University of Alberta

Factors affecting the bond strength of textile artifact/adhesive/support fabric laminates

by

Irene Frances Karsten ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment
of the requirements for the degree of Doctor of Philosophy

Department of Human Ecology

Edmonton, Alberta

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ABSTRACT

Three interrelated studies describe the effects and determine the relative importance of factors influencing the adequacy of the adhesive bond in textile artifact/adhesive/support fabric laminates. The first study examined the bond through peel testing. Fabric laminates consisting of silk habutae or nylon taffeta artifacts, one of six adhesives, (Acryloid F10, Beva 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, or Vinamul 3252) and a support fabric (nylon net, polyester crepeline, or silk crepeline) were peeled at a rate of 50 mm min^{-1} in a controlled environment of 20 ± 2°C and 65 ± 5% RH. The transfer of adhesive to the artifact fabric during peeling was observed visually and through scanning electron microscopy. The peel strength of the adhesives varied significantly according to the surface area of adhesive available for bonding and the mechanical properties of the adhesives. Bonds to silk habutae were stronger than bonds to nylon taffeta. Laminates supported on nylon net had weaker bonds than those supported on silk or polyester crepeline. The second study determined the surface free energy components of adhesive films and artifact fabrics in order to estimate work of adhesion between adhesive and fabric surfaces. The contact angles of three probing liquids were determined on the solids using drop shape analysis (adhesive films) and the Washburn technique (fabrics). Surface free energy components and work of adhesion were calculated using the van Oss-Chaudhury-Good approach. Adhesives and fabrics were characterized as predominantly basic, low energy solids. Work of adhesion showed good correlation to peel strength when results for Acryloid F10 were excluded. The third study was an exploratory survey of textile artifacts given adhesive support treatments primarily within the past twenty years. The survey focussed on flat textiles and on adhesives equivalent to those tested in the laboratory. Data describing thirty-six artifacts, their treatment, and subsequent history were collected. The successful stabilization of textile artifacts treated with both weak and strong adhesives demonstrated that for the artifacts surveyed, techniques used to control stress after treatment must contribute to treatment success as much as the bond strength provided by the adhesive.

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W_P = work of peeling

W_A = work of adhesion

W_B = work of bending

W_D = work of deformation

F_P = peel force

ΔL = displacement of the peel force

ω = peel angle

ΔX = length of interface exposed during peeling

W_{IJ} = work of adhesion for phases I and J

γ_{IJ} = interfacial free energy of phases I and J

θ = contact angle

θ_a = advancing contact angle

π_e = spreading pressure

γ^{LW} = Lifshitz-van der Waals component of the surface free energy

γ^{AB} = acid-base component of the surface free energy

γ^+ = acidic parameter of the acid-base component of the surface free energy

γ^- = basic parameter of the acid-base component of the surface free energy

γ_I = surface free energy of phase I

V/t = rate of liquid flow in a capillary

g = gravitational constant

ρ = density of the liquid

η = viscosity of the liquid

l = length of the capillary

h = height of liquid penetration into a capillary

Δp = change in pressure across the interface

R = radius

m = mass of liquid absorbed into a porous solid

C = material constant characterizing the capillary volume of a porous solid

CHAPTER 1

INTRODUCTION

Adhesive Support Treatments for Textile Artifacts

The conservation of historic textiles within the context of museum or private collections requires a delicate balance between the preservation of physical materials, respect for evidence of the artifact's original context, and the needs of society to appreciate, study, and use textile artifacts. Maintaining the balance between these competing demands is especially difficult when the artifact is damaged and weak. Textiles may become degraded for several reasons, the most common being extended exposure to light. Displaying a very brittle textile in a manner indicative of the textile's original use, storing it rolled or hung from a hanger, or studying the textile in a manner that requires manipulation may be not only inadvisable but impossible. For this reason degraded artifacts often languish in storage. The difficulties encountered in trying to prepare the textile for display or make it available for study prevent its use. Yet it is part of the conservator's ethical duty to try to find a way to make the artifact accessible while not compromising its preservation (Canadian Association for Conservation of Cultural Property & Canadian Association of Professional Conservators, 2000, Article 1).

Adhesive treatments have been used by professional conservators on weak textiles with varying degrees of success for at least forty years. In general, textile conservators use adhered supports on artifacts such as closely woven fabrics, painted textiles, and textiles embrittled due to light exposure, weighting with metal salts, or the use of iron mordants (Hillyer, Tinker, & Singer, 1997), artifacts that would be physically damaged or aesthetically disfigured by stitching or pressure mounts. A number of adhesive techniques have been developed to deal with these problems. The most common form of adhesive treatment for textile artifacts is adhesive support using a heat-sealing approach (Hillyer et al., 1997; Yates, 1987). In this treatment, a thermoplastic adhesive is brushed, rolled or sprayed onto a sheer support fabric and allowed to dry. The coated support is then positioned next to the "reverse" of the artifact and heat-sealed in place using a hand-held iron, spatula, or vacuum hot-table. The whole artifact or only parts of it may be supported in this manner. Although flat objects are most easily treated this way, many types of textiles, including garments, have been given adhered supports.

Adequate Bond Strength

In order for an adhesive support treatment to be successful, the bond between the artifact and support fabric must be stable and capable of supporting the textile artifact. Textile conservators have used the term “adequate support” when describing choices made for adhesive treatments (Hartog & Tinker, 1998). What “adequate” bond strength means and how it is achieved, however, are poorly defined in the textile conservation literature. Figure 1.1 illustrates the primary factors contributing to the adequacy of an adhesive bond. The left side of the diagram comprises the factors that are usually considered in relation to the strength of an adhesive bond: the materials used as adherends and adhesive, the joint design, or manner in which the adherends are fastened together by means of the adhesive (adhesive treatment techniques), and mechanical reinforcement, such as stitching, which may be added to ensure attachment of the adherends. Case studies and adhesive research that discuss bond strength tend to focus on analysing or modifying materials and bonding techniques. In the textile conservation literature, adhesive materials and joint design are often treated as almost synonymous. Pretzel (1997a; 1997b) compares the bond strength of several adhesives as they are used in treatments by conservators without discussing whether those application techniques, which vary from adhesive to adhesive, produce equivalent interfaces in all respects except adhesive formulation. Moreover, Pretzel judges the adequacy of these bonds in relation to a standard that was probably defined for industrial purposes, assuming that this standard is applicable to textile conservation requirements. The role of supplementary stitching in bond reinforcement has not been addressed in textile conservation research on adhesive treatments even though textile conservators often use stitching

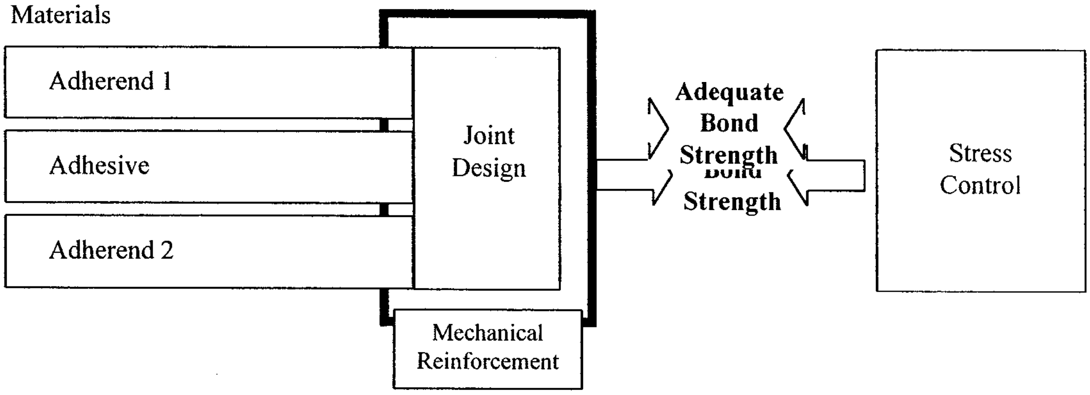

Figure 1.1 Factors contributing to adequate bond strength in adhered structures.

in addition to adhesives (Brooks, Eastop, Hillyer, & Lister, 1995). Given that Pretzel's study is the only one available to textile conservators that compares the bond strength of a selection of adhesive treatments suitable for conservation treatment, further research determining and distinguishing the effects of adhesive and adherend materials, joint design, and mechanical reinforcement is greatly needed.

The adequacy of an adhesive bond, however, can only be determined in relation to the function of the bond. The adhesive bond in a textile conservation treatment is one element of a treatment strategy used to stabilize the artifact. The right side of Figure 1.1 is another element of the textile conservator's strategy: control of the stresses to which the bond will be exposed. Stress control is preventive conservation as it applies to the adhesive bond. Conservators can reduce the need for high bond strength by restricting the forces to which the bond will be subjected; for example, by attaching the adhered textile to a rigid mount. Textile conservators have considered this aspect of ensuring adequate bond strength, but often incidentally rather than systematically, as part of the process of choosing an adhesive. Ethically, exploiting the potential of stress control might be key, if it permits the use of weaker bonds that optimize treatment reversibility. To date, however, conservators have no evidence that stress control is an effective means of achieving adequate bond strength.

Dissertation Overview

In order to make effective treatment decisions regarding adhesive support of textile artifacts, textile conservators need, therefore, clear definition of "adequate" bond strength, and detailed assessment of how materials and techniques used in adhesive support and supplementary treatments affect bond strength and prevent bond failure. Attempts to define "adequate" bond strength cannot succeed without a clear, tested model of the main factors contributing to it. This dissertation research was designed to demonstrate that the four broad factors depicted in Figure 1.1—adhesive and adherend materials, joint design, mechanical reinforcement, and stress control—are all important to the provision of adequate bond strength in adhesive support treatments for textile artifacts. This research will also test the effects of selected treatment materials and techniques on both bond strength and the frequency of bond delamination in treated artifacts. These primary goals form the purpose of this research.

Research Purpose

The purpose of this dissertation research is to determine the effects and the importance of the following factors towards the formation of an adequate adhesive bond in textile artifact/adhesive/support fabric laminates:

i) selected adhesive treatment materials,

ii) selected adhesive treatment techniques (joint design), and

iii) associated non-adhesive treatment techniques and post-treatment handling (mechanical reinforcement and stress control).

Three different research approaches were employed in examining bond strength: peel testing, surface characterization, and artifact survey. In addition to using these approaches for the research purpose stated above, this research assessed the usefulness of these approaches for textile conservation science, particularly the latter two, which have not been used to study fabric laminates. Three interrelated studies were conducted based on these research approaches. These studies comprise the three main chapters of the dissertation.

Chapter 2: Peel strength

The dissertation begins by using peel testing to examine bond strength in textile artifact/adhesive/support fabric laminates, the perspective used in research by conservation scientists and in mock-up testing by textile conservators. Assessment of peel strength is, at first glance, a highly appropriate technique for analysing factors affecting bond strength produced by textile conservation adhesive support techniques, since specimens can be prepared using materials and methods identical to those used in actual treatments. Numerous materials and technique variations could be studied using peel testing. Ideally the results of these tests would permit ranking adhesive and support materials in terms of the relative strength of the bonds they produce so that textile conservators could choose appropriate materials for a wide variety of treatment situations. Since peel tests do not measure a basic physical property of materials, however, categorizing the bond strength of adhesives based on peel testing of specimens produced from particular materials prepared in particular ways, as Pretzel (1997a; 1997b) does, may not be appropriate. The first purpose of this chapter is to demonstrate conclusively that such generalizaton is not valid. Meanwhile, the tests used in this demonstration permit comparison of the effects on peel strength of a selection of materials most often used in adhesive support treatments and of a few treatment techniques variations that are commonly used by textile conservators.

