360	4.397	43.13	8.19	7.84	8.02	10.69	22.240	17.790	20.015	0.1963
HAP5-172A	4.325	4.361	4.343	42.60	7.73	8.24	7.99	10.65	23.790	20.530	22.160	0.2174
HAP1-172B	3.940	3.772	3.856	37.83	8.36	7.82	8.09	10.79	15.020	14.170	14.595	0.1432
HAP2-172B	2.745	2.429	2.587	25.38	6.44	5.99	6.22	8.29	10.030	9.737	9.884	0.0970
HAP3-172B	3.561	3.164	3.363	32.99	6.58	5.78	6.18	8.24	11.410	10.390	10.900	0.1069
HAP4-172B	3.004	2.882	2.943	28.87	6.43	5.79	6.11	8.15	10.240	8.534	9.387	0.0921
HAP5-172B	2.609	2.442	2.526	24.78	5.24	5.18	5.21	6.95	8.772	7.207	7.990	0.0784
HAP1-172C	3.097	3.327	3.212	31.51	4.87	5.40	5.14	6.85	9.082	9.935	9.509	0.0933
HAP2-172C	3.941	3.843	3.892	38.18	6.68	6.74	6.71	8.95	12.900	13.420	13.160	0.1291
HAP3-172C	3.254	3.561	3.408	33.43	5.91	6.52	6.22	8.29	10.010	12.040	11.025	0.1082
HAP4-172C	3.603	3.745	3.674	36.04	6.93	6.92	6.93	9.23	13.740	13.080	13.410	0.1316
HAP5-172C	3.364	3.493	3.429	33.63	6.36	5.96	6.16	8.21	11.130	11.600	11.365	0.1115
MEAN	3.666	3.649	3.658	35.88	6.88	6.81	6.85	9.13	14.658	14.160	14.409	0.1414
ST.DEV.	0.678	0.730	0.695	6.82	1.12	1.13	1.10	1.47	5.664	5.129	5.311	0.0521

Table B4a. Colour Change, Stiffness, and Peel Strength Data for Habutae-Lascaux-Silk Crepeline Samples

Specimen	Colour Change				Overhang(cm)		Flex. Rigidity (mg-cm)			Peel Strength(mN/mm)			Add-on
	DL*	Da*	Db*	DE	a	b	a	b	ave	a	b	ave	(g/m2)
HLS1-0A	-0.01	0.00	-0.01	0.01	5.85	5.83	121	120	120	54.0	53.3	53.7	3.22
HLS2-0A	-0.08	0.03	-0.08	0.12	5.78	5.90	117	124	120	45.6	53.5	49.6	3.11
HLS3-0A	-0.02	0.03	-0.04	0.05	5.83	5.75	120	115	117	52.4	48.0	50.2	3.01
HLS4-0A	0.22	-0.06	0.05	0.23	5.78	5.80	117	118	117	47.3	59.0	53.1	3.51
HLS5-0A	0.00	0.01	0.01	0.01	5.58	5.83	105	120	112	46.3	43.8	45.1	2.97
HLS1-0B	-0.11	0.04	-0.04	0.12	5.90	5.53	124	102	113	47.8	41.2	44.5	2.93
HLS2-0B	0.20	0.08	0.06	0.22	6.28	6.00	150	131	140	40.4	42.0	41.2	2.75
HLS3-0B	-0.04	-0.05	0.00	0.06	5.80	5.83	118	120	119	54.9	40.0	47.5	3.09
HLS4-0B	-0.17	-0.06	0.02	0.18	5.68	5.63	111	108	109	42.8	33.1	38.0	2.80
HLS5-0B	0.06	0.01	-0.04	0.07	6.13	5.78	139	117	128	57.9	53.4	55.7	3.41
HLS1-0C	-0.07	-0.02	0.01	0.07	6.08	6.00	136	131	133	51.8	36.2	44.0	2.89
HLS2-0C	0.01	0.02	-0.03	0.04	6.55	6.55	170	170	170	39.1	30.7	34.9	2.94
HLS3-0C	0.03	0.02	-0.06	0.07	6.58	6.38	172	157	164	52.3	42.3	47.3	3.26
HLS4-0C	0.01	-0.01	0.01	0.02	6.55	6.63	170	176	173	76.8	55.3	66.0	4.04
HLS5-0C	-0.06	0.01	0.00	0.06	6.35	6.43	155	160	158	53.0	49.1	51.0	3.64
MEAN	0.00	0.00	-0.01	0.09	6.05	5.99	135	131	133	50.8	45.4	48.1	3.17
ST.DEV.	0.10	0.04	0.04	0.07	0.34	0.34	23	23	22	9.0	8.5	7.6	0.35
HLS1-86A	-1.22	0.11	3.66	3.86	6.00	5.95	131	127	129	59.9	62.7	61.3	3.31
HLS2-86A	-1.03	0.01	3.75	3.89	6.23	6.33	146	153	150	53.5	57.6	55.6	3.19
HLS3-86A	-1.27	0.15	3.53	3.75	6.13	6.08	139	136	137	67.0	52.5	59.8	3.11
HLS4-86A	-1.15	0.10	3.63	3.81	6.50	6.18	166	142	154	57.4	60.8	59.1	3.36
HLS5-86A	-1.44	0.09	3.99	4.24	6.18	6.33	142	153	148	69.6	64.1	66.9	3.44
HLS1-86B	-1.47	0.29	3.99	4.26	6.70	6.60	182	174	178	42.1	30.5	36.3	2.74
HLS2-86B	-1.44	0.29	4.30	4.54	7.48	7.53	253	258	255	49.4	39.6	44.5	2.61
HLS3-86B	-1.54	0.29	4.15	4.44	6.55	6.75	170	186	178	59.1	50.3	54.7	3.35
HLS4-86B	-1.18	0.33	3.97	4.15	6.78	6.48	188	164	176	48.0	32.5	40.2	2.66
HLS5-86B	-1.47	0.29	3.87	4.15	6.43	6.48	160	164	162	42.7	33.7	38.2	2.58
HLS1-86C	-1.62	0.28	3.57	3.93	7.65	8.25	271	340	305	60.6	50.8	55.7	3.34
HLS2-86C	-1.56	0.28	3.47	3.81	6.83	7.08	192	214	203	47.5	34.9	41.2	3.09
HLS3-86C	-1.48	0.32	3.17	3.51	7.10	7.18	217	224	220	61.5	48.3	54.9	3.08
HLS4-86C	-1.80	0.32	3.28	3.76	6.78	6.63	188	176	182	38.1	27.9	33.0	2.98
HLS5-86C	-1.71	0.31	3.62	4.02	7.10	7.95	217	304	260	47.9	36.0	41.9	3.03
MEAN	-1.43	0.23	3.73	4.01	6.69	6.78	184	194	189	53.6	45.5	49.6	3.06
ST.DEV.	0.22	0.11	0.32	0.28	0.49	0.68	41	63	51	9.4	12.6	10.6	0.29
HLS1-172A	-1.96	0.33	4.84	5.23	6.33	6.35	153	155	154	60.5	60.4	60.5	3.24
HLS2-172A	-2.03	0.39	4.87	5.29	6.55	6.75	170	186	178	60.8	58.3	59.6	3.24
HLS3-172A	-2.08	0.37	4.92	5.35	6.58	6.68	172	180	176	54.6	60.0	57.3	3.30
HLS4-172A	-1.80	0.33	4.75	5.09	7.43	7.35	248	240	244	63.3	71.9	67.6	3.54
HLS5-172A	-1.80	0.33	4.76	5.10	6.25	6.55	148	170	159	51.7	57.8	54.7	3.15
HLS1-172B	-2.45	0.34	6.05	6.54	8.38	8.00	355	310	333	66.2	57.2	61.7	3.74
HLS2-172B	-2.16	0.36	5.90	6.29	7.35	7.80	240	287	264	78.1	63.7	70.9	3.86
HLS3-172B	-2.09	0.43	5.39	5.80	7.43	7.55	248	260	254	37.0	43.2	40.1	2.43
HLS4-172B	-2.18	0.45	5.63	6.05	7.05	6.95	212	203	208	42.1	33.0	37.6	2.64
HLS5-172B	-2.12	0.37	6.09	6.46	7.73	7.78	279	284	282	56.5	45.6	51.1	3.20
HLS1-172C	-2.35	0.46	4.69	5.27	7.70	7.70	276	276	276	55.8	42.5	49.1	3.25
HLS2-172C	-2.22	0.47	4.48	5.02	8.23	7.80	337	287	312	39.5	31.5	35.5	3.16
HLS3-172C	-2.26	0.46	4.64	5.18	8.05	7.93	316	301	308	47.9	35.0	41.4	2.82
HLS4-172C	-2.32	0.43	4.70	5.26	7.75	7.58	282	263	272	48.3	34.8	41.5	3.11
HLS5-172C	-2.26	0.48	4.60	5.15	7.70	7.58	276	263	270	53.1	48.9	51.0	2.97
MEAN	-2.14	0.40	5.09	5.54	7.37	7.36	247	244	246	54.4	49.6	52.0	3.18
ST.DEV.	0.19	0.06	0.56	0.54	0.68	0.55	65	52	58	10.8	12.7	11.1	0.37

Table B4b. Tensile Data for Habutae-Lascaux-Silk Crepeline Samples

Specimen	Tensile Strength (kg/N)				Elongation (mm)			Extension	Energy to Rupture (kgf-mm/N-m)			
	a	b	ave	ave (N)	a	b	ave	%	a	b	ave	ave (Nm)
HLS1-0A	7.842	8.115	7.979	78.27	16.52	16.93	16.73	22.30	71.410	81.680	76.545	0.7509
HLS2-0A	7.546	7.519	7.533	73.89	15.16	16.46	15.81	21.08	64.480	72.890	68.685	0.6738
HLS3-0A	7.297	6.907	7.102	69.67	16.03	12.84	14.44	19.25	67.600	48.720	58.160	0.5705
HLS4-0A	7.723	7.879	7.801	76.53	15.55	15.34	15.45	20.59	68.920	68.320	68.620	0.6732
HLS5-0A	7.699	7.960	7.830	76.81	16.62	16.73	16.68	22.23	76.530	81.100	78.815	0.7732
HLS1-0B	6.803	6.580	6.692	65.64	14.70	14.96	14.83	19.77	55.400	54.780	55.090	0.5404
HLS2-0B	6.757	7.025	6.891	67.60	13.08	14.52	13.80	18.40	50.290	59.300	54.795	0.5375
HLS3-0B	6.931	7.157	7.044	69.10	15.62	16.87	16.25	21.66	63.760	70.420	67.090	0.6582
HLS4-0B	7.549	7.460	7.505	73.62	18.00	17.84	17.92	23.89	77.260	74.840	76.050	0.7461
HLS5-0B	6.400	5.812	6.106	59.90	13.32	13.08	13.20	17.60	46.980	44.750	45.865	0.4499
HLS1-0C	7.232	7.109	7.171	70.34	16.41	16.12	16.27	21.69	68.040	66.820	67.430	0.6615
HLS2-0C	6.357	7.246	6.802	66.72	11.73	13.79	12.76	17.01	45.140	56.640	50.890	0.4992
HLS3-0C	7.374	6.974	7.174	70.38	15.18	13.64	14.41	19.21	65.630	53.290	59.460	0.5833
HLS4-0C	7.893	7.860	7.877	77.27	15.29	15.60	15.45	20.59	72.170	71.580	71.875	0.7051
HLS5-0C	7.385	6.942	7.164	70.27	14.49	14.09	14.29	19.05	58.910	55.140	57.025	0.5594
MEAN	7.253	7.236	7.244	71.07	15.18	15.25	15.22	20.29	63.501	64.018	63.760	0.6255
ST.DEV.	0.498	0.599	0.517	5.07	1.58	1.56	1.43	1.91	10.143	11.605	10.057	0.0987
HLS1-86A	4.980	5.718	5.349	52.47	9.31	11.03	10.17	13.56	27.520	31.100	29.310	0.2875
HLS2-86A	5.256	5.903	5.580	54.73	9.64	10.89	10.27	13.69	25.150	33.330	29.240	0.2868
HLS3-86A	5.820	5.807	5.814	57.03	11.62	11.21	11.42	15.22	34.810	32.700	33.755	0.3311
HLS4-86A	5.356	5.648	5.502	53.97	9.40	9.72	9.56	12.75	23.940	27.450	25.695	0.2521
HLS5-86A	5.654	5.535	5.595	54.88	10.34	10.16	10.25	13.67	27.780	26.350	27.065	0.2655
HLS1-86B	4.436	4.537	4.487	44.01	9.10	9.17	9.14	12.18	18.980	19.540	19.260	0.1889
HLS2-86B	5.138	5.087	5.113	50.15	9.64	9.34	9.49	12.65	25.810	24.600	25.205	0.2473
HLS3-86B	4.444	4.784	4.614	45.26	8.81	10.20	9.51	12.67	18.880	23.460	21.170	0.2077
HLS4-86B	4.478	4.851	4.665	45.76	8.57	9.21	8.89	11.85	18.800	21.420	20.110	0.1973
HLS5-86B	4.411	4.578	4.495	44.09	8.82	8.96	8.89	11.85	20.120	21.340	20.730	0.2034
HLS1-86C	5.519	4.889	5.204	51.05	9.43	8.42	8.93	11.90	26.010	22.960	24.485	0.2402
HLS2-86C	4.573	3.868	4.221	41.40	7.66	6.59	7.13	9.50	17.040	13.650	15.345	0.1505
HLS3-86C	5.087	5.391	5.239	51.39	8.18	9.30	8.74	11.65	20.840	24.630	22.735	0.2230
HLS4-86C	5.060	4.988	5.024	49.29	9.32	9.47	9.40	12.53	22.460	23.260	22.860	0.2243
HLS5-86C	5.111	5.570	5.341	52.39	8.63	9.56	9.10	12.13	21.760	27.980	24.870	0.2440
MEAN	5.022	5.144	5.083	49.86	9.23	9.55	9.39	12.52	23.327	24.918	24.122	0.2366
ST.DEV.	0.465	0.574	0.481	4.72	0.93	1.14	0.95	1.27	4.665	5.191	4.625	0.0454
HLS1-172A	3.565	3.680	3.623	35.54	6.33	6.60	6.47	8.62	9.508	10.410	9.959	0.0977
HLS2-172A	3.564	3.809	3.687	36.16	7.43	7.28	7.36	9.81	12.080	11.850	11.965	0.1174
HLS3-172A	3.079	3.227	3.153	30.93	6.50	6.58	6.54	8.72	9.266	9.409	9.338	0.0916
HLS4-172A	3.925	3.958	3.942	38.67	6.62	6.77	6.70	8.93	11.800	12.110	11.955	0.1173
HLS5-172A	3.325	3.362	3.344	32.80	6.24	6.09	6.17	8.22	10.270	9.992	10.131	0.0994
HLS1-172B	3.209	2.702	2.956	28.99	6.34	7.01	6.68	8.90	8.811	9.866	9.339	0.0916
HLS2-172B	2.907	3.315	3.111	30.52	6.24	6.52	6.38	8.51	8.502	8.846	8.674	0.0851
HLS3-172B	3.593	3.338	3.466	34.00	7.16	6.41	6.79	9.05	10.660	8.874	9.767	0.0958
HLS4-172B	3.138	3.486	3.312	32.49	6.81	6.68	6.75	8.99	8.779	9.389	9.084	0.0891
HLS5-172B	3.260	3.080	3.170	31.10	6.00	5.96	5.98	7.97	8.000	7.036	7.518	0.0738
HLS1-172C	3.350	3.801	3.576	35.08	5.18	5.83	5.51	7.34	7.352	9.385	8.369	0.0821
HLS2-172C	3.566	3.634	3.600	35.32	5.08	5.48	5.28	7.04	8.371	9.101	8.736	0.0857
HLS3-172C	3.726	3.580	3.653	35.84	5.55	5.13	5.34	7.12	9.003	8.492	8.748	0.0858
HLS4-172C	3.318	3.725	3.522	34.55	5.86	6.30	6.08	8.11	8.665	10.160	9.413	0.0923
HLS5-172C	3.062	3.203	3.133	30.73	5.04	5.22	5.13	6.84	7.203	7.071	7.137	0.0700
MEAN	3.372	3.460	3.416	33.51	6.16	6.26	6.21	8.28	9.218	9.466	9.342	0.0916
ST.DEV.	0.279	0.331	0.274	2.69	0.72	0.63	0.65	0.87	1.442	1.413	1.343	0.0132

Table B5a. Colour Change, Stiffness, and Peel Strength Data for Habutae-Lascaux-Polyester Crepeline Samples