Objectives

The objectives of this study were:

- to measure the peel strength of laminates made from silk or nylon fabrics (the artifact), six adhesives, and silk crepeline, polyester crepeline, or nylon net support fabrics;
- to determine and distinguish between the effects of these selected materials and the effects of selected treatment techniques on peel strength; and
- to compare peel strength results and adhesive ranking by peel strength with the results observed by Pretzel (1997a; 1997b) in order to assess the validity of Pretzel's scoring system.

Hypotheses

This study tested the following hypotheses:

- the peel strength of the laminated textiles varies significantly according to the type of artifact fabric (silk habutae versus nylon taffeta), the type of adhesive (Acryloid F10, Beva 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252), and the type of support fabric (silk crepeline, polyester crepeline, or nylon net);
- the peel strength of the laminated textiles varies significantly with the concentration of dispersion adhesive solutions (1:10 versus 1:5 v/v) and with the adhesive application technique (spray versus brush) for solvent-based adhesives; and
- Pretzel's (1997a; 1997b) scoring system is not always valid when the materials or techniques used to create laminated specimens are changed.

Delimitations and limitations

Although peel testing permits close approximation of treated artifacts, laboratory experiments require some restriction of variability in order to isolate the effects of particular factors. For this study, the treated artifact was modeled using new, undyed fabrics to simulate the artifact and as support fabrics. Fabrics made from only two fibres, silk and nylon, were tested as representative of textile artifacts, and of these only smooth, plain-weave fabrics were used, even though the fabrics found in artifacts are more variable. No artifact decoration, such as paint or embroidery, were considered. A selection of adhesives was chosen with an intention to include adhesives used to treat the surveyed artifacts and to cover the major polymer types currently used by textile conservators. Adhesives were applied using textile conservation techniques in order to approximate the techniques used to treat the surveyed artifacts so that the results of this study could be compared to the observations recorded in the artifact survey.

Chapter 3: Surface interactions

From a surface science perspective, the adhesive bond comprises interactions at the interface between two materials at the molecular level. The second study in this dissertation examines the textile artifact/adhesive bond in terms of surface free energies and work of adhesion. This approach permits focussing on material effects on bond strength independent of the variations introduced by application technique.

Objectives

The objectives of this study were:

- to determine the surface free energy components of films made from six adhesives used by textile conservators (Acryloid F10, Beva 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252);
- to determine the surface free energy components of silk habutae and nylon taffeta;
- to calculate the work of adhesion of these two fabrics to the six adhesives;
- to correlate the results of work of adhesion those of peel strength; and
- to assess the usefulness of surface characterization techniques to the study of bond strength of textile artifact/adhesive/support fabric laminates.

Hypotheses

This study tested the following hypotheses:

- the surface free energies of adhesive films cast from Acryloid F10, Beva 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252 are distinct;
- the acid-base component of the surface free energy of silk habutae is greater than that of nylon taffeta;
- the work of adhesion between the adhesives and silk habutae is significantly greater than that between the adhesives and nylon taffeta;
- there is a significant correlation between the results for work of adhesion and peel strength; and
- the work of adhesion values for the adhesives do not vary as greatly as peel strength results.

Delimitations and limitations

Specimens analysed in this study were produced from the same materials as used for peel tests, in order that the results of these two studies could be compared. Only the interactions between the adhesives and the artifact fabrics were characterized, however, since delamination often occurs at the artifact-adhesive interface. The probing liquids used for contact angle measurements were liquids for which the Lifshitz-van der Waals and acid-base components are known and which are considered appropriate for the van Oss-Chaudhury-Good approach (Good, 1993). Although the probing liquids caused no obvious deleterious effects on the adhesive films and artifact fabrics, some swelling or surface reorientation of the fabrics and adhesive films may have occurred. The surface free energy and work of adhesion results of this study are, therefore, primarily used for comparing the adhesives and artifact fabrics.

Chapter 4: Artifact Survey

The final study in this dissertation approaches the bond in the textile laminate from the perspective of the treated textile artifact. To a textile conservator, the adhesive bond joins a valuable, unique, and fragile textile artifact to a coating of synthetic polymer on a sheer support fabric. The textile has probably been dyed, possibly painted or embroidered, and probably washed but not neccesarily fully cleaned. In addition to the adhesive treatment, the textile will probably also be supported with supplementary stitching and an appropriate mount. Ultimately, the adequacy of an adhesive bond—the ability of a bond to provide continued support without delamination—will be determined in this context: the treatment of a particular textile artifact. This chapter assesses the ability of adhesive treatment materials to produce adequate bonds on real artifacts by surveying a selection of textile artifacts that have been treated mostly within the past twenty years.

Objectives

The objectives of this study were:

- to design, with the help of textile conservators, a computerized database form suitable for surveying the treatment techniques and the current condition of adhesive-treated flat textile artifacts;
- to characterize the kinds of bond delamination observed on artifacts given adhesive supports;

- to relate the frequency of bond delamination to treatment materials (adhesives, support fabrics), the presence of mechanical reinforcement (supplementary stitching), and the use of techniques that reduce artifact flexing (stress control);
- to determine whether relatively high bond strength, as defined by Pretzel's (1997a; 1997b) criterion is necessary to prevent bond delamination; and
- to assess the challenges facing researchers who wish to use existing treated artifacts and the related treatment records to study questions concerning the success or failure of adhesive support treatments.

Hypotheses

This study tested the following hypotheses:

- the frequency of bond delamination in adhesive-treated textile artifacts is dependent on the type of adhesive and support fabric used;
- bond delamination in treated textile artifacts occurs less frequently when the bond is mechanically reinforced using supplementary stitching, and when the flexing of treated artifacts is prevented; and
- adhesive treatments that fail to meet Pretzel's (1997a; 1997b) criterion for adequate bond strength (100 N m^{-1}) can provide adequate support for textile artifacts with minimal bond delamination.

Delimitations and limitations

The survey was considered an exploratory test of the survey instrument in order to keep the survey of reasonable size given the time available. The survey focussed on flat textiles; therefore, only a few garments were examined. The population of textile artifacts sampled for the survey was limited to those in public collections where access was permitted. Since textile conservators have just begun to identify and consider brittle nylon artifacts for adhesive treatments, no adhesive-treated nylon artifacts were surveyed. Data gathered for the survey was limited by the quality of the treatment records, by the degree of access to the artifact granted by the institutions involved, and by the nature of the textile mounting system.

Chapter 5: Conclusions

The final chapter summarizes the results of the three studies. The conclusions drawn from each study in response to the hypotheses given above are reviewed. Connections between the three studies are highlighted. Information pertaining to the effects of the six adhesives, two artifact fabrics, and three support fabrics on textile laminate bonds is drawn together from the three studies. The usefulness of the three research approaches is evaluated. Finally the implications of the results of these studies for future research on the bond strength of textile artifact/adhesive/ support fabric laminates are reviewed.

Definition of key terms

For the purposes of this dissertation:

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, p. 342-343).

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

Advancing contact angle is a "recently advanced" angle (Good, 1993, p. 11), "the angle which [a] liquid makes on a flat solid surface, measured at the tangent to the drop at the triple point: liquid—solid—air, at the moment the drop has just stopped advancing" (van Oss, 2002, p. 671), or, more generally, the angle a liquid makes in relation to the solid as the liquid spreads over the solid.

Artifact refers to a textile of historic or artistic worth considered worthy of preservation. By extension, it is also used to describe the fabric swatches or specimens that represent the artifact in the laboratory experiments.

Bond strength is the force required to separate two materials to form two new surfaces.

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 cultural property as embodied in its physical and chemical nature, with the least possible intervention. Conservation includes...examination, documentation, preventive conservation, preservation, treatment restoration and reconstruction" (Canadian Association for Conservation of Cultural Property & Canadian Association of Professional Conservators, 2000, Article 1).

Contact angle is the angle, measured in the liquid, that is formed at the junction of three phases (Hiemenz & Rajagopalan, 1997, p. 252).

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

Dispersion refers to a two-phase system wherein one phase is suspended in another (Shields, 1984, p. 345). The adhesive dispersions referred to in this dissertation consist of solid polymer particles (dispersed phase) suspended in water (continuous phase).

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

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 two materials including that between an adhesive and adherend.

Interfacial free energy or *interfacial tension* is "the reversible work required to create a unit of interfacial area" (Wu, 1982, p. 1).

Nylon refers to polyamide fibres and fabrics made from the condensation polymerisation of hexamethylene diamine and adipic acid (nylon 6,6).

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 refers to poly(ethylene terephthalate) fibres, fabrics, and films.

Sample refers to a portion of a population (e.g. adhesive-treated textiles) that is examined in order to characterize that population.

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.

Specimen refers to "a specific portion of a material or laboratory sample upon which a test is performed or which is taken for that purpose" (Canadian General Standards Board (CGSB), 1987, p. 2).

Spreading coefficient is "the work required to expose a unit area of solid-vacuum interface while destroying corresponding amounts of solid-liquid and liquid-vacuum interfaces" (Connor, Bidaux, & Månson, 1997, pp. 5060-5061).

Support fabric refers to the layer of new textile material added to the reverse side of a weak textile artifact, either completely or in patches, for reinforcement, protection, or restoration of design features as part of a textile conservation treatment (Brooks et al., 1995, p. 5).

Surface free energy is the energy per unit area of the surface and is equivalent to the *surface tension* or the force per unit length of the boundary of the surface (Hiemenz & Rajagopalan, 1997, p. 255).

Taffeta is a plain weave fabric that has a fine, smooth, crisp, often lustrous face and usually a fine cross rib due to heavier weft yarns (Tortora & Merkel, 1996, p. 559).

Wetting tension is defined as "the work done in eliminating a unit area of the solid-liquid interface while exposing a unit area of solid-vacuum interface" (Connor et al., 1997, p. 5061).

Work of adhesion refers to the work required to reversibly separate a unit of solid-liquid interface and form a unit of liquid-vacuum and solid-vacuum interface (Connor et al., 1997, p. 5060), or, more generally, to the work required to reversibly separate two bulk phases (Wu, 1982, p. 4).

Work of peel is the force required to separate two solid layers joined by an adhesive over a unit distance through a peeling action.

Work of bending refers to the force expended in curving of the flexible adherends away from the adhered interface during the peeling of an adhered structure.

Work of deformation refers to the force expended in elastic and viscoelastic stretching of the adherends or adhesive during the peeling of an adhered structure.

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CHAPTER 2

PEEL STRENGTH OF SILK AND NYLON TEXTILES ADHERED TO SHEER SUPPORT FABRICS[1]

Introduction

Textile conservators regard bond strength as an important characteristic of adhesives when considering adhered support treatments for textile artifacts. Bond strength is often mentioned among adhesive properties considered when selecting a particular formulation (Cruickshank & Morgan, 1995; Hillyer, Tinker, & Singer, 1997; Lord, 1997; Mailand, 1998; Muir & Yates, 1987). Descriptions of mock-up tests used by conservators to determine treatment choices for adhesive support often include a qualitative assessment of bond strength or adhesion (Grant, 1995; Hartog & Tinker, 1998; Thomsen, 1984; Wills, 1995).