Specimen	Colour Change				Overhang(cm)		Flex. Rigidity (mg-cm)			Peel Strength(mN/mm)			Add-on
	DL*	Da*	Db*	DE	a	b	a	b	ave	a	b	ave	(g/m2)
HLP1-0A	-0.07	0.02	0.07	0.10	6.05	5.93	145	136	140	42.3	37.1	39.7	2.28
HLP2-0A	0.04	-0.01	-0.05	0.06	6.13	6.20	150	156	153	63.8	68.9	66.4	3.11
HLP3-0A	0.17	-0.02	-0.05	0.18	6.23	6.50	158	179	168	78.4	70.6	74.5	3.40
HLP4-0A	0.00	-0.02	-0.01	0.02	6.03	6.13	143	150	146	59.3	54.1	56.7	2.69
HLP5-0A	0.03	0.01	0.00	0.03	6.20	6.25	156	159	158	64.9	57.1	61.0	2.84
HLP1-0B	0.01	0.01	-0.05	0.05	6.78	7.03	203	226	215	58.2	47.1	52.6	3.21
HLP2-0B	0.02	0.00	0.00	0.02	6.68	6.63	194	190	192	69.2	57.9	63.6	3.44
HLP3-0B	0.13	0.03	-0.02	0.13	7.03	7.10	226	234	230	63.4	56.7	60.0	3.41
HLP4-0B	-0.26	-0.02	0.03	0.26	6.85	6.33	210	165	188	56.9	36.4	46.7	2.87
HLP5-0B	0.15	0.03	0.04	0.16	7.08	6.93	231	217	224	50.3	37.7	44.0	2.86
HLP1-0C	-0.07	-0.02	0.07	0.10	6.83	6.98	208	222	215	59.3	40.3	49.8	2.50
HLP2-0C	-0.04	0.00	0.01	0.04	7.00	6.85	224	210	217	35.9	42.1	39.0	2.57
HLP3-0C	-0.08	0.00	-0.06	0.10	6.75	7.03	201	226	214	37.9	30.1	34.0	2.21
HLP4-0C	0.11	0.03	-0.05	0.12	7.10	6.83	234	208	221	52.3	34.5	43.4	2.71
HLP5-0C	0.00	-0.01	0.01	0.01	7.05	6.75	229	201	215	52.7	42.6	47.6	3.14
MEAN	0.01	0.00	0.00	0.09	6.65	6.63	194	192	193	56.3	47.5	51.9	2.88
ST.DEV.	0.11	0.02	0.04	0.07	0.41	0.38	34	32	32	11.6	12.6	11.5	0.40
HLP1-86A	-1.43	-0.10	4.04	4.29	6.30	6.55	163	183	173	58.1	74.5	66.3	2.92
HLP2-86A	-1.44	-0.12	4.26	4.50	6.73	6.68	199	194	196	88.2	72.2	80.2	3.41
HLP3-86A	-1.40	-0.14	4.25	4.48	6.43	6.68	173	194	184	56.3	51.9	54.1	2.55
HLP4-86A	-1.50	-0.13	4.25	4.51	6.90	6.70	215	196	205	68.6	68.2	68.4	2.91
HLP5-86A	-1.36	-0.18	4.23	4.45	6.95	6.60	219	188	203	55.8	63.2	59.5	2.84
HLP1-86B	-2.05	0.03	5.12	5.52	6.93	7.00	217	224	220	50.6	36.7	43.7	2.74
HLP2-86B	-1.79	0.08	4.79	5.11	7.58	7.38	284	262	273	68.4	57.5	62.9	3.36
HLP3-86B	-1.68	0.16	4.52	4.82	7.48	6.95	273	219	246	54.0	39.5	46.8	2.48
HLP4-86B	-1.88	0.11	4.78	5.14	7.53	7.48	278	273	275	56.2	36.8	46.5	2.55
HLP5-86B	-1.97	0.04	5.15	5.51	7.10	7.33	234	257	245	55.1	68.0	61.6	3.21
HLP1-86C	-2.00	0.10	4.38	4.82	7.13	6.98	236	222	229	49.8	39.4	44.6	2.29
HLP2-86C	-1.87	0.14	4.29	4.68	7.33	7.10	257	234	245	57.6	46.6	52.1	3.36
HLP3-86C	-1.96	0.11	4.31	4.74	7.10	7.03	234	226	230	67.2	62.1	64.6	3.21
HLP4-86C	-1.88	0.13	4.26	4.66	7.25	7.30	249	254	251	74.4	54.5	64.5	2.94
HLP5-86C	-1.95	0.15	4.17	4.61	6.80	6.83	205	208	206	58.1	47.8	53.0	2.64
MEAN	-1.74	0.03	4.45	4.79	7.03	6.97	229	222	226	61.2	54.6	57.9	2.89
ST.DEV.	0.25	0.12	0.34	0.38	0.38	0.30	36	29	31	10.3	13.2	10.4	0.36
HLP1-172A	-2.43	0.21	5.48	6.00	7.10	6.93	234	217	225	56.1	60.4	58.2	2.53
HLP2-172A	-2.27	0.15	5.55	6.00	7.33	7.43	257	267	262	63.2	50.9	57.0	2.61
HLP3-172A	-2.44	0.25	5.33	5.87	6.70	6.88	196	212	204	63.7	61.4	62.5	2.91
HLP4-172A	-2.37	0.19	5.50	5.99	6.73	6.73	199	199	199	71.4	73.1	72.2	3.02
HLP5-172A	-2.44	0.16	5.66	6.17	6.93	6.98	217	222	219	46.9	60.9	53.9	2.79
HLP1-172B	-2.56	0.17	6.35	6.85	7.53	7.10	278	234	256	56.5	42.4	49.4	2.59
HLP2-172B	-2.59	0.18	6.40	6.91	7.78	7.63	307	289	298	69.3	51.1	60.2	3.29
HLP3-172B	-2.85	0.13	6.57	7.16	7.50	7.43	275	267	271	61.5	51.3	56.4	3.17
HLP4-172B	-2.70	0.13	6.53	7.07	7.33	7.30	257	254	255	52.4	43.4	47.9	2.69
HLP5-172B	-2.63	0.16	6.31	6.84	7.30	7.28	254	251	253	63.1	54.1	58.6	2.94
HLP1-172C	-2.84	0.23	5.91	6.56	7.03	7.23	226	246	236	62.5	68.2	65.4	3.00
HLP2-172C	-2.61	0.27	5.76	6.33	7.83	7.93	313	325	319	74.7	55.6	65.2	3.19
HLP3-172C	-2.51	0.33	5.54	6.09	8.28	8.45	370	394	382	64.0	43.5	53.8	3.06
HLP4-172C	-2.71	0.29	5.73	6.35	7.75	7.53	304	278	291	71.8	68.6	70.2	3.14
HLP5-172C	-2.59	0.30	5.84	6.40	8.13	8.18	350	357	354	59.9	41.3	50.6	2.64
MEAN	-2.57	0.21	5.90	6.44	7.41	7.40	269	268	268	62.5	55.1	58.8	2.90
ST.DEV.	0.16	0.06	0.42	0.43	0.48	0.49	52	55	53	7.5	10.2	7.3	0.25

Table B5b. Tensile Data for Habutae-Lascaux-Polyester Crepeline Samples

Specimen	Tensile Strength (kg/N)				Elongation (mm)			Extension	Energy to Rupture (kgf-mm/N-m)			
	a	b	ave	ave (N)	a	b	ave	%	a	b	ave	ave (Nm)
HLP1-0A	8.515	8.389	8.452	82.91	17.92	17.68	17.80	23.73	84.200	83.000	83.600	0.8201
HLP2-0A	8.897	8.851	8.874	87.05	18.01	17.72	17.87	23.82	91.860	90.330	91.095	0.8936
HLP3-0A	8.335	8.357	8.346	81.87	16.56	16.53	16.55	22.06	78.300	77.150	77.725	0.7625
HLP4-0A	8.961	8.279	8.620	84.56	16.11	17.13	16.62	22.16	75.880	80.990	78.435	0.7694
HLP5-0A	8.612	8.945	8.779	86.12	16.69	17.58	17.14	22.85	79.730	90.490	85.110	0.8349
HLP1-0B	8.105	7.989	8.047	78.94	17.92	16.01	16.97	22.62	76.800	71.550	74.175	0.7277
HLP2-0B	7.546	7.697	7.622	74.77	15.32	14.75	15.04	20.05	57.750	56.450	57.100	0.5602
HLP3-0B	8.601	8.335	8.468	83.07	18.52	17.30	17.91	23.88	88.160	78.700	83.430	0.8184
HLP4-0B	7.766	7.705	7.736	75.89	16.45	16.26	16.36	21.81	65.410	66.710	66.060	0.6480
HLP5-0B	7.135	6.642	6.889	67.58	13.59	13.17	13.38	17.84	52.650	52.720	52.685	0.5168
HLP1-0C	8.819	9.066	8.943	87.73	18.53	18.67	18.60	24.80	90.000	91.840	90.920	0.8919
HLP2-0C	8.483	8.588	8.536	83.73	18.19	18.06	18.13	24.17	85.950	86.790	86.370	0.8473
HLP3-0C	8.037	7.318	7.678	75.32	15.86	16.39	16.13	21.50	66.150	66.250	66.200	0.6494
HLP4-0C	8.142	8.497	8.320	81.61	16.58	17.12	16.85	22.47	71.920	78.940	75.430	0.7400
HLP5-0C	8.217	8.182	8.200	80.44	16.44	16.86	16.65	22.20	71.980	74.400	73.190	0.7180
MEAN	8.278	8.189	8.234	80.77	16.85	16.75	16.80	22.40	75.783	76.421	76.102	0.7466
ST.DEV.	0.512	0.644	0.557	5.47	1.36	1.37	1.31	1.75	11.653	11.949	11.557	0.1134
HLP1-86A	5.882	5.643	5.763	56.53	11.11	10.45	10.78	14.37	31.090	27.720	29.405	0.2885
HLP2-86A	7.195	6.596	6.896	67.64	12.84	12.26	12.55	16.73	45.610	39.390	42.500	0.4169
HLP3-86A	5.562	5.699	5.631	55.24	10.28	9.89	10.09	13.45	29.460	30.500	29.980	0.2941
HLP4-86A	7.087	6.872	6.980	68.47	13.40	13.14	13.27	17.69	49.210	44.210	46.710	0.4582
HLP5-86A	5.893	5.605	5.749	56.40	10.76	10.08	10.42	13.89	30.480	28.230	29.355	0.2880
HLP1-86B	5.552	5.326	5.439	53.36	10.70	10.10	10.40	13.87	26.630	24.780	25.705	0.2522
HLP2-86B	4.867	4.832	4.850	47.57	9.63	9.36	9.50	12.66	20.810	20.040	20.425	0.2004
HLP3-86B	4.601	4.412	4.507	44.21	9.30	8.73	9.02	12.02	24.300	24.370	24.335	0.2387
HLP4-86B	5.246	4.778	5.012	49.17	10.54	9.82	10.18	13.57	25.750	27.330	26.540	0.2604
HLP5-86B	4.331	4.366	4.349	42.66	8.46	8.15	8.31	11.07	22.710	21.020	21.865	0.2145
HLP1-86C	4.640	5.544	5.092	49.95	9.23	10.84	10.04	13.38	20.610	28.590	24.600	0.2413
HLP2-86C	5.850	5.342	5.596	54.90	10.66	10.56	10.61	14.15	29.920	27.800	28.860	0.2831
HLP3-86C	5.933	5.807	5.870	57.58	11.63	11.41	11.52	15.36	33.230	31.600	32.415	0.3180
HLP4-86C	5.791	6.086	5.939	58.26	10.52	10.58	10.55	14.07	28.680	30.930	29.805	0.2924
HLP5-86C	5.519	5.256	5.388	52.85	10.46	10.22	10.34	13.79	27.420	27.040	27.230	0.2671
MEAN	5.597	5.478	5.537	54.32	10.63	10.37	10.50	14.00	29.727	28.903	29.315	0.2876
ST.DEV.	0.816	0.714	0.744	7.30	1.29	1.25	1.24	1.66	8.106	6.243	7.039	0.0690
HLP1-172A	3.773	3.566	3.670	36.00	6.89	6.90	6.90	9.19	15.520	15.270	15.395	0.1510
HLP2-172A	3.758	3.297	3.528	34.60	6.48	5.50	5.99	7.99	14.120	11.960	13.040	0.1279
HLP3-172A	4.527	4.322	4.425	43.40	7.99	7.94	7.97	10.62	16.170	15.680	15.925	0.1562
HLP4-172A	4.370	4.280	4.325	42.43	8.11	7.81	7.96	10.61	15.030	15.000	15.015	0.1473
HLP5-172A	4.040	3.726	3.883	38.09	7.01	7.19	7.10	9.47	14.300	12.220	13.260	0.1301
HLP1-172B	3.243	3.078	3.161	31.00	6.54	6.19	6.37	8.49	9.406	11.280	10.343	0.1015
HLP2-172B	3.761	3.876	3.819	37.46	6.98	7.11	7.05	9.39	14.240	13.350	13.795	0.1353
HLP3-172B	3.436	2.969	3.203	31.42	7.57	6.77	7.17	9.56	11.330	11.340	11.335	0.1112
HLP4-172B	3.588	3.240	3.414	33.49	7.00	6.38	6.69	8.92	12.990	12.020	12.505	0.1227
HLP5-172B	3.083	3.216	3.150	30.90	6.92	6.75	6.84	9.11	9.607	11.410	10.509	0.1031
HLP1-172C	3.941	3.909	3.925	38.50	7.50	7.45	7.48	9.97	14.090	13.960	14.025	0.1376
HLP2-172C	3.601	3.843	3.722	36.51	5.97	6.48	6.23	8.30	10.410	11.700	11.055	0.1084
HLP3-172C	4.063	4.321	4.192	41.12	6.54	6.59	6.57	8.75	13.400	14.130	13.765	0.1350
HLP4-172C	3.764	3.832	3.798	37.26	6.79	7.03	6.91	9.21	12.140	12.420	12.280	0.1205
HLP5-172C	3.322	3.326	3.324	32.61	5.40	5.45	5.43	7.23	10.130	9.624	9.877	0.0969
MEAN	3.751	3.653	3.702	36.32	6.91	6.77	6.84	9.12	12.859	12.758	12.808	0.1256
ST.DEV.	0.400	0.453	0.411	4.03	0.71	0.72	0.69	0.91	2.219	1.734	1.899	0.0186