Research studies have used peel tests to distinguish the bonding ability of various adhesives used for support treatments by textile conservators (Pretzel, 1997a, 1997b; Karsten, 1998). Such tests are often used to assess bond strength in flexible laminates. Like other mechanical measures of bond strength, however, peel tests do not assess a basic physical property of materials. Peel tests quantify bond strength with respect to a particular test geometry and method conducted under particular environmental conditions and to a particular usage of the materials (Gardon, 1967; Kaelble, 1971, pp. 450-451). The angle, rate, and temperature at which the peel test is conducted affect the results as well as the properties of the adhesives and substrates and the manner in which they are employed to create the laminate. Since various adhesive concentrations or application techniques and few fabric types were used to make the specimens, the Pretzel and Karsten studies do not clarify the extent to which the recorded differences are due to adhesive formulations or to application technique and laminate fabrics.

The matrix developed by Pretzel (1997a; 1997b) is the only tool based on research results currently available to help textile conservators decide on an appropriate adhesive for a particular treatment. Pretzel used peel strength values among other test results and observations to construct the matrix. Peel test results were classified as good (> 100 N m^{-1}), acceptable (50-100 N m^{-1}), or poor (< 50 N m^{-1}) and scored accordingly (Table 2.1). Peel scores were combined with scores

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[1] A version of this chapter was presented at the meeting of the American Institute for Conservation Textile Specialty Group in Washington, DC on June 9, 2003 and has been accepted for publication in the postprints. Karsten, I. F. & Kerr, N. (in press). Peel strength and reversibility of adhesive support treatments on textiles: The nature of bond failure as revealed by scanning electron microscopy. *The Textile Specialty Group Postprints.*

from observations regarding the transfer of adhesive from the support fabric to the artifact fabric during the test to give a final bond strength score. The surface on which the adhesive was observed after peeling was classified as follows: support only, both support and artifact, or none apparent (adhesive is absorbed into the fabrics) (Table 2.1). The final bond strength score was computed by taking a weighted average of these two scores as follows:

$$\text{bond strength score} = [(3 \times \text{peel score}) + \text{surface score}] / 4 \qquad (2.1)$$

When using the matrix, conservators multiply these bond strength scores by a weighting factor that represents the significance of this property to the treatment under consideration.

As a means of ensuring the choice of an adhesive of adequate bond strength for the needs of a particular artifact, Pretzel's (1997a; 1997b) matrix may be misleading. Conservators use the matrix to select an adhesive. The bond strength scores result from peel tests of specimens produced from adhesive solutions of varying concentration (10 to 50% by volume) applied by brush in a particular manner over polyester crepeline laid on particular release materials and adhered after drying to silk habutae. Given that peel tests are affected by the materials used and the manner in which they are used, the validity of using a single set of tests to produce a generic ranking of adhesives according to bond strength in this manner is questionable. Textile conservators are known to employ a variety of adhesive solution concentrations, solvents, application techniques, and support fabrics to support different artifact fabrics (Karsten, 1998). Pretzel's method of ranking, as it pertains to bond strength, would be inadequate if altering the concentration, application method, or fabrics resulted in a different score.

Table 2.1 System used by Pretzel (1997a; 1997b) to classify peel strength and the surface on which the adhesive is observed after peeling.

Test	Observation	Score	Classification
Peel strength	> 100 $\mathrm{Nm^{-1}}$	0	good
	50 to 100 $\mathrm{Nm^{-1}}$	3	
	< 50 $\mathrm{Nm^{-1}}$	10	poor
Adhesive transfer	adhesive remained on support	0	good
	no adhesive apparent (absorbed)	7	undesirable
	adhesive on both support and 'artifact'	10	undesirable

A model that includes the effect of materials (adhesives and adherends) and techniques (joint design) as separate factors contributing to the provision of adequate bond strength (see Figure 1.1) could serve as the foundation for the building of a better instrument for assessing the ability of an adhesive to provide sufficient bond strength to support a particular artifact. This study will demonstrate that both the materials and techniques used to produce textile laminates significantly affect peel strength. It will show, moreover, that Pretzel's (1997a; 1997b) scoring system is not always valid when the materials or techniques used to create laminated specimens are changed. In doing so, this study will assess the effects on peel strength of the following materials: two artifact fabrics (silk habutae and nylon taffeta), six adhesives (Acryloid F10, Beva 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252), and three commonly used support fabrics (nylon net, polyester crepeline, and silk crepeline). In addition, it will examine the effects of two often used variations in laminate preparation technique: adhesive solution concentration for dispersion adhesives (1:10 versus 1:5 v/v) and adhesive application technique (spray versus brush) for solvent-based adhesives.

Factors affecting peel strength

Before reporting the experimental results of this study, it is important to consider more closely the factors that affect peel strength. Because peel strength represents a complex phenomenon, understanding these factors is necessary in order to interpret test results. The following is a general review of such factors. Many will not be tested directly in this study. Recognition of how all these variables might affect peel force, however, will improve the interpretation of these research results as they apply to the less controlled reality of treatment practice.

Theoretical modelling of peel force

Despite considerable attention paid to the development of a mathematical model describing the force exerted during peeling of flexible laminates, no model yet accounts for all the various geometries and materials that the peel test may be used to characterize. Most detailed models are built from a generally agreed upon basic understanding of the major components of the work expended to peel an adhered structure, W_P: work of adhesion, W_A, work of bending, W_B, and work of deformation, W_D:

$$W_P = W_A + W_B + W_D. \qquad (2.2)$$

The work of adhesion is the thermodynamic parameter, the intrinsic adhesion of the material or materials that form new surfaces upon fracture. The work of bending and deformation depend on the mechanical properties of the adhesive and adherend layers.

The work of peeling has also been described in terms of the basic definition of work: force exerted over a distance. The work of peeling equals the product of the peel force, F_P, as recorded by the peel test, and the displacement of the peel force, ΔL. (Kaelble, 1971, p. 426). The latter can be expressed in terms of the peel angle, ω, and the length of interface exposed by peeling, ΔX (Figure 2.1):

$$W_P = F_P \Delta L = F_P (1 - \cos \omega) \Delta X. \qquad (2.3)$$

Because neither equation 2.2 nor equation 2.3 describes the work of peeling in terms of the properties of the materials used to produce laminates, they are not very useful for predicting peel strength.

Researchers have attempted to define the mechanical properties of the laminate materials that must be considered when deconstructing the peel force. Energy can be dissipated through both elastic and plastic or viscoelastic mechanisms in either or both the adhesive and adherend layers (Aravas, Kim, & Loukis, 1989; Kaelble, 1971; Kinloch, Lau, & Williams, 1994). Strain energy may be stored in the peeled arm of the laminate if the material is extensible. Energy may

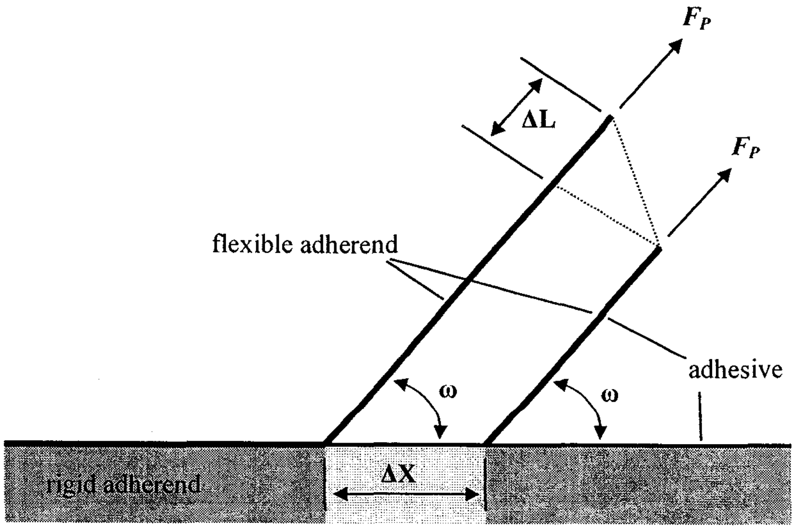


Figure 2.1. Diagram illustrating the physical work of peel, $W_P = F_P \Delta L$.
Note. Adapted from Kaelble (1971, p. 426).

also be dissipated due to tensile deformation of the peel arm and/or adhesive layer, and, in cases when the peel angle is less than 90°, shear deformation of the adhesive. Further energy is dissipated simply due to bending the peel arm. In the case of the T-peel test, the properties of two distinct adherends may be involved in addition to those of the adhesive, as is the case in laminates produced from the adhesive support treatment of historic textiles.

Peel testing variables

One of the characteristics of the manner in which peel tests have been used to test bonded materials, especially in the conservation literature, is the lack of consistent testing procedures. The numerical results of peel tests conducted in disparate ways cannot be compared if variations in test methods influence the results. Unfortunately, changing the test method does influence the results; therefore, an understanding of how the basic parameters of the testing procedure affect the measured peel force must precede the interpretation and comparison of any literature comparing materials or bonding techniques.

Rate-temperature dependence

Given that many adhesives are viscoelastic materials, the peel strength of adhered structures is, not surprisingly, affected by the rate and temperature of the test, as are the mechanical properties of viscoelastic polymers in general. Rate-temperature effects on peel strength have been depicted in two ways. Gerace (1983) constructed contour drawings consisting of sets of constant peel force "isocleaves" on rate versus temperature graphs. More frequently, graphs of peel force versus peel rate (Chalykh, Chalykh, & Gerasimov, 2002; Gandur, Kleinke, & Galembeck, 1997; Gardon, 1963, 1967; Mantel & Descaves, 1992; Pelton, Chen, Li, & Engel, 2001; Zosel & Schuler, 1999), peel temperature (Gardon, 1967; Takemoto, Kajiyama, Mizumachi, Takemura, & Ono, 2002), or both (Tse, Hamed, & Tathgur, 1997) are depicted. Peel rate and temperature data may also be assembled to form master peel curves at a reference temperature through the use of a horizontal shift factor, a_T (Derail, Allal, Marin, & Tordjeman, 1997; Derail, Allal, Marin, & Tordjeman, 1998; Gibert, Allal, Marin, & Derail, 1999; Kaelble, 1971, pp. 473-481; Wu, 1982, pp. 541-547; Yarusso, 1999). Such master curves are possible because the peel behaviour of certain adhesives exhibits a time-temperature dependence that corresponds to the Williams-Landel-Ferry (WLF) relation (Derail et al., 1997).

Change in peel rate or temperature affects the peel force through changes in the effective rheological properties of the adhesive (Figure 2.2). At low peel rates or high temperatures (well above the glass transition temperature, Tg), the adhesive is viscous and weak relative to the interfacial bond; thus, failure is cohesive, occurring within the bulk of the adhesive. At intermediate rates or temperatures (above Tg), the adhesive is still flexible but rubbery and stronger; failure is at the interface with the rigid substrate (interfacial or adhesive failure). Within each of these regions, peel strength increases with increased peel rate or decreased temperature. A drop in peel force often marks the transition from cohesive to interfacial failure. Mixed cohesive/adhesive failure may also be observed at this point (Gardon, 1967). At peel rates for which the behaviour of the adhesive is equivalent to that at Tg, a stick-slip failure occurs. The

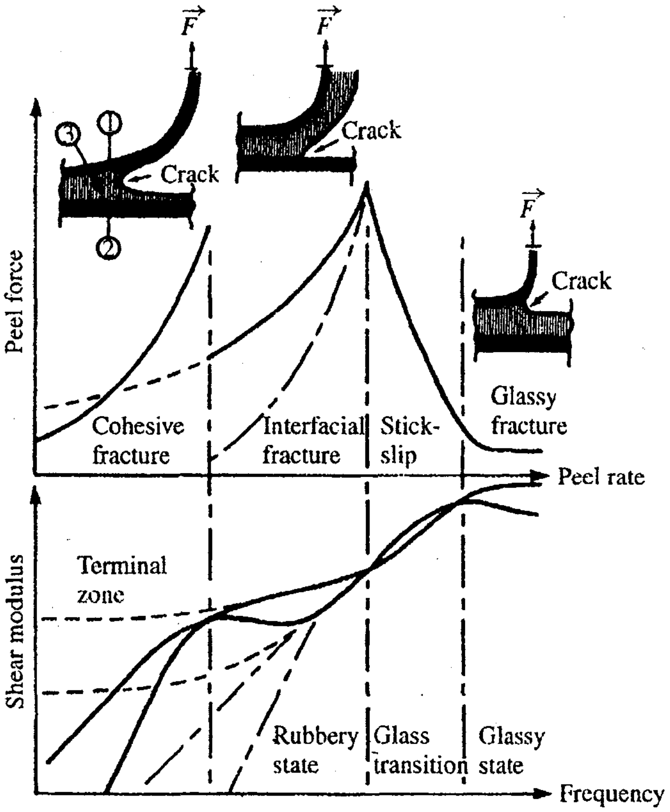


Figure 2.2. Schematic diagram of the relationship between the viscoelastic properties of the adhesive and the peel properties of the system.

Note. From "Effect of the rheological properties of industrial hot-melt and pressure-sensitive adhesives on the peel behavior" by F.X. Gibert et al., *Journal of Adhesion Science and Technology, 13*, p. 1030. Copyright 1999 VSP. Reprinted with permission.

bond fails in short spurts, discontinuously. In such cases the peel rate, or rate of fracture of the bond, must be distinguished from the pull rate, the speed of the testing instrument (Gandur et al., 1997). Finally, at very high peel rates or low temperatures, the adhesive exhibits glassy behaviour; peel strength is low, and the bond fails at the interface with the flexible member. In each case, failure occurs at the weakest point in the system (Kaelble, 1971, pp. 430-432). Derail et al. (1997) have demonstrated the correctness of these failure patterns with aluminium specimens adhered with commercial hot-melt adhesives. The location of failure shifted to the predicted location if the temperature was altered in the middle of the test, regardless of where failure was initiated. Based on such models, researchers have suggested that intrinsic adhesion might actually be measured at peel rates in which viscoelastic energy dissipation becomes negligible; that is, at very low peel rates (Farris & Goldfarb, 1993; Kinloch et al., 1994), or at very high peel rates (Gibert et al., 1999).

Although the variation of peel force with peel rate and temperature is known to conservators (Berger & Zeliger, 1984; Daly Hartin, Michalski, & Pacquet, 1993), the rationale for chosen peel rates in conservation science research has been poorly considered, leading to a variety of rates and data that cannot be easily compared. Berger (1972; 1984) introduced the use of very low peel rates (1-2 mm min^{-1}) on the assumption that such rates better model the type of force that would cause the delamination of a lined painting. The use of such a slow rate limits the number of specimens that can be tested simply because each peel test takes over one hour to complete. As a result, sample sizes are sometimes overly small in studies that use such slow rates (Hawker, 1987). Daly Hartin et al. (1993) chose, therefore, to use faster rates (40-50 mm min^{-1}) and test more specimens. At three specimens per treatment group, however, their sample size is still relatively small, even compared to other studies that used the slower rate (Allard & Katz, 1987; Berger, 1972; Katz, 1985). Although three specimens is consistent with the requirements of standard test methods for bonded fabrics (American Society for Testing and Materials (ASTM), 1998; Canadian General Standards Board (CGSB), 1997), it is insufficient for producing statistically reliable means given the variability of peel results for laminates that model conservation treatments. Another group of studies on adhesive linings for paintings used an even faster peel rate of 305 mm min^{-1} (Gayer, 1992; Hardy, 1992; Pullen, 1991), resulting in figures that cannot be directly compared with the rest of the research on the bond strength of lined paintings.

Pretzel (1997a; 1997b) illustrated the effect of temperature on peel strength of silk habutae/polyester crepeline laminates in a relatively crude way by measuring peel strength at room temperature and at elevated temperatures produced by a hot air blower. The hot peel strength of each adhesive tested was lower—often dramatically so—than that of the peel strength determined at room temperature (see Table 2.2). These results are consistent with the general trend towards lower peel strengths at higher peel temperatures discussed above.

Peel angle

Another factor complicating the results of peel tests is the angle at which the adherends are separated from each other. The peel angle is largely determined by the geometry of the test, the most frequent configurations in research involving textile laminates being the 90° T-peel and the 180° peel from one substrate held rigid. Peel angle influences the force required to separate laminates by changing the precise nature of the forces acting on the interface (Kaelble, 1971, p. 425). In a 90° peel, a tensile force is exerted on the bond. When the peel angle is lower than 90°, a shear force is exerted in addition to the tensile force. The shear force becomes the major component as the angle approaches 0°. When the peel angle is higher than 90°, a shear force in the opposite direction is expected in addition to tensile forces, although Kaelble has suggested that the tensile forces predominate.

Peel adhesion theory suggests the manner in which peel angle, ω, affects the magnitude of peel strength. Wu (1982, p. 551) showed through stress and energy analysis that the peel force, F_P, should vary inversely with $(1 - \cos \omega)$. This can be seen by modifying equation 2.3 given above:

$$F_P \Delta X = W_P / (1 - \cos \omega) \qquad (2.4)$$

where W_P is the work of peel. The peel force should, therefore, be highest at very small angles and lowest at 180°. Experimental results show that this holds for intermediate angles but not for very small or large angles where shear forces or bending deformation may influence the results (Wu, 1982, p. 551).

The actual angle at the peel front, however, may not equal the angle set by the test geometry. Recent studies have determined the actual angle of the peeled adherend to the rigid substrate where debonding occurs (Kinloch et al., 1994; Loukis & Aravas, 1991; Mantel & Descaves, 1992). Using aluminum and polyester terephthalate film laminates adhered with a polyethylene adhesive, Kinloch et al. (1994) found that the angle at the peel front was consistently lower than the peel test angle, and especially so when the testing angle was very high. Since the values of actual peel angles rarely exceeded 50°, although the largest testing angle was 150°, Kinloch et al. suggested that shear forces may be negligible at high peel test angles. Seletzky (1974), on the other hand, reported that the peel angle in bonded textile specimens may vary from 10° to 270° for a 180° peel test depending on the structure of the fabrics and how the yarns are embedded in the adhesive. Variation in peel angle may be especially complex when both adherends are flexible (Steven-Fountainet al., 2002).

Peel configuration

Which adherend layer in a flexible laminate is peeled can decidedly influence the peel strength results when the other layer is held rigid. Since the mechanical properties of the adherend will affect the amount of energy dissipated in bending and extending the layer, the choice of peel arm affects the results and possibly the location of failure. Daly Hartin et al. (1993) found that when the "painting" layer of model paintings supported with various wax-resin linings was peeled from the rigid lining, the peel force was constant and failure occurred at the painting-resin interface. When the lining was peeled from the "painting", on the other hand, the peel strength varied considerably and failure occurred at the resin-lining interface. Unfortunately this aspect of peel geometry has not always been described in conservation studies using peel tests. Specimen orientation may have less effect on the results of a 90° T-peel test since both adherends are bent. Textile test methods, nevertheless, specify that the "face" fabric be placed in the upper jaw of testing instruments (ASTM, 1998; CGSB, 1997).

Adhesive treatment materials and techniques

Ultimately, the usefulness of mechanical bond strength tests rests in their ability to provide a relatively simple and practical method of comparing materials and/or the techniques in which they are used to create laminated structures. In the case of adhesive support treatments for historic textiles, the materials are primarily adhesives and support fabrics, although testing could also examine the effects on peel strength of artifact characteristics such as fibre type, weave structure, or the presence of painted decoration. Treatment techniques include preparation of adhesive solutions, coating of support fabrics, and adhering the coated support to the artifact. Although comparing the effects of materials and techniques on bond strength may help conservators make treatment decisions, very little textile conservation research has studied adhesive support treatments systematically. This research is supplemented below with the results of other conservation and adhesives research that examines materials and techniques similar to those used in heat-sealing treatments for historic textiles.

Adhesives

Peel tests have been used to distinguish the bonding ability of different adhesive polymers and formulations. The effects on peel strength of such characteristics as copolymer composition (Chalykh et al., 2002; Laureau, Vicente, Barandiaran, Leiza, & Asua, 2001), core/shell structure of dispersion particles and composition of acrylic dispersions (Garrett, Lovell, Shea, & Viney, 2000; Li et al., 2001), molecular weight (Laureau et al., 2001; Satas, 1989a), and degree of cross-linking (Satas, 1989a) have been demonstrated. Additive effects have also been determined. Tackifying resins increase peel adhesion of pressure sensitive adhesives, while plasticizers decrease it (Satas, 1989a). Fillers increase peel strength at low concentrations but eliminate all adhesive properties at high concentrations (Satas, 1989a). Seletzky (1974) reported that anionic and non-ionic emulsifiers as well as defoamers and anti-foamers lower the peel strength of bonded fabrics considerably and may cause spontaneous delamination. He attributed this loss of bond strength to a weak boundary layer, the effect of which may be dependent on adhesive cure time. Zosel and Schuler (1999) showed that surfactants added after dispersion polymerization tend to lower peel strength more than the same surfactants added during polymerization. They associated peel strength loss with the migration of surfactant molecules to the interface. Because surfactant molecules vary widely, their effect on peel behaviour is complex (Holl, 2000).

Conservators are often dependent on available commercial adhesives whose formulations may not be well characterized; therefore, little conservation research has related peel behaviour to adhesive composition. Berger (1972) used peel testing to compare adhesive formulations during the development of Beva 371 for the treatment of paintings. Conservators tend to avoid altering adhesive formulations because the effects of additives on the ageing behaviour of adhesives are not fully understood and are still being studied (Down, 1999). Although some textile conservators previously suggested adding a wetting agent to solutions of synthetic dispersion adhesives in order to improve wetting of the support fabrics (Keyserlingk & Down, 1995), this practice is no longer recommended (Canadian Conservation Institute, 1999). Where adhesive formulations are used as supplied by the manufacturer in research studies, the effects of adhesive polymers and additives cannot be separated.