Table B6a. Colour Change and Stiffness Data for Appretan-Silk Crepeline Samples

Specimen	Colour Change				Overhang(cm)		Flex. Rigidity (mg-cm)			Add-on
	DL*	Da*	Db*	DE	a	b	a	b	ave	(g/m2)
AS1-0A	0.03	-0.02	-0.01	0.04	6.18	6.38	34	37	36	2.59
AS2-0A	0.01	0.00	-0.02	0.02	6.18	5.83	34	29	31	2.94
AS3-0A	0.04	-0.01	-0.01	0.04	5.93	6.10	30	33	31	2.79
AS4-0A	0.01	-0.01	0.00	0.01	5.95	6.05	30	32	31	3.34
AS5-0A	0.04	-0.02	-0.01	0.05	5.78	5.95	28	30	29	3.40
AS1-0B	0.01	0.01	-0.03	0.03	5.63	5.73	26	27	26	2.91
AS2-0B	0.01	-0.05	0.03	0.06	5.58	5.58	25	25	25	2.65
AS3-0B	-0.03	-0.02	-0.01	0.04	5.65	5.58	26	25	25	2.71
AS4-0B	0.02	-0.01	-0.01	0.02	5.55	5.48	25	24	24	3.16
AS5-0B	0.00	-0.02	-0.01	0.02	5.88	5.83	29	29	29	3.04
AS1-0C	0.02	0.00	0.00	0.02	6.00	5.80	31	28	30	3.24
AS2-0C	-0.01	0.00	0.00	0.01	5.63	5.88	26	29	27	3.26
AS3-0C	-0.01	0.02	-0.03	0.04	5.48	5.55	24	25	24	2.91
AS4-0C	-0.03	0.01	-0.03	0.04	5.75	5.83	27	29	28	3.53
AS5-0C	-0.07	0.00	-0.02	0.07	5.65	5.65	26	26	26	3.75
MEAN	0.00	-0.01	-0.01	0.03	5.79	5.81	28	28	28	3.08
ST.DEV.	0.03	0.02	0.02	0.02	0.22	0.24	3	4	3	0.34
AS1-86A	0.08	-0.12	1.29	1.30	5.98	5.98	31	31	31	3.11
AS2-86A	0.07	-0.13	1.35	1.36	5.85	5.90	29	30	29	3.64
AS3-86A	0.04	-0.11	1.31	1.32	5.93	5.93	30	30	30	2.50
AS4-86A	0.02	-0.11	1.32	1.32	5.78	5.85	28	29	28	3.29
AS5-86A	0.04	-0.13	1.32	1.33	5.95	6.08	30	32	31	3.27
AS1-86B	0.24	0.01	1.64	1.66	5.93	5.93	30	30	30	2.59
AS2-86B	0.20	0.00	1.65	1.66	6.00	6.00	31	31	31	2.79
AS3-86B	0.18	0.03	1.63	1.64	5.80	5.78	28	28	28	2.66
AS4-86B	0.20	-0.01	1.64	1.65	5.88	5.83	29	29	29	2.96
AS5-86B	0.25	-0.01	1.64	1.66	5.85	5.93	29	30	29	2.71
AS1-86C	-0.34	0.25	0.99	1.08	5.88	5.90	29	30	29	3.15
AS2-86C	-0.35	0.26	1.00	1.09	5.83	5.80	29	28	28	2.99
AS3-86C	-0.34	0.25	0.96	1.05	5.73	5.68	27	26	27	3.11
AS4-86C	-0.35	0.26	0.95	1.05	5.65	5.85	26	29	27	3.04
AS5-86C	-0.32	0.24	0.96	1.04	5.95	5.95	30	30	30	2.86
MEAN	-0.03	0.05	1.31	1.35	5.86	5.89	29	29	29	2.98
ST.DEV.	0.24	0.16	0.28	0.25	0.10	0.10	1	1	1	0.30
AS1-172A	-0.12	-0.19	1.98	1.99	5.88	6.00	29	31	30	2.75
AS2-172A	-0.15	-0.18	2.02	2.03	5.78	5.73	28	27	27	3.18
AS3-172A	-0.09	-0.17	2.01	2.02	5.90	5.85	30	29	29	3.10
AS4-172A	-0.03	-0.19	2.04	2.05	5.98	6.10	31	33	32	3.00
AS5-172A	-0.11	-0.18	2.00	2.01	5.88	6.03	29	32	30	2.95
AS1-172B	-0.03	-0.13	2.86	2.86	6.03	6.05	32	32	32	2.79
AS2-172B	-0.07	-0.11	2.88	2.88	5.88	5.85	29	29	29	3.21
AS3-172B	-0.04	-0.12	2.91	2.91	5.95	6.08	30	32	31	3.10
AS4-172B	-0.04	-0.11	2.87	2.87	5.80	5.88	28	29	29	3.32
AS5-172B	-0.03	-0.12	2.87	2.87	5.98	5.83	31	29	30	2.99
AS1-172C	-0.37	0.10	2.26	2.29	6.15	6.28	34	36	35	4.01
AS2-172C	-0.66	0.15	2.23	2.33	5.85	5.90	29	30	29	3.01
AS3-172C	-0.41	0.09	2.22	2.26	6.08	6.08	32	32	32	3.01
AS4-172C	-0.62	0.15	2.22	2.31	5.85	6.03	29	32	30	3.36
AS5-172C	-0.42	0.09	2.24	2.28	5.78	5.78	28	28	28	3.32
MEAN	-0.21	-0.06	2.37	2.40	5.92	5.96	30	31	30	3.14
ST.DEV.	0.22	0.13	0.38	0.37	0.11	0.15	2	2	2	0.30

Table B6b. Tensile Data for Appretan-Silk Crepeline Samples

Specimen	Tensile Strength (kg/N)				Elongation (mm)			Extension	Energy to Rupture (kgf-mm/N-m)			
	a	b	ave	ave (N)	a	b	ave	%	a	b	ave	ave (Nm)
AS1-0A	1.560	1.548	1.554	15.24	15.79	14.58	15.19	20.25	18.870	17.900	18.385	0.1804
AS2-0A	1.601	1.513	1.557	15.27	14.43	14.40	14.42	19.22	18.280	16.720	17.500	0.1717
AS3-0A	1.648	1.466	1.557	15.27	16.01	14.59	15.30	20.40	19.600	16.240	17.920	0.1758
AS4-0A	1.671	1.748	1.710	16.77	14.85	15.06	14.96	19.94	21.860	20.250	21.055	0.2065
AS5-0A	1.515	1.644	1.580	15.49	15.43	16.39	15.91	21.21	18.190	19.880	19.035	0.1867
AS1-0B	1.553	1.540	1.547	15.17	15.76	15.95	15.86	21.14	17.870	18.650	18.260	0.1791
AS2-0B	1.436	1.541	1.489	14.60	14.85	15.25	15.05	20.07	16.320	18.210	17.265	0.1694
AS3-0B	1.643	1.510	1.577	15.47	16.50	15.30	15.90	21.20	19.680	18.890	19.285	0.1892
AS4-0B	1.584	1.595	1.590	15.59	15.44	16.49	15.97	21.29	18.810	19.100	18.955	0.1859
AS5-0B	1.533	1.574	1.554	15.24	14.42	14.24	14.33	19.11	18.240	19.110	18.675	0.1832
AS1-0C	1.558	1.560	1.559	15.29	13.71	15.04	14.38	19.17	18.290	18.220	18.255	0.1791
AS2-0C	1.478	1.650	1.564	15.34	13.66	15.19	14.43	19.23	15.610	18.980	17.295	0.1697
AS3-0C	1.584	1.601	1.593	15.62	15.37	15.74	15.56	20.74	17.980	18.520	18.250	0.1790
AS4-0C	1.553	1.584	1.569	15.39	14.64	14.95	14.80	19.73	17.330	17.630	17.480	0.1715
AS5-0C	1.545	1.523	1.534	15.05	14.66	14.11	14.39	19.18	17.120	16.210	16.665	0.1635
MEAN	1.564	1.573	1.569	15.39	15.03	15.15	15.09	20.12	18.270	18.301	18.285	0.1794
ST.DEV.	0.063	0.069	0.046	0.45	0.82	0.73	0.63	0.84	1.479	1.204	1.065	0.0105
AS1-86A	0.812	0.952	0.882	8.65	3.86	5.77	4.82	6.42	2.796	4.306	3.551	0.0348
AS2-86A	1.003	0.879	0.941	9.23	6.14	4.49	5.32	7.09	3.918	2.935	3.427	0.0336
AS3-86A	1.043	0.952	0.997	9.78	6.43	5.99	6.21	8.28	4.914	4.123	4.519	0.0443
AS4-86A	0.874	0.934	0.904	8.87	4.96	5.43	5.20	6.93	2.910	3.499	3.205	0.0314
AS5-86A	1.101	0.997	1.049	10.29	6.35	5.99	6.17	8.23	4.794	4.121	4.458	0.0437
AS1-86B	0.846	0.980	0.913	8.95	5.64	7.20	6.42	8.56	3.280	4.729	4.005	0.0393
AS2-86B	0.840	0.791	0.815	8.00	5.49	4.53	5.01	6.68	3.254	2.512	2.883	0.0283
AS3-86B	0.879	0.780	0.830	8.14	6.06	4.53	5.30	7.06	3.706	2.383	3.045	0.0299
AS4-86B	0.824	0.894	0.859	8.43	5.00	6.12	5.56	7.41	2.898	3.800	3.349	0.0329
AS5-86B	0.854	0.760	0.807	7.91	6.45	5.96	6.21	8.27	3.904	2.953	3.429	0.0336
AS1-86C	0.843	0.797	0.820	8.05	4.54	4.27	4.41	5.87	3.238	2.665	2.952	0.0290
AS2-86C	0.819	0.777	0.798	7.83	3.84	3.43	3.64	4.85	2.995	2.285	2.640	0.0259
AS3-86C	0.817	0.936	0.877	8.60	4.66	5.88	5.27	7.03	2.847	3.740	3.294	0.0323
AS4-86C	0.668	0.813	0.741	7.27	2.84	4.01	3.43	4.57	1.358	2.623	1.991	0.0195
AS5-86C	0.714	0.866	0.790	7.75	2.87	4.39	3.63	4.84	2.281	3.028	2.655	0.0260
MEAN	0.863	0.874	0.868	8.52	5.01	5.20	5.10	6.81	3.273	3.313	3.293	0.0323
ST.DEV.	0.113	0.082	0.083	0.81	1.23	1.03	0.98	1.30	0.903	0.782	0.674	0.0066
AS1-172A	0.647	0.603	0.625	6.13	2.79	2.56	2.68	3.57	1.045	0.773	0.909	0.0089
AS2-172A	0.750	0.658	0.704	6.91	4.39	3.42	3.91	5.21	1.836	1.313	1.575	0.0154
AS3-172A	0.646	0.600	0.623	6.11	2.82	2.75	2.79	3.71	0.923	0.838	0.880	0.0086
AS4-172A	0.553	0.675	0.614	6.02	2.16	2.58	2.37	3.16	0.756	1.083	0.919	0.0090
AS5-172A	0.685	0.717	0.701	6.87	2.98	3.43	3.21	4.27	1.063	1.352	1.208	0.0118
AS1-172B	0.600	0.477	0.538	5.28	2.52	1.88	2.20	2.93	0.781	0.466	0.623	0.0061
AS2-172B	0.533	0.423	0.478	4.69	2.29	2.38	2.34	3.11	0.640	0.570	0.605	0.0059
AS3-172B	0.624	0.635	0.630	6.18	2.73	2.74	2.74	3.65	0.882	0.953	0.917	0.0090
AS4-172B	0.506	0.446	0.476	4.67	2.34	2.01	2.18	2.90	0.640	0.675	0.657	0.0064
AS5-172B	0.485	0.622	0.553	5.43	2.05	2.75	2.40	3.20	0.472	0.820	0.646	0.0063
AS1-172C	0.648	0.577	0.613	6.01	2.45	1.82	2.14	2.85	0.903	0.701	0.802	0.0079
AS2-172C	0.487	0.540	0.513	5.04	1.79	2.12	1.96	2.61	0.535	0.630	0.582	0.0057
AS3-172C	0.580	0.475	0.528	5.18	1.98	1.89	1.94	2.58	0.680	0.668	0.674	0.0066
AS4-172C	0.530	0.557	0.544	5.33	1.82	2.10	1.96	2.61	0.576	0.741	0.658	0.0065
AS5-172C	0.483	0.450	0.466	4.58	1.79	1.77	1.78	2.37	0.601	0.426	0.514	0.0050
MEAN	0.584	0.563	0.574	5.63	2.46	2.41	2.44	3.25	0.822	0.801	0.811	0.0080
ST.DEV.	0.082	0.092	0.077	0.76	0.66	0.54	0.56	0.75	0.334	0.274	0.279	0.0027

Table B7a. Colour Change and Stiffness Data for Appretan-Polyester Crepeline Samples

Specimen	Colour Change				Overhang(cm)		Flex. Rigidity (mg-cm)			Add-on
	DL*	Da*	Db*	DE	a	b	a	b	ave	(g/m2)
AP1-0A	0.01	-0.01	0.00	0.01	5.08	5.15	24	25	25	3.02
AP2-0A	-0.02	0.00	0.00	0.02	5.00	5.18	23	26	25	3.01
AP3-0A	0.06	-0.01	0.01	0.06	5.80	5.60	36	33	35	2.77
AP4-0A	-0.01	0.01	-0.01	0.02	5.85	5.78	37	36	37	3.09
AP5-0A	-0.01	0.01	-0.01	0.02	5.43	5.15	30	25	28	3.19
AP1-0B	-0.04	0.03	-0.01	0.05	5.48	5.18	31	26	28	2.98
AP2-0B	-0.04	0.00	0.02	0.04	5.43	5.48	30	31	30	2.68
AP3-0B	-0.04	0.00	0.03	0.05	5.70	5.58	35	32	33	2.35
AP4-0B	-0.01	0.01	0.01	0.02	5.58	5.70	32	35	33	2.37
AP5-0B	0.00	0.03	0.00	0.03	5.58	5.53	32	31	32	2.56
AP1-0C	-0.15	0.00	0.00	0.15	5.78	5.30	36	28	32	3.24
AP2-0C	-0.10	0.00	0.01	0.10	5.05	5.08	24	24	24	3.10
AP3-0C	-0.14	-0.01	0.02	0.14	5.68	5.63	34	33	34	3.10
AP4-0C	-0.04	0.00	0.00	0.04	5.45	5.83	30	37	34	3.42
AP5-0C	-0.07	-0.02	-0.01	0.07	5.15	5.35	25	29	27	3.38
MEAN	-0.04	0.00	0.00	0.06	5.47	5.43	31	30	30	2.95
ST.DEV.	0.06	0.01	0.01	0.04	0.28	0.25	5	4	4	0.34
AP1-86A	0.11	0.01	0.02	0.11	6.10	6.10	42	42	42	2.84
AP2-86A	0.12	0.01	0.02	0.12	5.93	6.10	39	42	41	2.84
AP3-86A	0.04	0.03	0.01	0.05	6.35	6.25	48	46	47	2.89
AP4-86A	0.04	0.00	0.01	0.04	6.20	5.85	44	37	41	3.04
AP5-86A	0.01	-0.01	0.04	0.04	6.10	5.78	42	36	39	2.92
AP1-86B	-0.12	-0.03	0.49	0.51	6.00	6.28	40	46	43	3.44
AP2-86B	-0.10	-0.03	0.45	0.46	5.93	6.30	39	47	43	3.11
AP3-86B	-0.17	0.02	0.46	0.49	5.88	5.98	38	40	39	2.94
AP4-86B	-0.25	0.02	0.47	0.53	6.05	6.13	41	43	42	2.34
AP5-86B	-0.21	0.00	0.48	0.52	6.30	6.03	47	41	44	2.37
AP1-86C	-0.08	0.13	0.28	0.32	6.05	5.93	41	39	40	3.09
AP2-86C	-0.19	0.12	0.33	0.40	5.98	5.75	40	35	38	3.27
AP3-86C	-0.20	0.12	0.33	0.40	5.75	6.08	35	42	39	3.16
AP4-86C	-0.26	0.11	0.34	0.44	5.78	5.63	36	33	35	3.42
AP5-86C	-0.21	0.12	0.32	0.40	5.58	5.83	32	37	35	3.15
MEAN	-0.10	0.04	0.27	0.32	6.00	6.00	40	40	40	2.99
ST.DEV.	0.13	0.06	0.19	0.19	0.21	0.20	4	4	3	0.32
AP1-172A	-0.04	0.01	0.09	0.10	6.43	6.20	49	44	47	2.97
AP2-172A	-0.06	-0.01	0.14	0.15	6.40	6.68	49	55	52	2.71
AP3-172A	-0.03	-0.02	0.12	0.13	6.30	5.95	47	39	43	3.16
AP4-172A	-0.01	-0.01	0.11	0.11	6.35	6.23	48	45	46	2.74
AP5-172A	-0.12	-0.02	0.13	0.18	6.38	6.33	48	47	48	2.85
AP1-172B	-0.18	-0.02	0.56	0.59	6.18	6.25	44	46	45	2.70
AP2-172B	-0.19	-0.02	0.61	0.64	6.25	6.13	46	43	44	2.27
AP3-172B	-0.15	-0.02	0.57	0.59	6.70	6.33	56	47	52	2.34
AP4-172B	-0.17	-0.03	0.59	0.61	6.43	6.23	49	45	47	2.52
AP5-172B	-0.19	-0.02	0.59	0.62	6.50	6.33	51	47	49	2.90
AP1-172C	-0.08	0.10	0.08	0.15	6.20	6.15	44	43	44	3.21
AP2-172C	-0.04	0.09	0.06	0.12	6.28	6.35	46	48	47	3.09
AP3-172C	-0.09	0.10	0.09	0.16	6.20	6.23	44	45	45	3.09
AP4-172C	-0.01	0.10	0.06	0.12	6.18	6.53	44	52	48	3.19
AP5-172C	-0.10	0.10	0.08	0.16	6.08	6.30	42	47	44	3.26
MEAN	-0.10	0.02	0.26	0.30	6.32	6.28	47	46	47	2.87
ST.DEV.	0.07	0.06	0.24	0.23	0.16	0.17	4	4	3	0.32