A few experimental studies of textile laminates for conservation have included the assessment of peel strength with the intent of comparing adhesives. In comparing several adhesives that have been used by textile conservators, Pretzel (1997a; 1997b) measured the peel strength at room temperature and at elevated temperatures through the use of a hot-air blower. Laminates composed of silk habutae adhered to polyester crepeline were aged for 35 days at 60°C and 70% RH before peeling. Pretzel also recorded whether adhesive residue remained on the silk or support fabric after peeling. The results of his testing are given in Table 2.2. Karsten (1998) conducted similar peel tests on laminates composed of silk habutae as the artifact fabric, silk and polyester crepeline support fabrics, and adhesives equivalent to two tested by Pretzel, Lascaux Hot-seal Adhesive 371 and Appretan MB extra (Table 2.2). Laminates exposed to 0, 86 and 172 hours of accelerated light ageing (xenon arc radiation) were peeled. Both adhesive type and support fabric resulted in significant differences in peel strength.

Because the adhesives were applied at varying concentrations or using different application techniques, these studies confound the effects of adhesive formulation and application technique. Karsten (1998) applied Appretan MB extra by brush but sprayed Lascaux Hot-seal Adhesive 371. Although the mass per unit area of the resulting adhesive coatings was approximately equal, the coatings were otherwise very different. Appretan MB extra produced a flat film that coated the yarns of the support fabric while Lascaux Hot-seal Adhesive 371 covered the yarns with a random dusting of fine particles. The adhesive solutions used in the Pretzel study (1997a; 1997b) were composed of 10% to 50% adhesive by volume. While most of the adhesives produced a continuous film covering the yarns and interstices of the support fabric, at least one, Vinamul 3252, coated only the yarns (Hillyer et al., 1997).

Together these studies provide strong evidence that application technique can affect peel strength substantially. The results can be compared with relative confidence, since, in addition to using specimens prepared from equivalent materials, both used the same peel geometry and rate, 90° T-peel at 50 mm min^{-1}. Beva 371 and Lascaux Hot-seal Adhesive 371, both similar ethylene-vinyl acetate copolymer adhesives, exhibited stronger bonds than Mowilith DMC2 and Appretan MB extra, equivalent vinyl acetate-maleate terpolymer adhesives. The peel strength of Lascaux Hot-seal Adhesive 371 bonds in silk habutae/polyester crepeline laminates (51.9 ± 11.5 N m^{-1}), however, is equivalent to that provided by a 1:5 v/v solution of Mowilith DMC2 (50 ± 10 N m^{-1}). Laminates joined with a 1:10 v/v solution of Appretan MB extra, therefore, exhibited peel strengths (17.8 ± 7.3 N m^{-1}) as different from that produced by the equivalent adhesive, Mowilith DMC2, at twice the concentration, as from that exhibited by laminates joined with a different adhesive, Lascaux Hot-seal Adhesive 371, using an adhesive coating of an equal mass per unit area. These results suggest that peel strength can be modified as easily through treatment technique as through adhesive choice. The possibility that Beva 371 or Lascaux Hot-seal Adhesive 371 could be applied in a manner that would result in weaker bonds than Mowilith DMC2 or Appretan MB extra is not ruled out by this research.

Table 2.2 Peel strength and adhesive residue location of silk/adhesive/support fabric laminates.

		Pretzel 1997a, 1997b[a]				Karsten, 1998[b]	
Adhesive	Concentration (v/v)	Peel Strength (Nm^{-1})	Surface with Adhesive Residue	Hot Peel Strength (Nm^{-1})	Surface with Adhesive Residue	Peel Strength (Nm^{-1})	Surface with Adhesive Residue
Acrylics							
Lascaux 360/498HV (1:1)	1:10	100 ± 10	support	11 ± 1	both		
Lascaux P550-40TB	1:10	10 ± 0	neither	6 ± 3	neither		
Paraloid (Acryloid) F10	1:10	10 ± 10	neither	4 ± 2	neither		
Texicryl 13-002	1:1	320 ± 20	both	100 30	both		
Vinyl Acetate/Maleate/Acrylic Copolymers							
Mowilith DMC2	1:5	50 ± 10	support	9 ± 2	support		
Mowilith DMC2/DM5 (1:1)	1:5	60 ± 20	support	9 ± 3	support		
Appretan MB Extra	1:10					11.3 ± 4.9 (S)	both
						17.8 ± 7.3 (P)	both
Ethylene/Vinyl Acetate Copolymers							
Beva 371	1:5	120 ± 10	both	3 ± 1	both		
Lascaux Hot-seal Adhesive 371	1:5					48.1 ± 7.6 (S)	both
						51.9 ± 11.5 (P)	both
Vinyl Acetate/Ethylene Copolymer							
Vinamul 3252	1:5	30 ± 10	support	17 ± 4	support		
Vinamul 3254	1:5	50 ± 10	support	6 ± 2	support		
Vinnapas EP1	1:4	60 ± 10	support	16 ± 4	support		

[a] silk laminates supported with polyester crepeline, average of 5 aged samples, peel rate of 50 mm/min

[b] silk laminates supported with silk (S) and polyester (P) crepeline, average of 15 unaged samples, peel rate of 50 mm/min

Recognizing whether adhesive and application technique effects have been effectively separated through the design of a research study is important since the manner in which an adhesive has been deposited has been shown to affect peel strength. Selm (1991) demonstrated that leather laminates adhered with discontinuous dot coatings of adhesive had lower peel strength than those adhered with a continuous film of adhesive. Film continuity affects the surface area of adhesive available for bonding. This likely affects the value of a bond strength measure like peel strength, which is determined as a function of the width of substrate material. Moreover, several studies have noted that peel strength depends on the thickness of the adhesive layer. Gardon (1963) observed an increase in peel strength with adhesive thickness at constant peel rate, and an increase in the critical peel rate at which failure shifted from cohesive to adhesive modes when testing cellophane laminates adhered with acrylic dispersions. The variability in peel strength also decreased with increasing adhesive thickness. Some studies of lining treatments for paintings have confirmed that peel strength is directly proportional to the number of adhesive coats (Gayer, 1992; Hardy, 1992). Others have recorded a more complicated relationship. Hawker (1987) noted that whether the peel strength of model lined paintings increased with increasing coat weight depended on whether the painting surface was sized, and on the heat-sealing temperature. In some cases, peel strength reached a maximum at intermediate thickness and then declined with increasing thickness. Kogan et al. (1998) found an intermediate range of thickness where peel strength was independent of adhesive thickness. For adhesive thickness below or above this range, the peel force was directly proportional to adhesive thickness. When working with wool twill fabrics, Asquith et al. (1975) observed that peel strength increased with adhesive thickness until the adhesive had filled in the troughs created by the weave. For thicker adhesive layers, the peel strength dropped due to cohesive failure of the adhesive. The effect of adhesive thickness on peel strength has been theoretically related to energy dissipation mechanisms (Kinloch et al., 1994; Wu, 1982, p. 534-535).

Adhesive concentration and solvent choice may affect peel strength by altering the continuity and thickness of the adhesive coating. Textile conservators have used solutions of 1:20 to 1:1 v/v dispersion adhesives in water for adhesive treatments (Bede, 1993; Hillyer, 1984, 1990; Landi, 1992), although concentrations of 1:10 to 1:4 v/v are more common (Boersma, 1998; Hillyer, 1993, 1995; Keyserlingk & Down, 1995). Mock-up tests reported by textile conservators suggest that increasing the adhesive concentration increases bond strength, although small changes may be difficult to assess subjectively (Hartog & Tinker, 1998). A change in solvent may alter the viscosity of the adhesive and thus the thickness of the adhesive coat. Pullen (1991) found that Beva 371 dissolved in varsol was less viscous than the same adhesive in naptha; the former solution resulted in thinner adhesive coatings and weaker bonds than the latter. The research by Pretzel (1997a; 1997b) and Karsten (1998) did not consider adhesive concentration or solvent type as a variable. Moreover, the degree of continuity of particular adhesive films was not well described by Pretzel. In order to understand better how adhesive concentration affects peel strength, and therefore to better compare adhesives, its effect needs to be studied systematically.

Textile conservators use many different techniques, from brushing and rolling to spraying, to apply adhesives to the support fabric for heat-sealing treatments (Hillyer et al., 1997; Karsten, 1998, p. 63). Conservators have made few comments comparing these techniques, although Keyserlingk (1990) states that bonds produced by Beva 371 are stronger when the adhesive solution is sprayed rather than brushed. The relative effectiveness of these textile conservation techniques has not been studied although research shows that it probably has an important effect. Daly (1983) found that a spray application of Beva 371 resulted in stronger bonds than roller application. Hawker (1987) observed that Beva film produced stronger bonds than roller-applied Beva gel, although it also needed higher temperatures for effective bonding. Similarly, Asquith et al. (1975) found that the peel strength of wool twill laminates formed with a cast film of vinyl acetate-ethylene copolymer adhesive was higher than that of laminates in which the liquid adhesive was applied directly to the fabric. By contrast, Gardon (1963) noted that cellophane dipped in acrylic dispersions, dried and adhered together with pressure and heat gave stronger bonds than similar laminates adhered with a separately dried film of the same adhesive. Although liquid adhesives generally wet substrates better than solid films, fabrics may absorb liquid adhesives away from the surface where bonding takes place.

The manner in which the adhesive forms a solid film on the support fabric or substrate may affect subsequent peel strength. The relative humidity during drying has been shown to affect, at least temporarily, the tensile properties of films cast from a vinyl acetate-dibutyl maleate copolymer dispersion adhesive (Karsten & Down, 2003). Textile laminates made from this adhesive were found to have higher peel strength when the adhesive was applied in warm, humid conditions than when applied in cooler, dry conditions (Karsten, 1998; Karsten & Kerr, 2003). The mean peel strengths of silk habutae adhered to support fabrics that were coated with adhesive on a humid day at 22°C and 58% RH were twice that of laminates made from coated supports dried in a humidified polyethylene tent. Average peel strengths were 17.6 N m^{-1} versus 8.1 N m^{-1} for silk crepeline and 26.9 N m^{-1} and 13.3 N m^{-1} for polyester crepeline, respectively. Gardon (1963) found that the peel strength of laminates made from cellophane coated with an acrylic dispersion that had been dried at 100°C varied with peel rate in a manner distinctly different from that of laminates whose adhesive layer dried at room temperature. High humidity or temperatures could be expected to enhance dispersion coalescence and thus the mechanical strength of the dried films in a manner that appears to affect peel strength. Charmeau, Berthet, Gringreau, Holl, and Kientz (1997) showed that acrylic latex adhesives gave stronger bonds to glass when deposited from solution in tetrahydrofurane than when coated as a dispersion. O'Connor and Macosko (2002) demonstrated that a styrene-isoprene-styrene triblock copolymer pressure sensitive adhesive gave higher peel strengths when applied to the polyethylene film substrate through hot-melt coating than as a solution in toluene.