Table B7b. Tensile Data for Appretan-Polyester Crepeline Samples

Specimen	Tensile Strength (kg/N)				Elongation (mm)			Extension	Energy to Rupture (kgf-mm/N-m)			
	a	b	ave	ave (N)	a	b	ave	%	a	b	ave	ave (Nm)
AP1-0A	2.968	2.984	2.976	29.19	20.12	20.16	20.14	26.85	35.240	36.590	35.915	0.3523
AP2-0A	2.956	2.954	2.955	28.99	19.93	19.89	19.91	26.55	37.320	39.560	38.440	0.3771
AP3-0A	2.902	2.981	2.942	28.86	20.92	20.03	20.48	27.30	37.630	37.190	37.410	0.3670
AP4-0A	2.785	2.957	2.871	28.16	19.15	19.28	19.22	25.62	38.920	41.710	40.315	0.3955
AP5-0A	2.930	3.020	2.975	29.18	18.99	21.22	20.11	26.81	37.060	38.310	37.685	0.3697
AP1-0B	2.766	2.733	2.750	26.97	21.35	20.68	21.02	28.02	35.680	37.670	36.675	0.3598
AP2-0B	3.012	3.047	3.030	29.72	21.24	22.14	21.69	28.92	41.000	41.530	41.265	0.4048
AP3-0B	2.946	2.981	2.964	29.07	20.16	20.86	20.51	27.35	40.280	37.300	38.790	0.3805
AP4-0B	2.875	2.995	2.935	28.79	18.15	20.20	19.18	25.57	35.440	36.050	35.745	0.3507
AP5-0B	2.863	2.923	2.893	28.38	17.67	18.88	18.28	24.37	36.790	35.170	35.980	0.3530
AP1-0C	3.031	2.980	3.006	29.48	22.20	20.95	21.58	28.77	41.300	41.440	41.370	0.4058
AP2-0C	2.899	2.867	2.883	28.28	21.43	20.21	20.82	27.76	40.130	38.370	39.250	0.3850
AP3-0C	2.962	2.968	2.965	29.09	20.33	20.13	20.23	26.97	40.600	42.050	41.325	0.4054
AP4-0C	2.921	2.932	2.927	28.71	18.95	19.62	19.29	25.71	32.730	37.470	35.100	0.3443
AP5-0C	2.996	2.973	2.985	29.28	20.69	20.14	20.42	27.22	39.780	36.220	38.000	0.3728
MEAN	2.921	2.953	2.937	28.81	20.09	20.29	20.19	26.92	37.993	38.442	38.218	0.3749
ST.DEV.	0.076	0.074	0.068	0.67	1.29	0.80	0.93	1.24	2.545	2.279	2.142	0.0210
AP1-86A	2.207	2.193	2.200	21.58	13.32	13.06	13.19	17.59	16.300	15.380	15.840	0.1554
AP2-86A	2.338	2.329	2.334	22.89	14.42	13.79	14.11	18.81	18.060	16.900	17.480	0.1715
AP3-86A	2.058	2.279	2.169	21.27	13.37	14.04	13.71	18.27	15.290	16.670	15.980	0.1568
AP4-86A	2.309	2.247	2.278	22.35	13.99	13.85	13.92	18.56	17.150	16.340	16.745	0.1643
AP5-86A	2.256	2.299	2.278	22.34	13.70	13.77	13.74	18.31	16.470	16.790	16.630	0.1631
AP1-86B	2.289	2.344	2.317	22.72	14.28	14.66	14.47	19.29	17.300	18.060	17.680	0.1734
AP2-86B	2.354	2.489	2.422	23.75	14.13	15.10	14.62	19.49	18.900	20.000	19.450	0.1908
AP3-86B	2.302	2.180	2.241	21.98	14.26	13.84	14.05	18.73	17.440	17.550	17.495	0.1716
AP4-86B	2.254	2.262	2.258	22.15	14.34	13.98	14.16	18.88	16.810	16.730	16.770	0.1645
AP5-86B	2.354	2.169	2.262	22.19	14.31	12.99	13.65	18.20	17.560	16.770	17.165	0.1684
AP1-86C	2.490	2.468	2.479	24.32	15.36	14.94	15.15	20.20	20.460	19.910	20.185	0.1980
AP2-86C	2.305	2.330	2.318	22.73	14.19	14.28	14.24	18.98	17.320	17.470	17.395	0.1706
AP3-86C	2.427	2.428	2.428	23.81	15.05	14.95	15.00	20.00	20.120	19.620	19.870	0.1949
AP4-86C	2.377	2.344	2.361	23.16	14.06	13.91	13.99	18.65	17.650	17.210	17.430	0.1710
AP5-86C	2.326	2.358	2.342	22.98	14.29	14.38	14.34	19.11	17.450	18.030	17.740	0.1740
MEAN	2.310	2.315	2.312	22.68	14.20	14.10	14.15	18.87	17.619	17.562	17.590	0.1726
ST.DEV.	0.099	0.098	0.086	0.84	0.53	0.63	0.52	0.69	1.357	1.355	1.300	0.0128
AP1-172A	1.968	2.058	2.013	19.75	12.41	12.46	12.44	16.58	13.300	13.910	13.605	0.1335
AP2-172A	1.868	1.949	1.909	18.72	12.34	12.47	12.41	16.54	12.520	13.140	12.830	0.1259
AP3-172A	2.051	1.973	2.012	19.74	12.70	12.47	12.59	16.78	14.320	13.280	13.800	0.1354
AP4-172A	1.953	1.852	1.903	18.66	12.37	12.21	12.29	16.39	13.360	12.750	13.055	0.1281
AP5-172A	1.821	1.944	1.883	18.47	11.95	12.38	12.17	16.22	12.000	13.010	12.505	0.1227
AP1-172B	2.054	2.097	2.076	20.36	12.98	13.15	13.07	17.42	15.050	14.690	14.870	0.1459
AP2-172B	1.876	1.783	1.830	17.95	11.85	11.44	11.65	15.53	12.320	11.750	12.035	0.1181
AP3-172B	1.964	2.013	1.989	19.51	12.57	12.89	12.73	16.97	14.060	13.960	14.010	0.1374
AP4-172B	1.988	1.934	1.961	19.24	12.53	12.67	12.60	16.80	13.430	13.730	13.580	0.1332
AP5-172B	2.058	1.860	1.959	19.22	12.81	11.88	12.35	16.46	14.150	12.110	13.130	0.1288
AP1-172C	1.966	1.886	1.926	18.89	12.61	11.81	12.21	16.28	13.450	12.530	12.990	0.1274
AP2-172C	2.099	2.137	2.118	20.78	13.38	13.58	13.48	17.97	15.020	15.630	15.325	0.1503
AP3-172C	1.977	1.952	1.965	19.27	12.53	12.17	12.35	16.47	13.540	12.780	13.160	0.1291
AP4-172C	1.950	1.988	1.969	19.32	12.60	12.85	12.73	16.97	13.340	13.900	13.620	0.1336
AP5-172C	1.969	2.071	2.020	19.82	11.93	12.57	12.25	16.33	12.700	13.900	13.300	0.1305
MEAN	1.971	1.966	1.969	19.31	12.50	12.47	12.49	16.65	13.504	13.405	13.454	0.1320
ST.DEV.	0.076	0.098	0.074	0.73	0.40	0.54	0.42	0.56	0.905	1.000	0.841	0.0082

Table B8a. Colour Change and Stiffness Data for Lascaux-Silk Crepeline Samples

Specimen	Colour Change				Overhang(cm)		Flex. Rigidity (mg-cm)			Add-on
	DL*	Da*	Db*	DE	a	b	a	b	ave	(g/m2)
LS1-0A	-0.01	0.01	-0.01	0.02	5.35	5.40	24	25	24	3.23
LS2-0A	-0.01	-0.01	0.00	0.01	5.28	5.35	23	24	23	2.83
LS3-0A	0.03	0.00	-0.01	0.03	5.40	5.48	25	26	25	3.26
LS4-0A	0.03	0.01	-0.01	0.03	5.15	5.35	21	24	23	3.47
LS5-0A	0.03	0.01	-0.02	0.04	5.43	5.53	25	26	26	3.13
LS1-0B	0.00	0.00	0.02	0.02	5.73	5.50	29	26	28	2.94
LS2-0B	-0.01	0.01	0.02	0.02	5.50	5.30	26	23	25	2.72
LS3-0B	0.03	0.00	0.02	0.04	5.38	5.23	24	22	23	3.26
LS4-0B	-0.01	0.00	0.01	0.01	5.60	5.33	28	24	26	2.94
LS5-0B	-0.02	-0.01	0.04	0.05	5.50	5.25	26	23	24	2.69
LS1-0C	-0.03	0.00	0.02	0.04	5.95	5.48	33	26	29	2.73
LS2-0C	-0.06	-0.01	0.01	0.06	5.18	5.35	22	24	23	3.89
LS3-0C	0.03	-0.01	-0.03	0.04	5.68	5.25	29	23	26	3.07
LS4-0C	0.08	0.00	-0.01	0.08	6.08	5.73	35	29	32	2.80
LS5-0C	0.04	0.02	-0.01	0.05	5.83	5.50	31	26	29	3.98
MEAN	0.01	0.00	0.00	0.04	5.53	5.40	27	25	26	3.13
ST.DEV.	0.03	0.01	0.02	0.02	0.27	0.13	4	2	3	0.40
LS1-86A	0.05	-0.25	1.47	1.49	5.68	5.50	29	26	27	3.16
LS2-86A	0.04	-0.27	1.46	1.49	5.70	5.85	29	31	30	2.96
LS3-86A	-0.01	-0.26	1.43	1.45	5.60	5.48	28	26	27	3.06
LS4-86A	0.03	-0.26	1.49	1.51	5.78	5.88	30	32	31	2.61
LS5-86A	0.03	-0.27	1.50	1.52	5.75	5.85	30	31	31	3.15
LS1-86B	-0.21	-0.07	2.32	2.33	5.75	5.83	30	31	30	2.60
LS2-86B	-0.23	-0.06	2.35	2.36	5.68	5.50	29	26	27	2.92
LS3-86B	-0.23	-0.06	2.37	2.38	5.90	5.68	32	29	30	3.21
LS4-86B	-0.20	-0.05	2.35	2.36	5.58	5.55	27	27	27	3.13
LS5-86B	-0.22	-0.06	2.30	2.31	5.58	5.53	27	26	27	2.86
LS1-86C	0.03	-0.06	1.40	1.40	5.68	5.75	29	30	29	3.67
LS2-86C	0.01	-0.07	1.39	1.39	5.70	5.75	29	30	29	3.94
LS3-86C	0.04	-0.07	1.37	1.37	5.83	5.95	31	33	32	3.17
LS4-86C	0.03	-0.06	1.36	1.36	6.13	5.75	36	30	33	3.02
LS5-86C	0.01	-0.05	1.34	1.34	5.78	5.68	30	29	29	3.09
MEAN	-0.06	-0.13	1.73	1.74	5.74	5.70	30	29	29	3.10
ST.DEV.	0.12	0.10	0.45	0.45	0.14	0.16	2	2	2	0.34
LS1-172A	-0.25	-0.35	2.59	2.63	5.73	5.75	29	30	30	3.32
LS2-172A	-0.24	-0.35	2.61	2.64	5.90	5.83	32	31	32	2.44
LS3-172A	-0.22	-0.36	2.59	2.62	5.65	5.50	28	26	27	3.44
LS4-172A	-0.23	-0.34	2.55	2.58	6.03	5.98	34	33	34	2.48
LS5-172A	-0.28	-0.33	2.54	2.58	5.63	5.50	28	26	27	3.21
LS1-172B	-0.67	-0.21	4.24	4.30	5.70	5.63	29	28	28	3.04
LS2-172B	-0.66	-0.21	4.27	4.33	5.65	5.68	28	29	28	2.92
LS3-172B	-0.67	-0.20	4.18	4.24	5.78	5.63	30	28	29	3.08
LS4-172B	-0.69	-0.20	4.21	4.27	5.88	5.70	32	29	30	2.78
LS5-172B	-0.66	-0.21	4.21	4.27	5.58	5.63	27	28	28	3.06
LS1-172C	-0.28	-0.17	2.57	2.59	6.38	5.93	41	33	37	2.34
LS2-172C	-0.28	-0.15	2.57	2.59	5.83	5.85	31	31	31	2.71
LS3-172C	-0.32	-0.16	2.58	2.60	5.73	5.63	29	28	29	2.71
LS4-172C	-0.28	-0.17	2.58	2.60	5.70	5.55	29	27	28	4.26
LS5-172C	-0.28	-0.16	2.56	2.58	6.05	6.00	35	34	34	2.53
MEAN	-0.40	-0.24	3.12	3.16	5.81	5.72	31	29	30	2.95
ST.DEV.	0.20	0.08	0.80	0.82	0.21	0.16	3	3	3	0.49

Table B8b. Tensile Data for Lascaux-Silk Crepeline Samples

Specimen	Tensile Strength (kg/N)				Elongation (mm)			Extension	Energy to Rupture (kgf-mm/N-m)			
	a	b	ave	ave (N)	a	b	ave	%	a	b	ave	ave (Nm)
LS1-0A	1.517	1.526	1.522	14.93	14.79	14.92	14.86	19.81	17.100	17.770	17.435	0.1710
LS2-0A	1.479	1.499	1.489	14.61	14.33	15.01	14.67	19.56	17.400	16.630	17.015	0.1669
LS3-0A	1.483	1.505	1.494	14.66	13.53	15.11	14.32	19.09	15.210	17.300	16.255	0.1595
LS4-0A	1.397	1.467	1.432	14.05	14.44	13.03	13.74	18.31	14.690	15.780	15.235	0.1495
LS5-0A	1.636	1.404	1.520	14.91	15.03	12.05	13.54	18.05	18.020	13.750	15.885	0.1558
LS1-0B	1.523	1.493	1.508	14.79	15.06	15.08	15.07	20.09	18.060	16.880	17.470	0.1714
LS2-0B	1.466	1.517	1.492	14.63	14.28	15.59	14.94	19.91	16.090	16.670	16.380	0.1607
LS3-0B	1.403	1.505	1.454	14.26	13.92	15.49	14.71	19.61	14.630	16.550	15.590	0.1529
LS4-0B	1.513	1.510	1.512	14.83	15.97	15.22	15.60	20.79	16.910	16.560	16.735	0.1642
LS5-0B	1.448	1.408	1.428	14.01	15.35	14.20	14.78	19.70	15.570	15.700	15.635	0.1534
LS1-0C	1.556	1.534	1.545	15.16	15.08	14.24	14.66	19.55	18.290	16.820	17.555	0.1722
LS2-0C	1.583	1.511	1.547	15.18	16.08	13.72	14.90	19.87	17.430	15.420	16.425	0.1611
LS3-0C	1.499	1.584	1.542	15.12	14.84	14.78	14.81	19.75	15.970	17.790	16.880	0.1656
LS4-0C	1.456	1.458	1.457	14.29	13.72	13.25	13.49	17.98	16.340	14.340	15.340	0.1505
LS5-0C	1.521	1.444	1.483	14.54	15.14	14.58	14.86	19.81	16.240	15.160	15.700	0.1540
MEAN	1.499	1.491	1.495	14.66	14.77	14.42	14.59	19.46	16.530	16.208	16.369	0.1606
ST.DEV.	0.064	0.048	0.039	0.38	0.75	1.01	0.59	0.78	1.195	1.174	0.791	0.0078
LS1-86A	0.911	0.877	0.894	8.77	5.99	5.66	5.83	7.77	3.837	3.296	3.567	0.0350
LS2-86A	0.909	0.934	0.921	9.04	5.78	5.62	5.70	7.60	3.586	3.826	3.706	0.0364
LS3-86A	0.960	0.953	0.956	9.38	6.13	6.14	6.14	8.18	3.944	4.333	4.139	0.0406
LS4-86A	0.987	0.907	0.947	9.29	6.02	5.39	5.71	7.61	3.984	3.279	3.632	0.0356
LS5-86A	0.886	0.969	0.928	9.10	5.16	6.36	5.76	7.68	3.146	4.187	3.667	0.0360
LS1-86B	0.776	0.879	0.828	8.12	4.63	5.92	5.28	7.03	2.768	3.383	3.076	0.0302
LS2-86B	0.868	0.864	0.866	8.50	6.25	6.06	6.16	8.21	3.567	3.464	3.516	0.0345
LS3-86B	0.926	0.910	0.918	9.01	6.78	6.27	6.53	8.70	4.293	4.107	4.200	0.0412
LS4-86B	0.862	0.863	0.862	8.46	6.23	6.27	6.25	8.33	3.552	3.407	3.480	0.0341
LS5-86B	0.791	0.781	0.786	7.71	5.01	5.23	5.12	6.83	2.727	2.666	2.697	0.0265
LS1-86C	0.890	0.905	0.897	8.80	6.28	6.32	6.30	8.40	3.596	3.842	3.719	0.0365
LS2-86C	0.856	0.909	0.883	8.66	5.30	5.75	5.53	7.37	3.065	3.576	3.321	0.0326
LS3-86C	0.928	0.890	0.909	8.91	6.27	5.48	5.88	7.83	4.004	3.643	3.824	0.0375
LS4-86C	0.889	0.842	0.865	8.49	5.89	5.39	5.64	7.52	3.533	3.119	3.326	0.0326
LS5-86C	0.771	0.788	0.779	7.64	4.73	4.71	4.72	6.29	2.519	2.590	2.555	0.0251
MEAN	0.881	0.885	0.883	8.66	5.76	5.77	5.77	7.69	3.475	3.515	3.495	0.0343
ST.DEV.	0.063	0.053	0.053	0.52	0.64	0.48	0.48	0.64	0.525	0.505	0.457	0.0045
LS1-172A	0.667	0.617	0.642	6.30	3.06	2.73	2.90	3.86	1.198	0.934	1.066	0.0105
LS2-172A	0.572	0.605	0.589	5.77	2.81	2.80	2.81	3.74	0.845	0.969	0.907	0.0089
LS3-172A	0.577	0.524	0.550	5.40	2.48	2.38	2.43	3.24	0.721	0.646	0.684	0.0067
LS4-172A	0.609	0.568	0.589	5.77	2.47	2.23	2.35	3.13	0.796	0.821	0.808	0.0079
LS5-172A	0.617	0.537	0.577	5.66	2.66	2.32	2.49	3.32	0.836	0.654	0.745	0.0073
LS1-172B	0.525	0.521	0.523	5.13	2.40	2.53	2.47	3.29	0.651	0.641	0.646	0.0063
LS2-172B	0.536	0.548	0.542	5.31	2.69	2.60	2.65	3.53	0.737	0.743	0.740	0.0073
LS3-172B	0.597	0.605	0.601	5.90	2.87	2.95	2.91	3.88	1.029	0.952	0.990	0.0097
LS4-172B	0.580	0.502	0.541	5.31	2.42	2.15	2.29	3.05	0.823	0.570	0.696	0.0068
LS5-172B	0.497	0.489	0.493	4.83	2.30	2.35	2.33	3.10	0.568	0.610	0.589	0.0058
LS1-172C	0.536	0.483	0.509	5.00	2.08	1.86	1.97	2.63	0.589	0.610	0.599	0.0059
LS2-172C	0.593	0.544	0.568	5.58	2.76	2.28	2.52	3.36	0.929	0.807	0.868	0.0085
LS3-172C	0.549	0.490	0.519	5.10	2.68	2.42	2.55	3.40	0.748	0.609	0.678	0.0067
LS4-172C	0.566	0.515	0.541	5.31	2.45	2.24	2.35	3.13	0.758	0.570	0.664	0.0065
LS5-172C	0.554	0.600	0.577	5.66	2.13	2.52	2.33	3.10	0.630	0.840	0.735	0.0072
MEAN	0.572	0.543	0.557	5.47	2.55	2.42	2.49	3.32	0.790	0.732	0.761	0.0075
ST.DEV.	0.042	0.046	0.040	0.39	0.27	0.28	0.25	0.33	0.168	0.144	0.141	0.0014