Adherends

Since most adhesives research focusses on adhesive performance, less is known about the effect of adherend characteristics on peel strength. Chalyhk et al. (2002) have demonstrated that peel strength increases with the surface free energy of polymer adherends, although peel rates high enough to give adhesive or mixed adhesive/cohesive failure are necessary to reveal this pattern. Physical properties of flexible adherends influence the peel force in a complex manner (Satas, 1989b). Modulus and thickness affect the amount of energy expended in deforming the peel arm. Adherend thickness can affect the actual peel angle, particularly for 180° tests (Satas, 1989b), which in turn affects the peel force as already discussed. Peeling the flexible adherend from flexible substrates in 90° peel tests can affect the peel force substantially, such that mathematical relations developed for peel force tested on rigid substrates do not apply (Steven-Fountain et al., 2002). Daly Hartin et al. (1993) found that peel strength increased when 2- or 3-ply linings were used to support model paintings with wax-resin. The plied supports were formed by adhering layers of the fabric with wax-resin on the vacuum hot table. Daly Hartin et al. attributed these results to an increase in curvature in the linings when peeled at 180°, which resulted in wax-resin fracture that occurred over a larger area when compared to the yarn-by-yarn fracture of the single ply laminates. As described above, the lower actual peel angle, due to the stiffer support fabric, itself accounts for higher peel strengths. Furthermore, the stiffer support fabric would dissipate more energy simply in bending.

The roughness of the adherend surface has also been related to peel strength. Surface roughening is often used to increase bond strength by increasing the area available for bonding. The bond strength of adhered textile yarns or fabrics is increased by the presence of staple fibre ends that project into the adhesive layer at the bonding surface. The force required to rupture such a bond depends on the relative magnitudes of the shear force needed to pull the fibres from the adhesive or the tensile force needed to break the fibres, which in turn depends on the length of embedded fibre (Wake, 1982, p. 286). The embedding of fibre ends may have a greater influence on bond strength than the fabric surface texture (Wake, 1982, pp. 282-283). Researchers studying lining treatments for paintings have found that peel strength increases both with fibre embedding (Daly Hartin et al., 1993) and with increased fabric surface texture (Daly Hartin et al., 1993) or increased surface area available for bonding (Phenix & Hedley, 1984). Similarly, Dickson and LePoutre (1997) found that the peel strength of coatings on paper increased with paper roughness due to increased mechanical interlocking. Rough papers are also more likely to delaminate due to peel stress than smooth papers (Pelton et al., 2001). By contrast, studies of pressure sensitive adhesives tend to show that peel strength decreases with increased roughness of the adherend surface (Christensen & Flint, 2000). The effect may be due to lower actual contact area, since the adhesive may not be able to fully wet a rough surface. Alternatively, it may be due to changes in the cavitation and fibrillation process by which pressure sensitive adhesives fail (Zosel, 1998). In general, increased surface roughness will increase peel strength if the adhesive is able to wet the surface well but will decrease peel strength if the adhesive wets the surface poorly.

The effect of different support fabrics used in adhesive treatments for textiles on peel strength has been little studied. Karsten (1998) found that bonds in silk laminates supported with polyester crepeline (Tetex, Stabiltex) were statistically stronger than those supported by silk crepeline, although the difference was not necessarily great (Table 2.2). For example, the mean peel strength of silk habutae adhered to polyester and silk crepeline with Appretan MB extra was 17.8 N m^{-1} and 11.3 N m^{-1}, respectively while for Lascaux Hot-seal Adhesive 371 it was 51.9 N m^{-1} and 48.1 N m^{-1}, respectively. Karsten attributed the difference to the higher modulus of polyester fibres and to the larger diameter of the polyester yarns, which could carry more adhesive than silk crepeline yarns and thus produce higher peak peel forces. In addition, the relative ability of the support material to be wet by the adhesive solution may have affected the thickness of the adhesive coating. Textile conservators have noted that water-based adhesives stay on the surface of polyester crepeline to a greater degree than silk crepeline (Hillyer et al., 1997). The absorptive ability of the substrate may also account for Selm's (1991) finding that the peel strength of leather-support fabric laminates was higher when the adhesive was applied to the polyester support rather than the leather surface. Hartog and Tinker (1998) observed that higher concentrations of Vinamul 3252 needed to be coated on nylon net than on silk crepeline to give the same degree of adhesion. They attributed this difference to fewer points of contact between the layers when net was used. Nylon net has a much lower fabric count (yarns per cm) than silk crepeline.

Ensuring clean substrate surfaces is a basic principle of adhesion. "Dirt" or surface "contaminants" generally consists of materials that are poorly bonded to the substrate surface or materials of substantially different chemical properties that lower the efficacy of the bond. Asquith et al. (1975) showed that methylene chloride extraction of residual grease from wool twill fabrics increased peel strength more than washing the fabrics with a neutral scour. Textile conservators are aware of the necessity of cleaning artifacts and support fabrics before treatments (Bede, 1993; Keyserlingk, 1990, 1993). Nevertheless, artifacts have been given adhesive support treatments when unstable dyes or paints precluded full cleaning (de Groot, 1994; Hillyer, 1984; Vahlne, 1997). Moreover, the gentle cleaning techniques used by textile conservators may not remove all dirt that might interfere with a bond (Boersma, 1998; de Groot, 1997; Hillyer & White, 1998). Some surface residues or stains, such as the resins and bodily oils found on burial shrouds, may even have historical importance (Hillyer & White, 1998).

Peel strength may be modified by altering the substrate surface in ways that are generally unethical for textile conservation treatments. A common industrial approach to maximizing adhesion in addition to cleaning is to modify the surface of the adherend chemically (Asquith et al., 1975). The effect of sizing of both linen canvas and support fabrics with polymeric resins has been studied in research examining lining treatments for paintings (Allard & Katz, 1987; Katz, 1985; Daly Hartin et al., 1993; Hawker, 1987; Pullen, 1991). Sizing techniques have not been used by textile conservators for the preparation of support or artifact fabrics prior to adhesion because of the loss of flexibility that results from such treatment.

Heat-sealing

For textiles laminated through a heat-sealing or fusing technique, the interconnected variables of temperature, pressure, and time of fusing exert an important influence on bond strength. In general, increases in any of these factors when heat-sealing textiles results in increased bond strength, but only up to a point. For non-textile substrates and curable adhesives, further increases do not increase peel strength (Gardon, 1967, p. 286). For thermoplastic adhesives on textile substrates, however, peel strength diminishes above a certain time-temperature-pressure optimum combination. The increase in peel strength with increased temperature has been demonstrated in several studies on lining techniques for paintings (Gayer, 1992; Hardy, 1992; Hawker, 1987; Pullen, 1991). These studies generally focussed on a small range of temperatures close to those recommended for the adhesive. Only Hawker showed that peel strength falls off above a certain temperature, the level of which is dependent on the thickness of the adhesive.

Temperature, however, should not be considered apart from the time of heat-sealing. Cusick and Cook (1971) studied the time-temperature dependence of the peel strength of fusible interlinings adhered to worsted suiting fabrics in great detail. They showed that the optimum peel strength occurs at a single glue line temperature (temperature of the adhesive), regardless of the temperature of the press (Figure 2.3). This temperature was reached more quickly at high press temperatures; therefore shorter pressing times were sufficient. The optimum glue line temperature varied with adhesive type. The observation that model paintings lined with 3-ply fabrics adhered with Beva 371 had relatively weak bonds has been attributed to the difficulty in achieving a suitable glue line temperature through such a thick substrate (Daly Hartin et al., 1993).

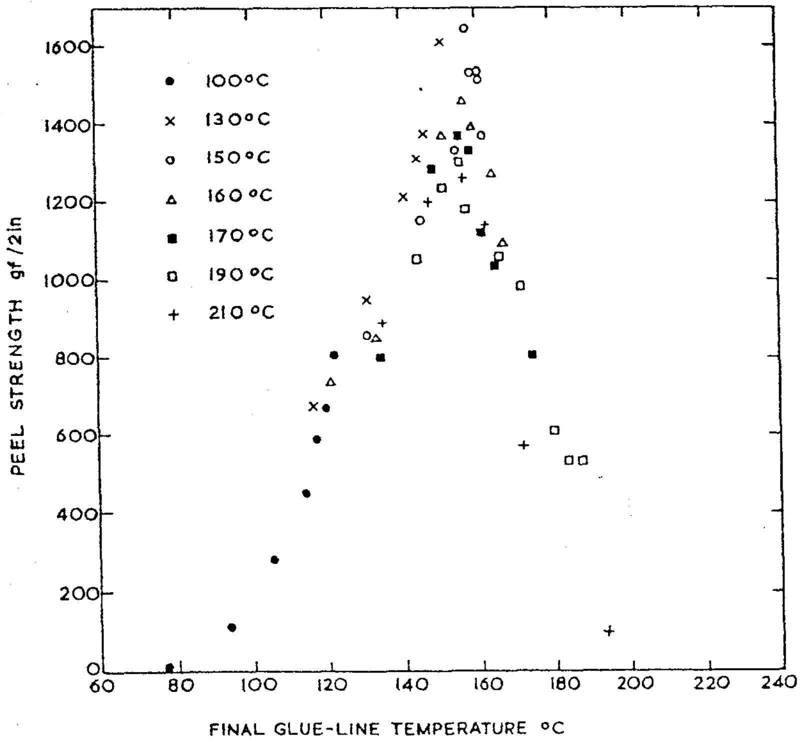


Figure 2.3 Peel strength versus the final glue line temperature for a plasticized poly(vinyl chloride) dot coated cotton fusible interlining fused onto a worsted suiting fabric. The results show that optimum peel strength occurs at a single glue line temperature regardless of fusing temperature.

Note: From "Factors concerning the use of fusible interlinings in garment construction" by G.E. Cusick and L.J. Cook, *Applied Polymer Symposium*, No. 18, p. 1327. Copyright 1971 John Wiley & Sons. Reprinted by permission of John Wiley & Sons, Inc.

The question of optimum temperature for adhesive treatments for textile conservation cannot be considered independently of the type of heat-sealing apparatus available to conservators. Although vacuum hot tables, which provide more overall control of the time, temperature, and pressure of heat-sealing have been used for textile treatments, the majority of textile conservators use hand held spatulas or irons (Hillyer et al., 1997). Such an instrument introduces the likelihood of significant variability in time-temperature-pressure combinations across the surface of the artifact, especially when in the hands of inexperienced conservators. The temperature of these instruments can vary considerably over time and from one position to another on the heated plate. Neither does the use of a vacuum hot table eliminate this problem for large artifacts, since the temperature over the surface of such tables has been described as uneven enough to account for poor replication of bond strength results of laminates adhered with Beva 371 (Daly Hartin et al., 1993). Further research regarding the effects of temperature, time, and pressure on the bond strength of laminates made with conservation materials cannot be of much practical use unless conservators have suitably precise equipment to apply what is learned from the results.

The orientation of the fabric layers during heat-sealing, both relative to each other and relative to the source of the heat, may also affect the resulting bond. The orientation of the warp and weft in fabric laminates has been found to have a significant effect on peel strength. When the fabric has a noticeable direction to the weave, as in the twill fabrics studied by Asquith et al. (1975), bond strength drops with increasing non-alignment of the bars in the weave. Daly (1983) found that model lined paintings adhered with wax-resin in a warp/weft orientation had stronger bonds than when both warps were aligned. The direction of heat transfer may also affect the bond, since adhesive tends to travel towards the heat source (Cusick & Cook, 1971). When heat is applied through the support fabric, as is recommended for conservation treatment in order to reduce heat exposure of the artifact, the adhesive could flow back into the support fabric away from the interface, in what is called “strike back” in the textile industry. When heat is applied to the face or artifact fabric, on the other hand, excessive adhesive could be drawn into the artifact. This could potentially result in “strike through”, an unacceptable risk for historic textiles. When Cusick and Cook (1971) studied the effect of the direction of fusing on peel strength, however, they did not observe any consistent difference.

Performance over time

An issue of further interest to textile conservators is the performance of the adhesive support materials over time. This issue has been barely studied in conservation science although it has been shown that adhesive bond strength can change over time at different rates and that some adhesives that give excellent initial adhesion may lose bond strength faster than initially weaker adhesives under conditions of use (Lyons, 1951). Pressure sensitive adhesives have been shown to give increased tack and peel strength with increased time in contact with a substrate (Amouroux, Petit, & Léger, 2001; Zosel, 1998). Cyclical loading can alter the strength of bonds. Repeated stress exposure below the failure level may weaken bonds, but if the adhesive is plastic enough to permit self-healing of cracks, bonds may strengthen (Rajeckas, 1989). Karsten (1998) showed that the peel strength of silk laminates adhered with Appretan MB extra and Lascaux Hot-seal Adhesive 371 had increased slightly but not necessarily significantly after light ageing. Although Pretzel (1997a; 1997b) tested specimens subjected to a high RH ageing regime, the lack of unaged specimens for comparison makes it impossible to determine the effect of this type of ageing on peel strength.

Summary

The above review indicates that the factors affecting peel strength are numerous and interconnected, sometimes in complex ways. A numerical value for peel force is affected by the manner in which the peel test is conducted (peel rate and angle) and the temperature of the test. How the specimens are prepared, the concentration of adhesive used, the manner in which the adhesive is applied to the substrate, the time, temperature, pressure, and substrate orientation during heat-sealing all affect peel strength in some way. Furthermore, the particular adhesive formulations and substrates used to prepare the laminated specimens can affect the peel strength. Separating the effects of peel test technique, laminate preparation technique, and materials should be approached with caution when the intent of research is to provide improved guidance to conservators undertaking adhesive support treatments of historical artifacts.

The following study extends our knowledge of adhesive support treatments for textiles by focussing on a few material and technique variables that have been and can be easily exploited by textile conservators. Application techniques commonly used for certain adhesives are followed on the assumption that conservators have chosen them for good reason and in order to produce results that can be compared to previous studies and treated artifacts. Materials chosen are those commonly used by textile conservators, as well as some that may find increased use in the future. The above analysis of factors affecting peel strength will provide the framework for interpreting the results of these tests in a manner that respects the complexity of this phenomenon while being helpful to conservators.

Experimental Procedures

Preparation of laminated fabric specimens

Laminated fabric specimens were prepared from two artifact fabrics, three support fabrics, and six adhesives. Two undyed, plain weave fabrics served as the artifact: a light-weight, degummed, *Bombyx mori* silk habutae (Testfabrics # 609) and a semi-dull nylon taffeta (Testfabrics # 306A). Three undyed, open weave fabrics were used as support fabrics: nylon net, polyester crepeline (Stabiltex, Tetex), and silk crepeline. The fabrics were washed in a 0.3% (w/w) sodium lauryl sulphate detergent solution, rinsed with distilled water, and air dried at room temperature before cutting into swatches measuring 200 x 30 mm (warp x weft) and ravelled to 20 mm in width (for details see Appendix A). Fabric and yarn structure, fabric mass, and fabric tensile properties were determined using standard test procedures (Appendix A). The ravelled swatches were randomly assigned to laminate groups before adhesive coating and heat-sealing. Six adhesives were used to produce the laminates (Table 2.3). The ageing behaviour of Acryloid (Paraloid) F10, Beva 371, Lascaux 360HV and 498HV, Vinamul 3252 and adhesives equivalent to Clariant T1601 (Mowilith DMC2 and Appretan MB extra) has been studied for conservation purposes (Berger, 1972; Blackshaw & Ward, 1982; Down, MacDonald, Tétreault, & Williams, 1996; Horton-James, Walston, & Zounis, 1991; Howells, Burnstock, Hedley, & Hackney, 1984; Verdu, Bellenger, & Kleitz, 1984). Dur-O-Set E150, a neat dispersion, has not been used for conservation treatments but is currently being tested for its stability and suitability for conservation at the Canadian Conservation Institute (Down, 1999).

Adhesive solutions were prepared and applied using textile conservation techniques (Canadian Conservation Institute, 1999). Dispersion adhesives were diluted with distilled water (H_2O) to two levels of adhesive concentration: 1:10 and 1:5 (volume adhesive:volume solvent). The two Lascaux acrylic dispersions were combined in a 1:1 mass ratio prior to dilution. Resin solutions were produced by diluting one part resin by volume with 8 parts toluene ($C_6H_5CH_3$) for Acryloid F10 and 1 part toluene for Beva 371. Beva 371 solutions were heated in a water bath at 40°C to ensure proper mixing. Adhesive solutions were either brushed or sprayed onto the support fabric swatches. For brushing, swatches were clamped to a sheet of Teflon-coated glass cloth attached to a level glass plate in a fume hood. The adhesive was applied in a single brush stroke. Beva 371 and Acryloid F10 solutions were also applied using a Preval aerosol sprayer from a distance of 1.1 metres through a cardboard tube (110 x 13 x 25 cm), one end of which was set into a fume hood. The support fabric swatch was clipped to the end of the tube in the fume

Table 2.3 Adhesive composition.

Adhesive	Polymer	Polymer Structure	Major Additives
Resins			
Acryloid F10	PBMA	$[CH_2C(CH_3)(CO_2C_4H_9)]_n$	Stoddard solvent, other hydrocarbon and aromatic solvents
Beva 371	EVA	$[CH_2CH_2]_n$ / $[CH_2CH(OCOCH_3)]_n$	Laropal K80, paraffin, phthalate ester of hydroabietyl alcohol, toluene, VM&P naptha
Dispersions			
Clariant T1601	VAC/maleate terpolymer	$[CH_2CH(OCOCH_3)]_n$ / $[CH(CO_2C_4H_9)]_n$	hydroxyethyl cellulose stabilized
Lascaux 360/498HV	PBA/PMMA	$[CH_2CH(CO_2C_4H_9)]_n$ / $[CH_2C(CH_3)(CO_2CH_3)]_n$	acrylic butylester thickener
Dur-O-Set E150	VAE	$[CH_2CH(OCOCH_3)]_n$ / $[CH_2CH_2]_n$	poly(vinyl alcohol) stabilized
Vinamul 3252	VAE	$[CH_2CH(OCOCH_3)]_n$ / $[CH_2CH_2]_n$	poly(vinyl alcohol) stabilized, sodium carboxy methyl cellulose

EVA = ethylene-vinyl acetate, PBA = poly(butyl acrylate), PBMA = poly(butyl methacrylate), PMMA = poly(methyl methacrylate), VAC = vinyl acetate, VAE = vinyl acetate-ethylene

hood. The adhesives were sprayed from the other end for 4 seconds. All coated swatches were allowed to air dry in the fume hood overnight. The average temperature and relative humidity of the laboratory during adhesive application and drying was 19 ± 1°C and 33 ± 4% RH. The mass of the adhesive coating (add-on) was determined for each specimen by measuring the mass of the support fabric swatches before and after coating. The degree to which the dried adhesive film coated the support fabric yarns and filled the interstices was also recorded. Coated swatches were stored in the dark for six weeks before heat-sealing.

The coated support fabric swatches were heat-sealed to artifact fabric swatches in a modified Seal Commercial 210 M drymount press. A Ducor 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. Layered swatches were heat-sealed for 20 seconds at either 65°C (Acryloid, Beva, Lascaux) or 95°C (Clariant, Dur-O-Set, Vinamul). An interleaving of polyester film (12.7 μm Mylar) prevented adhesion of the upper 40 mm and ravelled edges of each specimen. Laminated specimens were stored in the dark for six weeks before peel testing.

Determination of peel strength

Peel strength was determined using a T-peel test according to the procedures of the test method CAN/CGSB-4.2 No. 65-M91 (CGSB, 1997). Tests were conducted on an Instron Universal Testing Instrument, Model 4202, using a 2.5 N load cell and 6 mm wide spring-loaded fibre grips set at a gauge length of 25 mm. The non-adhered fabric ends were reinforced with self-adhesive paper tabs so that the grain of the edges extending beyond the grips remained aligned during peeling. These ends of the artifact and coated support fabric of each laminate were placed in the upper and lower grips respectively (Figure 2.4). Each specimen was then peeled over 10 mm of its adhered length at a crosshead speed of 50 mm min^{-1}. This rate, adopted from the test method, ISO 36: 1993 (E) (International Organization for Standardization, 1993), was in keeping with those used in conservation science research. Tests were conducted in a controlled environment of 20 ± 2°C and 65 ± 2% RH. Peel strength was calculated manually from the resulting graph for each specimen. The five highest and five lowest peak forces were recorded and these ten values averaged. The peel strength per metre width was calculated as follows:

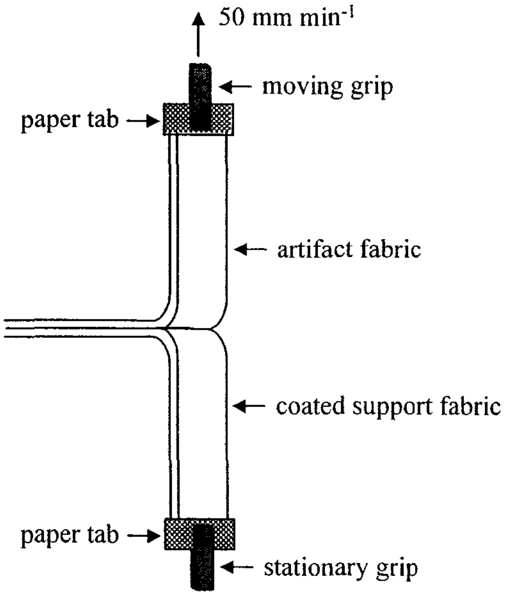


Figure 2.4 Configuration of laminated specimen for T-peel test.

peel strength (N m^{-1}) = average peak force (N) / width of specimen (m) (2.5)

The peel strength values of ten specimens represented each treatment group.

The results of the peel tests were further characterized through visual observation and scanning electron microscopy. The relative amount of adhesive transfer to the artifact fabric during peeling was recorded. The artifact and coated support fabric surfaces of peeled laminates were examined using scanning electron microscopy in order to characterize the nature of the adhesive coatings and whether failure was adhesive, cohesive, or mixed. Small pieces of laminate were cut from the unpeeled ends of representative specimens. The pieces were adhered to stubs using double-sided carbon tape, support fabric side down. The artifact fabric was peeled back manually and adhered in place with carbon tape. The specimens were sputter-coated with gold in a Nanotech SEMPREP 2 Sputter Coater prior to microscopic examination in a Jeol JSM 6301 FXV at 5 KV using magnifications ranging from 15 to 550 times.

Data Analysis

The significance of the effects of adhesive type (formulation plus application technique), artifact fabric, and support fabric was determined through three-way analysis of variance (ANOVA) using SAS, release 8.2. Tests for normality, homogeneity of variance, and independence of the residuals indicated failure to meet the assumptions behind ANOVA. The analyses were repeated after using a log transformation on the data, producing results that better met the assumptions. The results reported here are from the analyses of the transformed data; they do not differ greatly from those of the original data. The significance of the differences among the levels of the variables was determined using a multiple comparisons test coupled with Tukey's adjustment.