Table B9a. Colour Change and Stiffness Data for Lascaux-Polyester Crepeline Samples

Specimen	Colour Change				Overhang(cm)		Flex. Rigidity (mg-cm)			Add-on
	DL*	Da*	Db*	DE	a	b	a	b	ave	(g/m2)
LP1-0A	0.01	0.00	0.00	0.01	5.28	5.10	28	26	27	3.01
LP2-0A	-0.01	0.02	-0.01	0.02	5.13	5.35	26	30	28	2.65
LP3-0A	-0.04	0.02	-0.01	0.05	5.18	4.95	27	23	25	2.79
LP4-0A	-0.02	0.02	0.00	0.03	4.93	4.68	23	20	21	2.92
LP5-0A	-0.08	-0.01	0.02	0.08	4.93	5.28	23	28	26	3.24
LP1-0B	-0.08	-0.01	0.01	0.08	5.50	5.48	32	32	32	2.61
LP2-0B	-0.10	-0.02	0.00	0.10	5.30	5.43	29	31	30	3.01
LP3-0B	-0.15	-0.03	0.03	0.16	5.48	5.33	32	29	30	2.96
LP4-0B	-0.08	-0.01	0.01	0.08	5.13	5.35	26	30	28	2.72
LP5-0B	-0.06	-0.01	-0.01	0.06	5.20	5.35	27	30	28	3.32
LP1-0C	0.04	0.02	0.00	0.04	5.35	5.58	30	33	32	3.09
LP2-0C	0.07	0.02	0.00	0.07	5.18	5.20	27	27	27	2.61
LP3-0C	0.01	-0.01	0.01	0.02	5.05	5.00	25	24	25	2.95
LP4-0C	-0.02	0.00	0.01	0.02	5.13	5.30	26	29	27	3.36
LP5-0C	-0.07	-0.01	0.02	0.07	5 00	5.13	24	26	25	2.47
MEAN	-0.04	0.00	0.01	0.06	5.18	5.23	27	28	27	2.91
ST.DEV.	0.06	0.02	0.01	0.04	0.18	0.23	3	4	3	0.27
LP1-86A	-0.51	-0.14	0.75	0.92	5.18	5.33	27	29	28	3.00
LP2-86A	-0.50	-0.16	0.74	0.91	5.43	5.38	31	30	30	2.72
LP3-86A	-0.53	-0.15	0.75	0.93	5.53	5.28	33	28	30	2.94
LP4-86A	-0.51	-0.18	0.78	0.95	5.15	5.30	26	29	28	2.96
LP5-86A	-0.49	-0.18	0.78	0.94	5.40	5.15	30	26	28	3.19
LP1-86B	-0.43	-0.34	1.43	1.53	6.35	6.18	49	45	47	3.04
LP2-86B	-0.40	-0.33	1.47	1.56	5.88	6.13	39	44	42	2.49
LP3-86B	-0.38	-0.33	1.52	1.60	5.95	5.93	41	40	40	2.97
LP4-86B	-0.38	-0.32	1.47	1.55	5.88	5.63	39	34	37	3.39
LP5-86B	-0.37	-0.31	1.45	1.53	6.08	5.75	43	37	40	2.88
LP1-86C	-0.23	-0.20	0.83	0.88	5.88	5.53	39	33	36	3.19
LP2-86C	-0.25	-0.22	0.81	0.88	5.75	5.63	37	34	36	3.62
LP3-86C	-0.31	-0.23	0.83	0.92	5.93	5.85	40	39	39	3.03
LP4-86C	-0.25	-0.22	0.84	0.90	5.73	5.50	36	32	34	2.64
LP5-86C	-0.23	-0.21	0.79	0.85	5.55	5.70	33	36	34	2.44
MEAN	-0.38	-0.23	1.02	1.12	5.71	5.62	36	34	35	2.97
ST.DEV.	0.11	0.07	0.33	0.32	0.33	0.31	6	6	6	0.32
LP1-172A	-0.62	-0.27	1.21	1.39	5.63	5.65	34	35	35	2.74
LP2-172A	-0.63	-0.28	1.20	1.38	5.80	5.63	38	34	36	3.04
LP3-172A	-0.69	-0.26	1.21	1.42	5.83	5.70	38	36	37	2.76
LP4-172A	-0.66	-0.29	1.24	1.43	5.40	5.55	30	33	32	2.96
LP5-172A	-0.66	-0.29	1.24	1.43	5.83	6.00	38	42	40	3.01
LP1-172B	-0.43	-0.40	1.59	1.69	6.55	6.15	54	45	50	2.71
LP2-172B	-0.38	-0.41	1.64	1.73	6.15	6.13	45	44	45	2.51
LP3-172B	-0.44	-0.41	1.61	1.72	6.23	6.05	47	43	45	2.86
LP4-172B	-0.37	-0.39	1.60	1.69	6.45	6.15	52	45	48	2.84
LP5-172B	-0.44	-0.39	1.58	1.69	5.93	5.83	40	38	39	2.52
LP1-172C	-0.42	-0.22	1.03	1.13	6.03	5.80	42	38	40	3.39
LP2-172C	-0.44	-0.21	1.00	1.11	5.50	5.78	32	37	35	2.59
LP3-172C	-0.45	-0.22	1.02	1.14	5.80	5.88	38	39	38	3.04
LP4-172C	-0.46	-0.22	1.02	1.14	5.93	6.00	40	42	41	2.48
LP5-172C	-0.40	-0.21	1.01	1.11	5.93	6.00	40	42	41	2.65
MEAN	-0.50	-0.30	1.28	1.41	5.93	5.89	41	39	40	2.81
ST.DEV.	0.12	0.08	0.25	0.25	0.32	0.20	7	4	5	0.25

Table B9b. Tensile Data for Lascaux-Polyester Crepeline Samples

Specimen	Tensile Strength (kg/N)				Elongation (mm)			Extension	Energy to Rupture (kgf-mm/N-m)			
	a	b	ave	ave (N)	a	b	ave	%	a	b	ave	ave (Nm)
LP1-0A	2.733	2.778	2.756	27.03	16.63	17.17	16.90	22.53	28.410	30.920	29.665	0.2910
LP2-0A	2.868	2.746	2.807	27.54	18.79	17.28	18.04	24.05	32.140	28.790	30.465	0.2989
LP3-0A	2.642	2.831	2.737	26.85	16.28	18.48	17.38	23.17	25.000	34.720	29.860	0.2929
LP4-0A	2.838	2.838	2.838	27.84	18.49	18.83	18.66	24.88	31.850	35.050	33.450	0.3281
LP5-0A	2.851	2.989	2.920	28.65	18.29	19.99	19.14	25.52	34.010	36.430	35.220	0.3455
LP1-0B	3.012	3.016	3.014	29.57	21.01	20.70	20.86	27.81	38.900	36.750	37.825	0.3711
LP2-0B	2.993	2.970	2.982	29.25	20.35	20.04	20.20	26.93	37.700	38.580	38.140	0.3742
LP3-0B	3.012	2.984	2.998	29.41	21.10	20.86	20.98	27.97	37.150	37.520	37.335	0.3663
LP4-0B	3.016	2.997	3.007	29.49	21.39	21.10	21.25	28.33	40.000	39.940	39.970	0.3921
LP5-0B	2.983	2.850	2.917	28.61	20.45	18.42	19.44	25.91	35.190	30.890	33.040	0.3241
LP1-0C	2.952	3.020	2.986	29.29	19.85	20.64	20.25	26.99	39.780	38.110	38.945	0.3821
LP2-0C	3.000	2.965	2.983	29.26	20.83	20.38	20.61	27.47	40.170	38.540	39.355	0.3861
LP3-0C	3.001	3.067	3.034	29.76	21.35	22.94	22.15	29.53	40.400	44.070	42.235	0.4143
LP4-0C	2.948	2.993	2.971	29.14	19.97	20.65	20.31	27.08	36.220	39.320	37.770	0.3705
LP5-0C	2.969	3.044	3.007	29.49	20.92	22.65	21.79	29.05	39.110	44.410	41.760	0.4097
MEAN	2.921	2.939	2.930	28.75	19.71	20.01	19.86	26.48	35.735	36.936	36.336	0.3565
ST.DEV.	0.113	0.102	0.099	0.97	1.66	1.70	1.57	2.09	4.657	4.443	4.168	0.0409
LP1-86A	1.792	1.733	1.763	17.29	11.92	11.98	11.95	15.93	12.530	11.300	11.915	0.1169
LP2-86A	2.148	2.133	2.141	21.00	12.83	12.51	12.67	16.89	15.210	14.370	14.790	0.1451
LP3-86A	2.051	2.012	2.032	19.93	12.59	12.58	12.59	16.78	14.000	14.020	14.010	0.1374
LP4-86A	2.004	2.040	2.022	19.84	12.87	12.52	12.70	16.93	14.170	13.820	13.995	0.1373
LP5-86A	2.063	2.051	2.057	20.18	12.84	12.57	12.71	16.94	14.110	14.660	14.385	0.1411
LP1-86B	2.047	1.969	2.008	19.70	12.58	12.08	12.33	16.44	14.100	13.350	13.725	0.1346
LP2-86B	1.945	1.978	1.962	19.24	12.19	12.78	12.49	16.65	14.170	14.010	14.090	0.1382
LP3-86B	2.030	2.180	2.105	20.65	12.54	13.00	12.77	17.03	14.020	15.050	14.535	0.1426
LP4-86B	1.827	2.087	1.957	19.20	12.57	13.15	12.86	17.15	13.120	14.510	13.815	0.1355
LP5-86B	2.001	2.055	2.028	19.89	12.83	12.76	12.80	17.06	14.170	14.060	14.115	0.1385
LP1-86C	2.001	2.054	2.028	19.89	12.04	12.55	12.30	16.39	13.650	13.830	13.740	0.1348
LP2-86C	2.007	2.114	2.061	20.21	12.70	13.25	12.98	17.30	14.010	14.870	14.440	0.1417
LP3-86C	1.899	2.021	1.960	19.23	12.37	12.48	12.43	16.57	14.230	14.440	14.335	0.1406
LP4-86C	2.023	1.966	1.995	19.57	12.18	12.43	12.31	16.41	13.650	14.270	13.960	0.1369
LP5-86C	1.883	2.036	1.960	19.22	11.58	12.67	12.13	16.17	13.160	13.850	13.505	0.1325
MEAN	1.981	2.029	2.005	19.67	12.44	12.62	12.53	16.71	13.887	14.027	13.957	0.1369
ST.DEV.	0.095	0.102	0.086	0.84	0.39	0.34	0.29	0.39	0.616	0.876	0.662	0.0065
LP1-172A	1.687	1.585	1.636	16.05	10.96	10.91	10.94	14.58	10.920	10.540	10.730	0.1053
LP2-172A	1.613	1.658	1.636	16.04	10.54	10.45	10.50	13.99	9.887	9.837	9.862	0.0967
LP3-172A	1.741	1.830	1.786	17.52	11.22	11.38	11.30	15.07	11.110	11.330	11.220	0.1101
LP4-172A	1.668	1.715	1.692	16.59	10.82	11.05	10.94	14.58	10.570	10.670	10.620	0.1042
LP5-172A	1.707	1.690	1.699	16.66	10.64	10.52	10.58	14.11	10.220	9.876	10.048	0.0986
LP1-172B	1.636	1.749	1.693	16.60	10.52	11.06	10.79	14.39	10.670	10.950	10.810	0.1060
LP2-172B	1.737	1.776	1.757	17.23	10.72	11.04	10.88	14.51	10.510	10.970	10.740	0.1054
LP3-172B	1.591	1.745	1.668	16.36	11.36	11.11	11.24	14.98	11.090	10.900	10.995	0.1079
LP4-172B	1.654	1.646	1.650	16.19	10.51	10.89	10.70	14.27	10.060	10.450	10.255	0.1006
LP5-172B	1.714	1.656	1.685	16.53	11.10	10.57	10.84	14.45	10.810	10.340	10.575	0.1037
LP1-172C	1.695	1.600	1.648	16.16	10.49	10.33	10.41	13.88	10.280	9.666	9.973	0.0978
LP2-172C	1.714	1.615	1.665	16.33	10.69	10.26	10.48	13.97	10.370	9.594	9.982	0.0979
LP3-172C	1.619	1.718	1.669	16.37	10.74	11.09	10.92	14.55	10.110	10.660	10.385	0.1019
LP4-172C	1.742	1.596	1.669	16.37	10.86	9.86	10.36	13.81	10.710	10.280	10.495	0.1030
LP5-172C	1.750	1.639	1.695	16.62	11.04	10.68	10.86	14.48	10.910	10.290	10.600	0.1040
MEAN	1.685	1.681	1.683	16.51	10.81	10.75	10.78	14.37	10.548	10.424	10.486	0.1029
ST.DEV.	0.052	0.073	0.042	0.41	0.27	0.41	0.28	0.37	0.384	0.515	0.399	0.0039

Table B10a. Colour Change and Stiffness Data for Silk Crepeline Samples

Specimen	Colour Change				Overhang(cm)		Flex. Rigidity (mg-cm)		
	DL*	Da*	Db*	DE	a	b	a	b	ave
S1-0A	0.02	0.00	0.01	0.02	5.73	6.13	21	26	24
S2-0A	0.02	0.01	-0.05	0.05	5.93	6.23	24	27	26
S3-0A	0.02	0.01	-0.03	0.04	6.60	6.08	33	26	29
S4-0A	-0.01	-0.01	-0.04	0.04	5.88	6.23	23	27	25
S5-0A	-0.01	0.00	-0.01	0.01	6.05	6.18	25	27	26
S1-0B	-0.04	0.00	-0.05	0.06	6.63	7.10	33	41	37
S2-0B	-0.01	0.01	-0.08	0.08	6.50	6.33	31	29	30
S3-0B	-0.04	0.02	-0.06	0.07	6.98	6.75	39	35	37
S4-0B	-0.05	-0.01	0.04	0.06	5.63	5.53	20	19	20
S5-0B	0.05	-0.02	-0.03	0.06	6.48	5.90	31	23	27
S1-0C	0.03	0.00	-0.03	0.04	6.10	5.93	26	24	25
S2-0C	0.01	0.00	-0.02	0.02	6.25	6.15	28	26	27
S3-0C	-0.02	-0.02	0.08	0.08	6.38	6.25	29	28	29
S4-0C	0.00	0.00	0.03	0.03	6.30	6.35	28	29	29
S5-0C	0.02	0.00	-0.02	0.03	6.28	6.25	28	28	28
MEAN	0.00	0.00	-0.02	0.05	6.25	6.22	28	28	28
ST.DEV.	0.03	0.01	0.04	0.02	0.37	0.36	5	5	4
S1-86A	0.04	-0.02	0.81	0.81	6.25	6.53	28	32	30
S2-86A	0.02	-0.01	0.82	0.82	6.50	6.28	31	28	30
S3-86A	0.03	-0.01	0.79	0.79	6.28	6.20	28	27	28
S4-86A	0.05	0.00	0.79	0.79	6.13	6.33	26	29	27
S5-86A	0.08	0.01	0.78	0.78	6.03	6.30	25	28	27
S1-86B	0.07	-0.08	2.07	2.07	6.05	6.15	25	26	26
S2-86B	0.00	-0.08	2.10	2.10	6.30	6.05	28	25	27
S3-86B	0.01	-0.07	2.12	2.12	5.98	5.83	24	22	23
S4-86B	-0.01	-0.08	2.16	2.16	5.98	6.10	24	26	25
S5-86B	0.04	-0.08	2.14	2.14	5.90	5.85	23	23	23
S1-86C	-0.48	0.09	1.22	1.31	6.58	6.53	32	32	32
S2-86C	-0.34	0.09	1.25	1.30	6.13	6.10	26	26	26
S3-86C	-0.40	0.09	1.29	1.35	6.08	6.15	26	26	26
S4-86C	-0.34	0.07	1.26	1.31	6.18	6.23	27	27	27
S5-86C	-0.35	0.09	1.25	1.30	6.10	6.10	26	26	26
MEAN	-0.11	0.00	1.39	1.41	6.16	6.18	27	27	27
ST.DEV.	0.21	0.07	0.57	0.56	0.19	0.20	3	3	2
S1-172A	-0.38	-0.10	1.96	2.00	6.00	6.20	25	27	26
S2-172A	-0.43	-0.08	2.11	2.15	6.23	6.33	27	29	28
S3-172A	-0.40	-0.07	1.95	1.99	6.23	6.40	27	30	29
S4-172A	-0.37	-0.09	2.01	2.05	6.18	6.25	27	28	27
S5-172A	-0.36	-0.09	1.95	1.98	6.15	6.33	26	29	28
S1-172B	-0.05	-0.25	3.39	3.40	6.03	6.25	25	28	26
S2-172B	-0.10	-0.25	3.42	3.43	6.00	6.03	25	25	25
S3-172B	-0.04	-0.25	3.40	3.41	6.25	6.25	28	28	28
S4-172B	-0.06	-0.24	3.34	3.35	6.18	6.13	27	26	26
S5-172B	-0.11	-0.24	3.39	3.40	5.85	5.95	23	24	23
S1-172C	-0.49	0.00	2.44	2.49	6.23	6.10	27	26	27
S2-172C	-0.62	0.02	2.52	2.60	6.35	6.45	29	31	30
S3-172C	-0.61	0.01	2.51	2.58	6.40	6.38	30	29	30
S4-172C	-0.67	0.00	2.50	2.59	6.25	6.25	28	28	28
S5-172C	-0.61	0.01	2.44	2.52	6.33	6.30	29	28	29
MEAN	-0.35	-0.11	2.62	2.66	6.18	6.24	27	28	27
ST.DEV.	0.23	0.11	0.60	0.58	0.15	0.14	2	2	2

Table B10b. Tensile Data for Silk Crepeline Samples

Specimen	Tensile Strength (kg/N)				Elongation (mm)			Extension	Energy to Rupture (kgf-mm/N-m)			
	a	b	ave	ave (N)	a	b	ave	%	a	b	ave	ave (Nm)
S1-0A	1.443	1.470	1.457	14.29	12.30	14.14	13.22	17.63	17.040	18.200	17.620	0.1729
S2-0A	1.549	1.482	1.516	14.87	15.12	13.55	14.34	19.11	19.340	18.040	18.690	0.1833
S3-0A	1.533	1.489	1.511	14.82	14.72	13.15	13.94	18.58	19.450	19.030	19.240	0.1887
S4-0A	1.388	1.423	1.406	13.79	14.64	13.77	14.21	18.94	17.540	17.330	17.435	0.1710
S5-0A	1.383	1.613	1.498	14.70	13.60	14.75	14.18	18.90	17.140	19.210	18.175	0.1783
S1-0B	1.451	1.423	1.437	14.10	15.27	13.16	14.22	18.95	18.830	17.170	18.000	0.1766
S2-0B	1.467	1.529	1.498	14.70	14.17	15.02	14.60	19.46	17.900	18.870	18.385	0.1804
S3-0B	1.397	1.442	1.420	13.93	14.55	13.59	14.07	18.76	17.260	18.390	17.825	0.1749
S4-0B	1.407	1.472	1.440	14.12	15.14	15.22	15.18	20.24	16.930	16.940	16.935	0.1661
S5-0B	1.459	1.409	1.434	14.07	14.53	15.06	14.80	19.73	17.980	17.730	17.855	0.1752
S1-0C	1.572	1.442	1.507	14.78	14.87	14.90	14.89	19.85	17.840	16.060	16.950	0.1663
S2-0C	1.544	1.494	1.519	14.90	14.67	15.54	15.11	20.14	18.460	17.310	17.885	0.1755
S3-0C	1.487	1.349	1.418	13.91	14.55	12.30	13.43	17.90	17.660	16.560	17.110	0.1678
S4-0C	1.471	1.387	1.429	14.02	14.19	13.95	14.07	18.76	17.420	17.150	17.285	0.1696
S5-0C	1.485	1.532	1.509	14.80	15.04	14.71	14.88	19.83	18.630	18.640	18.635	0.1828
MEAN	1.469	1.464	1.466	14.39	14.49	14.19	14.34	19.12	17.961	17.775	17.868	0.1753
ST.DEV.	0.061	0.065	0.042	0.41	0.75	0.93	0.57	0.77	0.812	0.945	0.676	0.0066
S1-86A	0.934	0.971	0.952	9.34	5.77	6.38	6.08	8.10	4.129	5.378	4.754	0.0466
S2-86A	1.089	1.051	1.070	10.50	8.45	8.42	8.44	11.25	7.756	7.451	7.604	0.0746
S3-86A	0.878	0.984	0.931	9.13	5.74	6.84	6.29	8.39	3.935	5.781	4.858	0.0477
S4-86A	0.928	1.005	0.966	9.48	6.18	6.37	6.28	8.37	4.485	4.868	4.677	0.0459
S5-86A	0.932	1.008	0.970	9.51	6.65	6.96	6.81	9.07	5.270	5.767	5.519	0.0541
S1-86B	0.823	0.882	0.852	8.36	6.00	6.43	6.22	8.29	3.936	4.031	3.984	0.0391
S2-86B	0.813	0.838	0.826	8.10	5.10	5.97	5.54	7.38	3.080	3.612	3.346	0.0328
S3-86B	0.855	0.842	0.848	8.32	6.41	6.27	6.34	8.45	4.321	3.701	4.011	0.0393
S4-86B	0.836	0.836	0.836	8.20	6.24	5.78	6.01	8.01	3.733	3.599	3.666	0.0360
S5-86B	0.863	0.809	0.836	8.20	5.89	5.90	5.90	7.86	4.257	3.429	3.843	0.0377
S1-86C	0.871	0.940	0.905	8.88	6.50	7.37	6.94	9.25	4.259	5.195	4.727	0.0464
S2-86C	0.835	0.832	0.834	8.18	5.13	5.00	5.07	6.75	3.292	3.376	3.334	0.0327
S3-86C	0.952	0.860	0.906	8.89	7.28	5.77	6.53	8.70	5.020	3.684	4.352	0.0427
S4-86C	0.811	0.847	0.829	8.13	5.03	5.45	5.24	6.99	3.234	3.493	3.364	0.0330
S5-86C	0.921	0.928	0.924	9.07	6.42	6.49	6.46	8.61	4.479	4.720	4.600	0.0451
MEAN	0.889	0.909	0.899	8.82	6.19	6.36	6.27	8.36	4.346	4.539	4.442	0.0436
ST.DEV.	0.073	0.079	0.071	0.70	0.88	0.83	0.79	1.06	1.124	1.193	1.087	0.0107
S1-172A	0.613	0.694	0.654	6.41	3.33	3.74	3.54	4.71	1.199	1.630	1.415	0.0139
S2-172A	0.662	0.710	0.686	6.73	3.19	3.54	3.37	4.49	1.175	1.421	1.298	0.0127
S3-172A	0.706	0.827	0.766	7.52	4.03	4.96	4.50	5.99	2.099	2.736	2.418	0.0237
S4-172A	0.635	0.652	0.644	6.31	2.97	3.37	3.17	4.23	1.428	1.326	1.377	0.0135
S5-172A	0.550	0.581	0.566	5.55	2.56	2.62	2.59	3.45	0.942	1.027	0.985	0.0097
S1-172B	0.452	0.447	0.450	4.41	1.78	2.09	1.94	2.58	0.456	0.446	0.451	0.0044
S2-172B	0.630	0.673	0.651	6.39	3.46	3.62	3.54	4.72	1.401	1.630	1.516	0.0149
S3-172B	0.530	0.483	0.507	4.97	2.23	1.92	2.08	2.77	0.667	0.552	0.609	0.0060
S4-172B	0.409	0.434	0.422	4.13	1.93	1.96	1.95	2.59	0.427	0.452	0.440	0.0043
S5-172B	0.483	0.473	0.478	4.69	2.45	2.43	2.44	3.25	0.571	0.573	0.572	0.0056
S1-172C	0.608	0.562	0.585	5.74	3.02	2.63	2.83	3.77	1.024	0.860	0.942	0.0092
S2-172C	0.588	0.599	0.593	5.82	2.52	2.51	2.52	3.35	0.968	0.980	0.974	0.0096
S3-172C	0.541	0.529	0.535	5.25	2.22	2.16	2.19	2.92	0.747	0.674	0.710	0.0070
S4-172C	0.460	0.483	0.472	4.63	2.06	2.03	2.05	2.73	0.578	0.516	0.547	0.0054
S5-172C	0.497	0.522	0.509	5.00	1.93	2.17	2.05	2.73	0.597	0.670	0.634	0.0062
MEAN	0.558	0.578	0.568	5.57	2.65	2.78	2.71	3.62	0.952	1.033	0.992	0.0097
ST.DEV.	0.086	0.114	0.098	0.96	0.66	0.88	0.76	1.01	0.456	0.629	0.538	0.0053

Table B11a. Colour Change and Stiffness Data for Polyester Crepeline Samples

Specimen	Colour Change				Overhang(cm)		Flex. Rigidity (mg-cm)		
	DL*	Da*	Db*	DE	a	b	a	b	ave
P1-0A	-0.08	0.01	0.03	0.09	5.53	5.40	27	25	26
P2-0A	-0.03	0.00	0.02	0.04	5.48	5.50	26	26	26
P3-0A	-0.02	-0.03	0.03	0.05	5.48	5.68	26	29	27
P4-0A	0.02	-0.01	0.01	0.02	5.55	5.45	27	26	26
P5-0A	-0.02	-0.01	0.01	0.02	5.40	5.20	25	22	24
P1-0B	0.04	0.03	-0.02	0.05	5.40	5.80	25	31	28
P2-0B	0.02	-0.03	0.01	0.04	5.50	5.70	26	29	28
P3-0B	-0.01	-0.01	0.01	0.02	5.63	5.48	28	26	27
P4-0B	0.04	-0.03	0.01	0.05	5.73	5.63	30	28	29
P5-0B	0.03	-0.02	0.04	0.05	5.45	5.55	26	27	26
P1-0C	0.04	0.00	0.00	0.04	5.68	5.95	29	33	31
P2-0C	-0.01	0.00	-0.02	0.02	5.35	5.38	24	24	24
P3-0C	-0.05	0.00	-0.02	0.05	5.83	5.80	31	31	31
P4-0C	0.02	0.00	-0.02	0.03	5.60	5.75	28	30	29
P5-0C	0.06	0.01	-0.01	0.06	5.25	5.40	23	25	24
MEAN	0.00	-0.01	0.01	0.04	5.52	5.58	27	27	27
ST.DEV.	0.04	0.02	0.02	0.02	0.15	0.20	2	3	2
P1-86A	-0.11	0.01	0.22	0.25	5.43	5.55	25	27	26
P2-86A	-0.10	0.03	0.22	0.24	5.58	5.10	27	21	24
P3-86A	-0.13	0.01	0.24	0.27	5.65	5.43	28	25	27
P4-86A	-0.15	0.05	0.21	0.26	5.48	5.50	26	26	26
P5-86A	-0.16	0.01	0.25	0.30	5.70	5.65	29	28	29
P1-86B	-0.25	-0.10	0.85	0.89	6.25	6.10	39	36	37
P2-86B	-0.27	-0.09	0.81	0.86	5.85	5.83	32	31	31
P3-86B	-0.23	-0.10	0.82	0.86	5.95	6.13	33	36	35
P4-86B	-0.23	-0.07	0.82	0.85	5.98	6.08	34	35	34
P5-86B	-0.25	-0.08	0.83	0.87	6.35	6.23	40	38	39
P1-86C	0.00	0.08	-0.14	0.16	6.80	6.28	50	39	44
P2-86C	-0.06	0.09	-0.15	0.18	6.18	6.18	37	37	37
P3-86C	0.04	0.08	-0.15	0.17	6.13	6.10	36	36	36
P4-86C	0.00	0.08	-0.14	0.16	6.83	6.40	50	41	46
P5-86C	-0.07	0.07	-0.14	0.17	6.43	6.15	42	37	39
MEAN	-0.13	0.00	0.30	0.43	6.04	5.91	35	33	34
ST.DEV.	0.10	0.07	0.41	0.32	0.44	0.38	8	6	7
P1-172A	-0.34	0.00	0.22	0.40	6.05	6.08	35	35	35
P2-172A	-0.34	0.04	0.19	0.39	5.68	6.08	29	35	32
P3-172A	-0.34	0.03	0.20	0.40	5.60	5.65	28	28	28
P4-172A	-0.30	0.07	0.20	0.37	6.20	5.40	38	25	31
P5-172A	-0.36	0.08	0.18	0.41	5.60	5.80	28	31	29
P1-172B	-0.48	-0.08	0.98	1.09	6.25	6.30	39	39	39
P2-172B	-0.49	-0.08	1.01	1.13	6.63	6.65	46	46	46
P3-172B	-0.47	-0.08	1.00	1.11	6.30	6.35	39	40	40
P4-172B	-0.47	-0.08	0.99	1.10	6.58	6.25	45	39	42
P5-172B	-0.48	-0.07	0.97	1.08	6.43	6.38	42	41	41
P1-172C	-0.15	0.07	-0.07	0.18	6.50	6.45	43	42	43
P2-172C	-0.15	0.08	-0.09	0.19	6.38	6.60	41	45	43
P3-172C	-0.18	0.07	-0.08	0.21	6.55	6.23	44	38	41
P4-172C	-0.15	0.08	-0.10	0.20	6.30	6.50	39	43	41
P5-172C	-0.10	0.07	-0.09	0.15	6.73	6.40	48	41	45
MEAN	-0.32	0.01	0.37	0.56	6.25	6.21	39	38	38
ST.DEV.	0.14	0.07	0.47	0.41	0.37	0.35	7	6	6

Table B11b. Tensile Data for Polyester Crepeline Samples

Specimen	Tensile Strength (kg/N)				Elongation (mm)			Extension	Energy to Rupture (kgf-mm/N-m)			
	a	b	ave	ave (N)	a	b	ave	%	a	b	ave	ave (Nm)
P1-0A	3.000	2.956	2.978	29.21	21.12	20.28	20.70	27.60	43.460	41.190	42.325	0.4152
P2-0A	2.903	2.933	2.918	28.63	18.64	19.14	18.89	25.19	38.700	39.020	38.860	0.3812
P3-0A	2.968	2.913	2.941	28.85	20.73	19.63	20.18	26.91	42.500	42.760	42.630	0.4182
P4-0A	2.859	2.968	2.914	28.58	21.44	20.35	20.90	27.86	39.870	40.360	40.115	0.3935
P5-0A	2.966	2.992	2.979	29.22	20.53	20.67	20.60	27.47	41.060	42.010	41.535	0.4075
P1-0B	3.039	2.946	2.993	29.36	21.82	19.76	20.79	27.72	42.750	45.130	43.940	0.4311
P2-0B	2.973	2.949	2.961	29.05	20.47	20.22	20.35	27.13	38.490	39.490	38.990	0.3825
P3-0B	2.995	2.993	2.994	29.37	21.21	21.18	21.20	28.26	40.940	41.230	41.085	0.4030
P4-0B	2.968	2.977	2.973	29.16	20.28	20.78	20.53	27.37	37.930	39.150	38.540	0.3781
P5-0B	3.003	3.005	3.004	29.47	21.51	21.90	21.71	28.94	41.830	40.310	41.070	0.4029
P1-0C	2.968	2.940	2.954	28.98	20.55	20.01	20.28	27.04	40.660	38.490	39.575	0.3882
P2-0C	2.995	2.957	2.976	29.19	21.01	20.33	20.67	27.56	39.990	39.910	39.950	0.3919
P3-0C	2.925	2.985	2.955	28.99	20.20	20.94	20.57	27.43	42.750	41.500	42.125	0.4132
P4-0C	2.854	2.985	2.920	28.64	20.49	20.87	20.68	27.57	40.140	41.310	40.725	0.3995
P5-0C	3.024	2.945	2.985	29.28	21.34	19.85	20.60	27.46	40.850	39.660	40.255	0.3949
MEAN	2.963	2.963	2.963	29.07	20.76	20.39	20.58	27.43	40.795	40.768	40.781	0.4001
ST.DEV.	0.055	0.026	0.029	0.28	0.76	0.69	0.60	0.80	1.662	1.703	1.538	0.0151
P1-86A	2.463	2.581	2.522	24.74	16.47	18.05	17.26	23.01	26.440	28.060	27.250	0.2673
P2-86A	2.627	2.713	2.670	26.19	16.95	17.98	17.47	23.29	28.800	30.090	29.445	0.2889
P3-86A	2.570	2.611	2.591	25.41	16.25	16.78	16.52	22.02	25.960	26.120	26.040	0.2555
P4-86A	2.536	2.507	2.522	24.74	16.06	17.09	16.58	22.10	26.920	28.140	27.530	0.2701
P5-86A	2.476	2.545	2.511	24.63	16.56	16.54	16.55	22.07	25.200	27.420	26.310	0.2581
P1-86B	2.517	2.592	2.555	25.06	15.76	16.40	16.08	21.44	24.830	25.180	25.005	0.2453
P2-86B	2.667	2.658	2.663	26.12	16.42	16.90	16.66	22.21	26.590	27.660	27.125	0.2661
P3-86B	2.565	2.570	2.568	25.19	16.49	16.57	16.53	22.04	25.200	26.310	25.755	0.2527
P4-86B	2.499	2.525	2.512	24.64	16.84	16.15	16.50	21.99	25.730	25.490	25.610	0.2512
P5-86B	2.494	2.527	2.511	24.63	15.76	16.06	15.91	21.21	25.520	25.470	25.495	0.2501
P1-86C	2.620	2.616	2.618	25.68	16.57	16.52	16.55	22.06	25.720	26.290	26.005	0.2551
P2-86C	2.580	2.572	2.576	25.27	16.76	16.64	16.70	22.27	24.810	24.880	24.845	0.2437
P3-86C	2.604	2.616	2.610	25.60	15.85	16.07	15.96	21.28	25.760	26.670	26.215	0.2572
P4-86C	2.498	2.376	2.437	23.91	16.04	15.82	15.93	21.24	23.950	23.760	23.855	0.2340
P5-86C	2.529	2.495	2.512	24.64	16.23	15.81	16.02	21.36	25.910	25.110	25.510	0.2503
MEAN	2.550	2.567	2.558	25.10	16.33	16.63	16.48	21.97	25.823	26.443	26.133	0.2564
ST.DEV.	0.061	0.079	0.064	0.63	0.38	0.68	0.46	0.61	1.117	1.610	1.324	0.0130
P1-172A	2.360	2.321	2.341	22.96	15.02	15.69	15.36	20.47	21.380	22.760	22.070	0.2165
P2-172A	2.180	2.262	2.221	21.79	15.08	14.71	14.90	19.86	19.780	20.500	20.140	0.1976
P3-172A	2.271	2.258	2.265	22.21	15.15	14.45	14.80	19.73	20.290	19.990	20.140	0.1976
P4-172A	2.342	2.400	2.371	23.26	14.54	15.59	15.07	20.09	20.060	21.770	20.915	0.2052
P5-172A	2.310	2.278	2.294	22.50	14.91	15.18	15.05	20.06	20.830	20.360	20.595	0.2020
P1-172B	2.271	2.358	2.315	22.71	14.69	14.74	14.72	19.62	20.930	20.880	20.905	0.2051
P2-172B	2.142	2.158	2.150	21.09	14.13	13.65	13.89	18.52	17.870	18.020	17.945	0.1760
P3-172B	2.365	2.285	2.325	22.81	14.50	13.95	14.23	18.97	19.920	20.630	20.275	0.1989
P4-172B	2.244	2.342	2.293	22.49	14.43	14.35	14.39	19.19	20.740	20.600	20.670	0.2028
P5-172B	2.153	2.299	2.226	21.84	13.81	14.73	14.27	19.03	18.790	19.310	19.050	0.1869
P1-172C	2.274	2.275	2.275	22.31	14.23	14.20	14.22	18.95	19.100	19.030	19.065	0.1870
P2-172C	2.327	2.321	2.324	22.80	14.66	14.56	14.61	19.48	20.900	19.660	20.280	0.1989
P3-172C	2.199	2.303	2.251	22.08	14.03	14.90	14.47	19.29	19.220	19.720	19.470	0.1910
P4-172C	2.142	2.224	2.183	21.42	13.84	14.23	14.04	18.71	18.100	18.540	18.320	0.1797
P5-172C	2.170	2.290	2.230	21.88	14.15	14.45	14.30	19.07	18.730	18.870	18.800	0.1844
MEAN	2.250	2.292	2.271	22.28	14.48	14.63	14.55	19.40	19.776	20.043	19.909	0.1953
ST.DEV.	0.081	0.057	0.061	0.60	0.44	0.56	0.42	0.56	1.097	1.241	1.113	0.0109

APPENDIX C: ANOVA Results

Table C1. ANOVA of Results for Colour Change, Stiffness, and Tensile Properties of Laminates and Plain Habutae Samples by *Sample Type* and *Exposure* (all effects entered simultaneously)

		Unique Method					
		Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	DeltaE	1644.319	6	274.053	2173.596	.000
		Flex	1457777	6	242962.8	171.168	.000
		Strength	60757.249	6	10126.208	361.031	.000
		Extension	6139.084	6	1023.181	597.369	.000
		Energy	13.433	6	2.239	531.302	.000
	sample type	DeltaE	48.133	4	12.033	95.439	.000
		Flex	1313376	4	328344.0	231.320	.000
		Strength	3647.632	4	911.908	32.512	.000
		Extension	93.748	4	23.437	13.683	.000
		Energy	.292	4	7.305E-02	17.335	.000
	exposure	DeltaE	1596.186	2	798.093	6329.909	.000
		Flex	144400.9	2	72200.440	50.866	.000
		Strength	57109.617	2	28554.808	1018.067	.000
		Extension	6045.336	2	3022.668	1764.739	.000
		Energy	13.140	2	6.570	1559.235	.000
2-Way Interactions	sample type *exposure	DeltaE	23.632	8	2.954	23.429	.000
		Flex	47171.609	8	5896.451	4.154	.000
		Strength	577.425	8	72.178	2.573	.011
		Extension	9.526	8	1.191	.695	.696
		Energy	4.244E-02	8	5.305E-03	1.259	.267
Model		DeltaE	1667.951	14	119.139	944.929	.000
		Flex	1504949	14	107496.3	75.732	.000
		Strength	61334.674	14	4381.048	156.198	.000
		Extension	6148.609	14	439.186	256.412	.000
		Energy	13.475	14	.963	228.420	.000
Residual		DeltaE	26.477	210	.126		
		Flex	298082.0	210	1419.438		
		Strength	5890.092	210	28.048		
		Extension	359.691	210	1.713		
		Energy	.885	210	4.214E-03		
Total		DeltaE	1694.428	224	7.564		
		Flex	1803031	224	8049.244		
		Strength	67224.766	224	300.111		
		Extension	6508.300	224	29.055		
		Energy	14.360	224	6.411E-02		

Table C2. ANOVA for Flexural Rigidity of Laminates and their Corresponding Backing Fabrics by *Lamination* and *Exposure* (all effects entered simultaneously)

			Unique Method				
		Sample Pairs	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	HAS/AS	419049.1	3	139683.0	209.740	.000
		HAP/AP	632940.5	3	210980.2	204.751	.000
		HLS/LS	634708.7	3	211569.6	197.660	.000
		HLP/LP	881512.3	3	293837.4	366.165	.000
	lamination	HAS/AS	402671.1	1	402671.1	604.627	.000
		HAP/AP	614378.8	1	614378.8	596.238	.000
		HLS/LS	582900.5	1	582900.5	544.579	.000
		HLP/LP	852445.3	1	852445.3	1062.273	.000
	exposure	HAS/AS	16378.022	2	8189.011	12.296	.000
		HAP/AP	18561.667	2	9280.833	9.007	.000
		HLS/LS	51808.156	2	25904.078	24.201	.000
		HLP/LP	29066.956	2	14533.478	18.111	.000
2-Way Interactions	lamination* exposure	HAS/AS	14394.156	2	7197.078	10.807	.000
		HAP/AP	5502.156	2	2751.078	2.670	.075
		HLS/LS	44349.356	2	22174.678	20.717	.000
		HLP/LP	14861.756	2	7430.878	9.260	.000
Model		HAS/AS	433443.3	5	86688.658	130.167	.000
		HAP/AP	638442.7	5	127688.5	123.918	.000
		HLS/LS	679058.1	5	135811.6	126.883	.000
		HLP/LP	896374.1	5	179274.8	223.403	.000
Residual		HAS/AS	55942.533	84	665.983		
		HAP/AP	86555.733	84	1030.425		
		HLS/LS	89911.067	84	1070.370		
		HLP/LP	67407.733	84	802.473		
Total		HAS/AS	489385.8	89	5498.717		
		HAP/AP	724998.4	89	8146.049		
		HLS/LS	768969.1	89	8640.102		
		HLP/LP	963781.8	89	10829.009		

Table C3. ANOVA for Tensile Strength of Laminates and their Corresponding Backing Fabrics by *Lamination* and *Exposure* (all effects entered simultaneously)

			Unique Method				
		Sample Pairs	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	HAS/AS	46255.585	3	15418.528	1330.695	.000
		HAP/AP	33439.296	3	11146.432	389.633	.000
		HLS/LS	47737.708	3	15912.569	1711.144	.000
		HLP/LP	40659.508	3	13553.169	803.168	.000
	lamination	HAS/AS	37891.822	1	37891.822	3270.251	.000
		HAP/AP	23781.228	1	23781.228	831.294	.000
		HLS/LS	39468.550	1	39468.550	4244.216	.000
		HLP/LP	28349.590	1	28349.590	1680.012	.000
	exposure	HAS/AS	8363.763	2	4181.882	360.917	.000
		HAP/AP	9658.069	2	4829.034	168.803	.000
		HLS/LS	8269.158	2	4134.579	444.608	.000
		HLP/LP	12309.918	2	6154.959	364.746	.000
2-Way Interactions	lamination* exposure	HAS/AS	2892.960	2	1446.480	124.838	.000
		HAP/AP	3763.450	2	1881.725	65.777	.000
		HLS/LS	3020.630	2	1510.315	162.410	.000
		HLP/LP	3900.071	2	1950.035	115.560	.000
Model		HAS/AS	49148.544	5	9829.709	848.352	.000
		HAP/AP	37202.746	5	7440.549	260.091	.000
		HLS/LS	50758.338	5	10151.668	1091.651	.000
		HLP/LP	44559.579	5	8911.916	528.125	.000
Residual		HAS/AS	973.293	84	11.587		
		HAP/AP	2403.029	84	28.607		
		HLS/LS	781.147	84	9.299		
		HLP/LP	1417.469	84	16.875		
Total		HAS/AS	50121.838	89	563.167		
		HAP/AP	39605.775	89	445.009		
		HLS/LS	51539.486	89	579.095		
		HLP/LP	45977.049	89	516.596		

Table C4. ANOVA for Extension at Break of Laminates and their Corresponding Backing Fabrics by *Lamination* and *Exposure* (all effects entered simultaneously)

			Unique Method				
		Sample Pairs	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	HAS/AS	3808.631	3	1269.544	1409.634	.000
		HAP/AP	2874.510	3	958.170	559.186	.000
		HLS/LS	3409.968	3	1136.656	951.923	.000
		HLP/LP	2922.039	3	974.013	515.732	.000
	lamination	HAS/AS	336.400	1	336.400	373.521	.000
		HAP/AP	776.748	1	776.748	453.309	.000
		HLS/LS	282.669	1	282.669	236.729	.000
		HLP/LP	361.602	1	361.602	191.465	.000
	exposure	HAS/AS	3472.231	2	1736.115	1927.691	.000
		HAP/AP	2097.762	2	1048.881	612.125	.000
		HLS/LS	3127.299	2	1563.649	1309.519	.000
		HLP/LP	2560.438	2	1280.219	677.865	.000
2-Way Interactions	lamination* exposure	HAS/AS	125.726	2	62.863	69.800	.000
		HAP/AP	31.171	2	15.585	9.096	.000
		HLS/LS	82.732	2	41.366	34.643	.000
		HLP/LP	24.890	2	12.445	6.589	.002
Model		HAS/AS	3934.357	5	786.871	873.701	.000
		HAP/AP	2905.681	5	581.136	339.150	.000
		HLS/LS	3492.700	5	698.540	585.011	.000
		HLP/LP	2946.929	5	589.386	312.075	.000
Residual		HAS/AS	75.652	84	.901		
		HAP/AP	143.935	84	1.714		
		HLS/LS	100.301	84	1.194		
		HLP/LP	158.643	84	1.889		
Total		HAS/AS	4010.009	89	45.056		
		HAP/AP	3049.616	89	34.265		
		HLS/LS	3593.001	89	40.371		
		HLP/LP	3105.572	89	34.894		

Table C5. ANOVA for Energy to Rupture of Laminates and their Corresponding Backing Fabrics by *Lamination* and *Exposure* (all effects entered simultaneously)

			Unique Method				
		Sample Pairs	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	HAS/AS	3.761	3	1.254	813.491	.000
		HAP/AP	3.446	3	1.149	329.046	.000
		HLS/LS	3.329	3	1.110	552.359	.000
		HLP/LP	3.953	3	1.318	401.381	.000
	lamination	HAS/AS	1.498	1	1.498	971.700	.000
		HAP/AP	.625	1	.625	179.020	.000
		HLS/LS	1.412	1	1.412	702.753	.000
		HLP/LP	.794	1	.794	241.860	.000
	exposure	HAS/AS	2.264	2	1.132	734.386	.000
		HAP/AP	2.821	2	1.410	404.059	.000
		HLS/LS	1.917	2	.958	477.163	.000
		HLP/LP	3.159	2	1.579	481.141	.000
2-Way Interactions	lamination* exposure	HAS/AS	.632	2	.316	205.007	.000
		HAP/AP	.463	2	.231	66.281	.000
		HLS/LS	.570	2	.285	141.788	.000
		HLP/LP	.521	2	.261	79.433	.000
Model		HAS/AS	4.393	5	.879	570.097	.000
		HAP/AP	3.908	5	.782	223.940	.000
		HLS/LS	3.898	5	.780	388.131	.000
		HLP/LP	4.474	5	.895	272.602	.000
Residual		HAS/AS	.129	84	1.541E-03		
		HAP/AP	.293	84	3.490E-03		
		HLS/LS	.169	84	2.009E-03		
		HLP/LP	.276	84	3.283E-03		
Total		HAS/AS	4.523	89	5.082E-02		
		HAP/AP	4.201	89	4.721E-02		
		HLS/LS	4.067	89	4.570E-02		
		HLP/LP	4.750	89	5.337E-02		

Table C6. ANOVA of Results for Stiffness, Tensile Properties, and Peel Strength of Laminates by *Adhesive*, *Backing*, and *Exposure* (all effects entered simultaneously)

			Unique Method				
		Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	Flex	279416.3	4	69854.072	39.397	.000
		Strength	49867.600	4	12466.900	380.947	.000
		Extension	5011.017	4	1252.754	651.292	.000
		Energy	10.973	4	2.743	555.196	.000
		Peel	51860.680	4	12965.170	177.258	.000
	adhesive	Flex	29057.606	1	29057.606	16.388	.000
		Strength	29.646	1	29.646	.906	.343
		Extension	1.389E-03	1	1.389E-03	.001	.979
		Energy	4.417E-03	1	4.417E-03	.894	.346
		Peel	48389.843	1	48389.843	661.579	.000
	backing	Flex	74054.450	1	74054.450	41.766	.000
		Strength	1333.617	1	1333.617	40.751	.000
		Extension	70.313	1	70.313	36.555	.000
		Energy	.192	1	.192	38.838	.000
		Peel	1720.513	1	1720.513	23.523	.000
	exposure	Flex	176304.2	2	88152.117	49.717	.000
		Strength	48504.337	2	24252.168	741.065	.000
		Extension	4940.703	2	2470.351	1284.305	.000
		Energy	10.777	2	5.388	1090.525	.000
		Peel	1750.324	2	875.162	11.965	.000
2-Way Interactions	(Combined)	Flex	13680.383	5	2736.077	1.543	.179
		Strength	342.443	5	68.489	2.093	.069
		Extension	6.383	5	1.277	.664	.652
		Energy	2.332E-02	5	4.665E-03	.944	.454
		Peel	199.150	5	39.830	.545	.742
	adhesive* backing	Flex	44.006	1	44.006	.025	.875
		Strength	2.046	1	2.046	.063	.803
		Extension	2.427	1	2.427	1.262	.263
		Energy	5.104E-04	1	5.104E-04	.103	.748
		Peel	.896	1	.896	.012	.912
	adhesive* exposure	Flex	9276.678	2	4638.339	2.616	.076
		Strength	104.755	2	52.378	1.600	.205
		Extension	.445	2	.223	.116	.891
		Energy	9.997E-04	2	4.999E-04	.101	.904
		Peel	172.261	2	86.131	1.178	.311
	backing* exposure	Flex	4359.700	2	2179.850	1.229	.295
		Strength	235.642	2	117.821	3.600	.029
		Extension	3.510	2	1.755	.912	.404
		Energy	2.181E-02	2	1.091E-02	2.207	.113
		Peel	25.992	2	12.996	.178	.837
3-Way Interactions	adhesive* backing* exposure	Flex	1526.144	2	763.072	.430	.651
		Strength	19.378	2	9.689	.296	.744
		Extension	2.637	2	1.319	.686	.505
		Energy	1.106E-02	2	5.532E-03	1.120	.329
		Peel	57.280	2	28.640	.392	.677

Table C6. ANOVA of Results for Stiffness, Tensile Properties, and Peel Strength of Laminates by *Adhesive*, *Backing*, and *Exposure* (all effects entered simultaneously) (con't)

		Unique Method				
	Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Model	Flex	294622.8	11	26783.892	15.106	.000
	Strength	50229.420	11	4566.311	139.531	.000
	Extension	5020.037	11	456.367	237.260	.000
	Energy	11.008	11	1.001	202.522	.000
	Peel	52117.110	11	4737.919	64.776	.000
Residual	Flex	297876.9	168	1773.077		
	Strength	5497.984	168	32.726		
	Extension	323.147	168	1.923		
	Energy	.830	168	4.941E-03		
	Peel	12288.020	168	73.143		
Total	Flex	592499.8	179	3310.054		
	Strength	55727.404	179	311.326		
	Extension	5343.183	179	29.850		
	Energy	11.838	179	6.613E-02		
	Peel	64405.130	179	359.805		

Table C7. ANOVA of Results for Stiffness and Tensile Properties of Coated and Uncoated Backing Fabrics by *Adhesive*, *Backing*, and *Exposure* (all effects entered simultaneously)

			Unique Method				
		Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	Flex	7009.485	5	1401.897	99.890	.000
		Strength	17311.809	5	3462.362	7871.287	.000
		Extension	16461.207	5	3292.241	3924.848	.000
		Energy	3.928	5	.786	4226.895	.000
	adhesive	Flex	746.007	2	373.004	26.578	.000
		Strength	166.580	2	83.290	189.350	.000
		Extension	180.905	2	90.452	107.833	.000
		Energy	.102	2	5.098E-02	274.285	.000
	backing	Flex	3549.781	1	3549.781	252.934	.000
		Strength	13034.587	1	13034.587	29632.656	.000
		Extension	7857.008	1	7857.008	9366.738	.000
		Energy	1.818	1	1.818	9779.335	.000
	exposure	Flex	2713.696	2	1356.848	96.680	.000
		Strength	4110.642	2	2055.321	4672.540	.000
		Extension	8423.294	2	4211.647	5020.918	.000
		Energy	2.009	2	1.004	5403.286	.000
2-Way Interactions	(Combined)	Flex	1924.652	8	240.581	17.142	.000
		Strength	250.500	8	31.312	71.185	.000
		Extension	650.820	8	81.353	96.984	.000
		Energy	.144	8	1.795E-02	96.576	.000
	adhesive* backing	Flex	271.785	2	135.893	9.683	.000
		Strength	166.883	2	83.441	189.694	.000
		Extension	140.655	2	70.327	83.841	.000
		Energy	6.963E-02	2	3.481E-02	187.304	.000
	adhesive* exposure	Flex	138.993	4	34.748	2.476	.045
		Strength	82.701	4	20.675	47.003	.000
		Extension	79.377	4	19.844	23.657	.000
		Energy	1.321E-02	4	3.303E-03	17.771	.000
	backing* exposure	Flex	1513.874	2	756.937	53.934	.000
		Strength	.916	2	.458	1.041	.355
		Extension	430.788	2	215.394	256.782	.000
		Energy	6.076E-02	2	3.038E-02	163.459	.000
3-Way Interactions	adhesive* backing* exposure	Flex	76.859	4	19.215	1.369	.245
		Strength	65.026	4	16.256	36.957	.000
		Extension	34.395	4	8.599	10.251	.000
		Energy	1.347E-02	4	3.368E-03	18.120	.000
Model		Flex	9010.996	17	530.059	37.769	.000
		Strength	17627.335	17	1036.902	2357.279	.000
		Extension	17146.422	17	1008.613	1202.419	.000
		Energy	4.085	17	.240	1292.915	.000
Residual		Flex	3536.667	252	14.034		
		Strength	110.848	252	.440		
		Extension	211.383	252	.839		
		Energy	4.684E-02	252	1.859E-04		
Total		Flex	12547.663	269	46.646		
		Strength	17738.183	269	65.941		
		Extension	17357.805	269	64.527		
		Energy	4.132	269	1.536E-02		

Table C8. ANOVA of Results for Tensile Properties of Backing Fabric Samples Coated with Appretan MB extra by *Backing* and *Exposure* (all effects entered simultaneously)

			Unique Method				
		Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	Strength	5705.695	3	1901.898	3658.054	.000
		Extension	5668.974	3	1889.658	2141.121	.000
		Energy	1.274	3	.425	3064.733	.000
	backing	Strength	4258.583	1	4258.583	8190.829	.000
		Extension	2604.996	1	2604.996	2951.651	.000
		Energy	.529	1	.529	3816.004	.000
	exposure	Strength	1447.113	2	723.556	1391.666	.000
		Extension	3063.978	2	1531.989	1735.855	.000
		Energy	.745	2	.373	2689.097	.000
2-Way Interactions	backing* exposure	Strength	2.121	2	1.060	2.039	.136
		Extension	182.558	2	91.279	103.426	.000
		Energy	2.107E-02	2	1.053E-02	76.046	.000
Model		Strength	5707.816	5	1141.563	2195.648	.000
		Extension	5851.532	5	1170.306	1326.043	.000
		Energy	1.295	5	.259	1869.258	.000
Residual		Strength	43.673	84	.520		
		Extension	74.135	84	.883		
		Energy	1.164E-02	84	1.385E-04		
Total		Strength	5751.489	89	64.623		
		Extension	5925.666	89	66.581		
		Energy	1.306	89	1.468E-02		

Table C9. ANOVA of Results for Tensile Properties of Backing Fabric Samples Coated with Lascaux Hot-seal Adhesive 371 by *Backing* and *Exposure* (all effects entered simultaneously)

			Unique Method				
		Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	Strength	5081.548	3	1693.849	4275.106	.000
		Extension	5103.321	3	1701.107	1758.697	.000
		Energy	1.110	3	.370	1224.577	.000
	backing	Strength	3263.563	1	3263.563	8236.906	.000
		Extension	1836.928	1	1836.928	1899.117	.000
		Energy	.388	1	.388	1284.208	.000
	exposure	Strength	1817.985	2	908.992	2294.206	.000
		Extension	3266.393	2	1633.196	1688.488	.000
		Energy	.722	2	.361	1194.761	.000
2-Way Interactions	backing* exposure	Strength	46.689	2	23.344	58.919	.000
		Extension	62.022	2	31.011	32.061	.000
		Energy	4.711E-02	2	2.356E-02	77.983	.000
Model		Strength	5128.236	5	1025.647	2588.631	.000
		Extension	5165.344	5	1033.069	1068.043	.000
		Energy	1.157	5	.231	765.939	.000
Residual		Strength	33.282	84	.396		
		Extension	81.249	84	.967		
		Energy	2.537E-02	84	3.021E-04		
Total		Strength	5161.518	89	57.995		
		Extension	5246.593	89	58.950		
		Energy	1.182	89	1.328E-02		

Table C10. ANOVA of Results for Tensile Properties of Uncoated Backing Fabric Samples by *Backing* and *Exposure* (all effects entered simultaneously)

			Unique Method				
		Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	Strength	6607.571	3	2202.524	5458.761	.000
		Extension	5728.039	3	1909.346	2864.088	.000
		Energy	1.526	3	.509	4346.483	.000
	backing	Strength	5679.324	1	5679.324	14075.707	.000
		Extension	3555.739	1	3555.739	5333.735	.000
		Energy	.971	1	.971	8296.454	.000
	exposure	Strength	928.246	2	464.123	1150.289	.000
		Extension	2172.301	2	1086.150	1629.264	.000
		Energy	.555	2	.277	2371.497	.000
2-Way Interactions	backing* exposure	Strength	17.132	2	8.566	21.230	.000
		Extension	220.603	2	110.301	165.456	.000
		Energy	6.053E-03	2	3.027E-03	25.868	.000
Model		Strength	6624.703	5	1324.941	3283.749	.000
		Extension	5948.642	5	1189.728	1784.635	.000
		Energy	1.532	5	.306	2618.237	.000
Residual		Strength	33.893	84	.403		
		Extension	55.999	84	.667		
		Energy	9.828E-03	84	1.170E-04		
Total		Strength	6658.596	89	74.816		
		Extension	6004.641	89	67.468		
		Energy	1.542	89	1.732E-02		

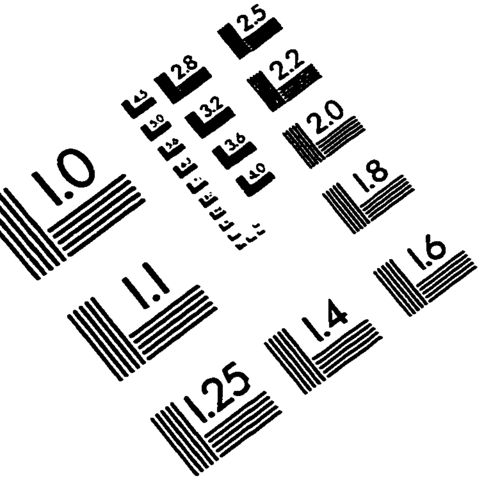
Table C11. ANOVA of Results for Tensile Properties of Coated and Uncoated Silk Crepeline Samples by *Adhesive* and *Exposure* (all effects entered simultaneously)

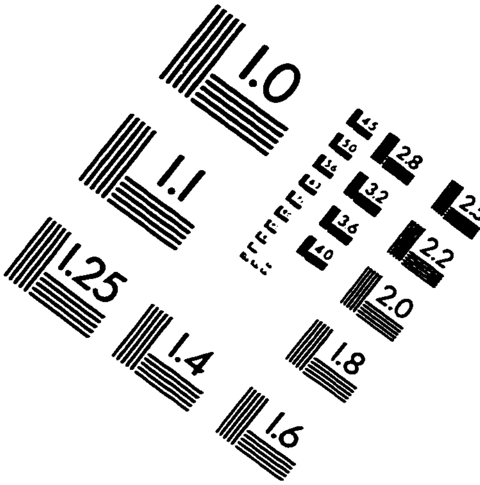
			Unique Method				
		Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	Strength	1999.142	4	499.785	1254.127	.000
		Extension	6330.558	4	1582.639	2101.232	.000
		Energy	.688	4	.172	3619.499	.000
	adhesive	Strength	1.866	2	.933	2.341	.100
		Extension	2.357	2	1.178	1.564	.213
		Energy	1.783E-03	2	8.915E-04	18.769	.000
	exposure	Strength	1997.276	2	998.638	2505.913	.000
		Extension	6328.201	2	3164.101	4200.901	.000
		Energy	.686	2	.343	7220.229	.000
2-Way Interactions	adhesive* exposure	Strength	7.012	4	1.753	4.399	.002
		Extension	25.132	4	6.283	8.342	.000
		Energy	2.281E-03	4	5.702E-04	12.004	.000
Model		Strength	2006.153	8	250.769	629.263	.000
		Extension	6355.690	8	794.461	1054.787	.000
		Energy	.690	8	8.624E-02	1815.751	.000
Residual		Strength	50.213	126	.399		
		Extension	94.903	126	.753		
		Energy	5.985E-03	126	4.750E-05		
Total		Strength	2056.366	134	15.346		
		Extension	6450.593	134	48.139		
		Energy	.696	134	5.193E-03		

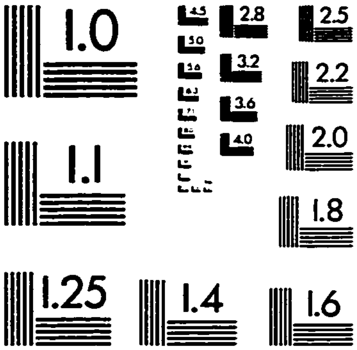
Table C12. ANOVA of Results for Tensile Properties of Coated and Uncoated Polyester Crepeline Samples by *Adhesive* and *Exposure* (all effects entered simultaneously)

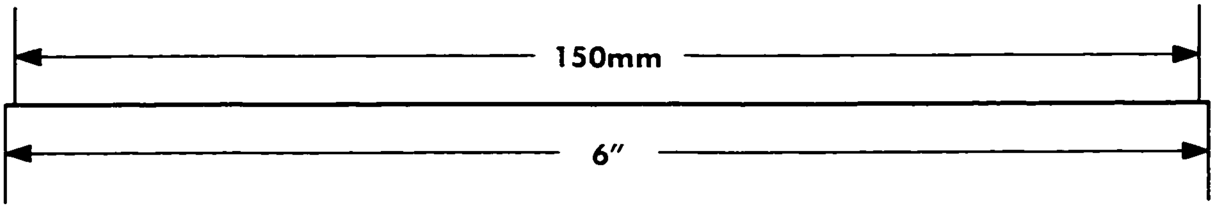
			Unique Method				
		Dependent Variable	Sum of Squares	df	Mean Square	F	Sig.
Main Effects	(Combined)	Strength	2445.879	4	611.470	1270.634	.000
		Extension	2845.084	4	711.271	769.404	.000
		Energy	1.553	4	.388	1197.636	.000
	adhesive	Strength	331.597	2	165.798	344.529	.000
		Extension	319.203	2	159.601	172.646	.000
		Energy	.170	2	8.490E-02	261.854	.000
	exposure	Strength	2114.282	2	1057.141	2196.738	.000
		Extension	2525.881	2	1262.941	1366.162	.000
		Energy	1.383	2	.692	2133.419	.000
2-Way Interactions	adhesive* exposure	Strength	140.715	4	35.179	73.102	.000
		Extension	88.640	4	22.160	23.971	.000
		Energy	2.440E-02	4	6.101E-03	18.815	.000
Model		Strength	2586.594	8	323.324	671.868	.000
		Extension	2933.724	8	366.715	396.687	.000
		Energy	1.578	8	.197	608.226	.000
Residual		Strength	60.635	126	.481		
		Extension	116.480	126	.924		
		Energy	4.085E-02	126	3.242E-04		
Total		Strength	2647.230	134	19.755		
		Extension	3050.204	134	22.763		
		Energy	1.619	134	1.208E-02		

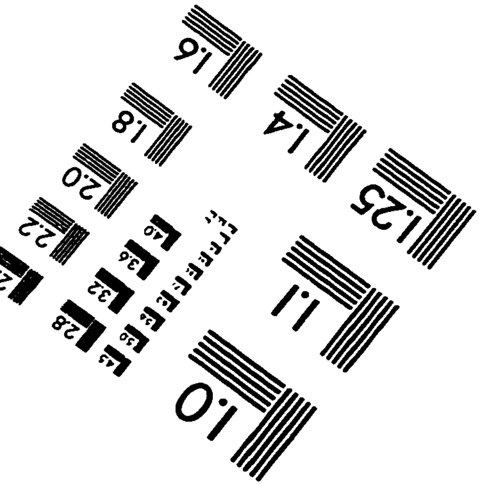
IMAGE EVALUATION
TEST TARGET (QA-3)











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