Results

Peel strength

The laminate types exhibited a wide range of peel strength values (Table 2.4, Appendix B). The ANOVA results (Appendix C, Table C.1) revealed the overall significance of the effects of adhesive type (formulation plus application technique) and laminate fabrics on peel strength. Adhesive type was significant, but in a manner dependent on the type of artifact and support fabric used. Both two-way interactions, adhesive type by artifact fabric, F(11, 648) = 22.81,

Table 2.4 Mean peel strength (with standard deviation) by adhesive, technique, artifact fabric, and support fabric.

Adhesive/ Support Fabric	Adhesive Add-on (g)	Peel Strength (Nm^{-1})		Adhesive Add-on (g)	Peel Strength (Nm^{-1})	
		nylon taffeta	silk habutae		nylon taffeta	silk habutae
Acryloid F10	*1:8 (v/v) by brush*			*1:8 (v/v) by spray*		
nylon net	0.0063 ± 0.0014	1.4 ± 0.2	3.0 ± 0.3	0.0113 ± 0.0015	1.0 ± 0.2	2.0 ± 0.3
polyester crepeline	0.0082 ± 0.0016	1.5 ± 0.2	2.8 ± 0.5	0.0168 ± 0.0028	1.0 ± 0.2	1.8 ± 0.3
silk crepeline	0.0087 ± 0.0020	1.4 ± 0.3	2.2 ± 0.5	0.0175 ± 0.0038	0.9 ± 0.3	1.7 ± 0.3
Clariant T1601	*1:10 (v/v) by brush*			*1:5 (v/v) by brush*		
nylon net	0.0087 ± 0.0012	3.9 ± 0.7	9.8 ± 1.9	0.0206 ± 0.0051	6.3 ± 1.2	18.7 ± 2.5
polyester crepeline	0.0127 ± 0.0014	7.1 ± 1.3	18.2 ± 3.4	0.0251 ± 0.0032	12.9 ± 2.3	33.3 ± 3.2
silk crepeline	0.0140 ± 0.0034	6.1 ± 1.8	13.8 ± 3.8	0.0263 ± 0.0038	10.5 ± 1.7	24.7 ± 2.5
Lascaux 360/498HV	*1:10 (v/v) by brush*			*1:5 (v/v) by brush*		
nylon net	0.0110 ± 0.0019	7.0 ± 2.1	11.6 ± 2.4	0.0240 ± 0.0072	22.0 ± 6.4	29.4 ± 5.9
polyester crepeline	0.0126 ± 0.0017	6.0 ± 1.8	9.9 ± 2.4	0.0255 ± 0.0038	25.0 ± 5.2	31.1 ± 6.8
silk crepeline	0.0142 ± 0.0031	7.4 ± 1.8	8.1 ± 1.6	0.0273 ± 0.0048	17.9 ± 4.1	22.7 ± 3.7
Dur-O-Set E150	*1:10 (v/v) by brush*			*1:5 (v/v) by brush*		
nylon net	0.0100 ± 0.0032	7.7 ± 2.3	16.4 ± 5.6	0.0241 ± 0.0046	11.7 ± 1.5	25.4 ± 3.7
polyester crepeline	0.0151 ± 0.0031	14.2 ± 2.4	25.9 ± 6.5	0.0258 ± 0.0043	18.9 ± 3.2	36.8 ± 5.7
silk crepeline	0.0156 ± 0.0025	11.8 ± 2.6	19.3 ± 4.3	0.0287 ± 0.0038	17.2 ± 2.9	30.2 ± 4.9
Vinamul 3252	*1:10 (v/v) by brush*			*1:5 (v/v) by brush*		
nylon net	0.0104 ± 0.0029	9.5 ± 2.8	13.5 ± 3.0	0.0205 ± 0.0038	20.0 ± 5.2	27.1 ± 6.8
polyester crepeline	0.0134 ± 0.0018	14.2 ± 2.7	19.7 ± 3.5	0.0243 ± 0.0042	28.9 ± 3.4	39.2 ± 8.2
silk crepeline	0.0161 ± 0.0021	12.2 ± 2.0	17.4 ± 3.2	0.0272 ± 0.0043	29.8 ± 4.1	36.0 ± 4.9
Beva 371	*1:1 (v/v) by brush*			*1:1 (v/v) by spray*		
nylon net	0.0502 ± 0.0105	34.8 ± 6.7	47.5 ± 15.3	0.0323 ± 0.0055	32.9 ± 6.2	42.0 ± 9.3
polyester crepeline	0.0492 ± 0.0130	42.6 ± 6.7	50.7 ± 9.5	0.0466 ± 0.0060	53.2 ± 6.5	72.1 ± 9.5
silk crepeline	0.0586 ± 0.0117	46.7 ± 13.0	56.7 ± 13.3	0.0460 ± 0.0085	49.5 ± 11.4	63.2 ± 13.2

$p < .0001$, and adhesive type by support fabric, $F(22, 648) = 11.80$, $p < .0001$, were significant. The interaction between artifact fabric and support fabric was also significant, $F(2, 648) = 8.13$, $p = .0003$, but the interaction among all three variables was not, $F(22, 648) = 0.68$, $p = .8646$. All three factors and the way they interrelate were necessary to understanding the differences in peel strength of these artifact/support fabric laminates.

Effect of application technique

Although application technique was not separated from adhesive formulation in the ANOVA, the significance of the effects of application technique on peel strength could be determined by examining the results of the multiple comparisons tests (Appendix C, Table C.2). These tests indicated that both adhesive concentration and the tool used to apply the adhesive can have a significant effect on peel strength. The effect of adhesive concentration on peel strength was clearly apparent. The peel strength of fabric laminates produced using a 1:5 v/v solution (coded "t" in Table C.2) was always significantly higher than the corresponding laminates produced with a 1:10 v/v solution of the same adhesive (coded "o" in Table C.2) regardless of artifact or support fabric. Twice as much adhesive by volume in the dispersion solution generated bonds that were approximately twice as strong (Table 2.4); for example, the mean peel strength of silk habutae/silk crepeline laminates adhered with 1:10 and 1:5 v/v solutions of Vinamul 3252 was 17.4 N m^{-1} and 36.0 N m^{-1}, respectively.

The effect of spray versus brush application depended on the type of adhesive. For Acryloid F10, brush application of a 1:8 v/v toluene solution gave significantly higher peel strengths than spray application regardless of the type of artifact or support fabric (Table 2.4). Spray application of a 1:1 v/v toluene solution of Beva 371 tended to yield higher peel strengths than brush application unless the support fabric was nylon net. The mean peel strength of silk habutae/polyester crepeline laminates, for example, was 72.1 N m^{-1} when Beva 371 was sprayed for four seconds but 50.7 N m^{-1} when it was brushed. In contrast, the mean peel strength of silk habutae/nylon net laminates was 42.0 N m^{-1} when Beva 371 was sprayed but 47.5 N m^{-1} when brushed. Because of considerable variation in the results, the differences for Beva 371 were only significant when the support fabric was polyester crepeline.

Effect of the artifact fabrics

The artifact fabrics used to create the laminates also significantly affected peel strength. Nylon taffeta laminates consistently exhibited weaker adhesive bonds than the corresponding silk habutae laminates regardless of adhesive type or manner of application (Figure 2.5).

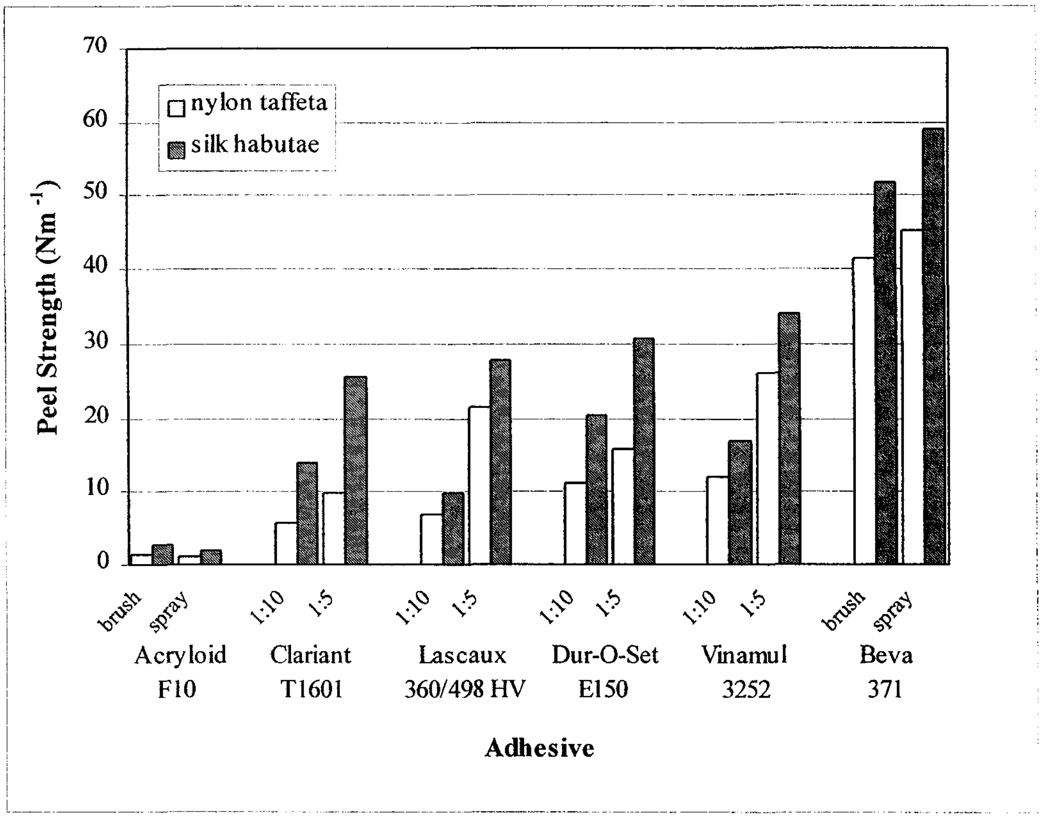


Figure 2.5 Peel strength (N m^{-1}) of nylon taffeta and silk habutae laminates adhered with Acryloid F10, Beva 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252.

Effect of the support fabrics

Multiple comparisons tests also indicated the particular effects of the support fabrics on peel strength. Silk habutae and nylon taffeta laminates supported with nylon net were weaker than the corresponding laminates supported with silk or polyester crepeline when the adhesive was Clariant T1601, Dur-O-Set E150, Vinamul 3252, or Beva 371 applied by spray (Figure 2.6). The peel strengths of the silk and polyester crepeline laminates for these adhesives were not significantly different, although polyester crepeline laminate bonds were usually stronger on average than those of silk crepeline laminates. Silk crepeline specimens adhered with a 1:5 v/v solution of Lascaux 360/498 HV had weaker peel strengths than the corresponding polyester crepeline specimens. The Lascaux specimens supported with nylon net had intermediate peel strengths and were not statistically different from those supported with either silk or polyester crepeline. The peel strength of laminates adhered with Acryloid F10, Beva 371 applied by brush,

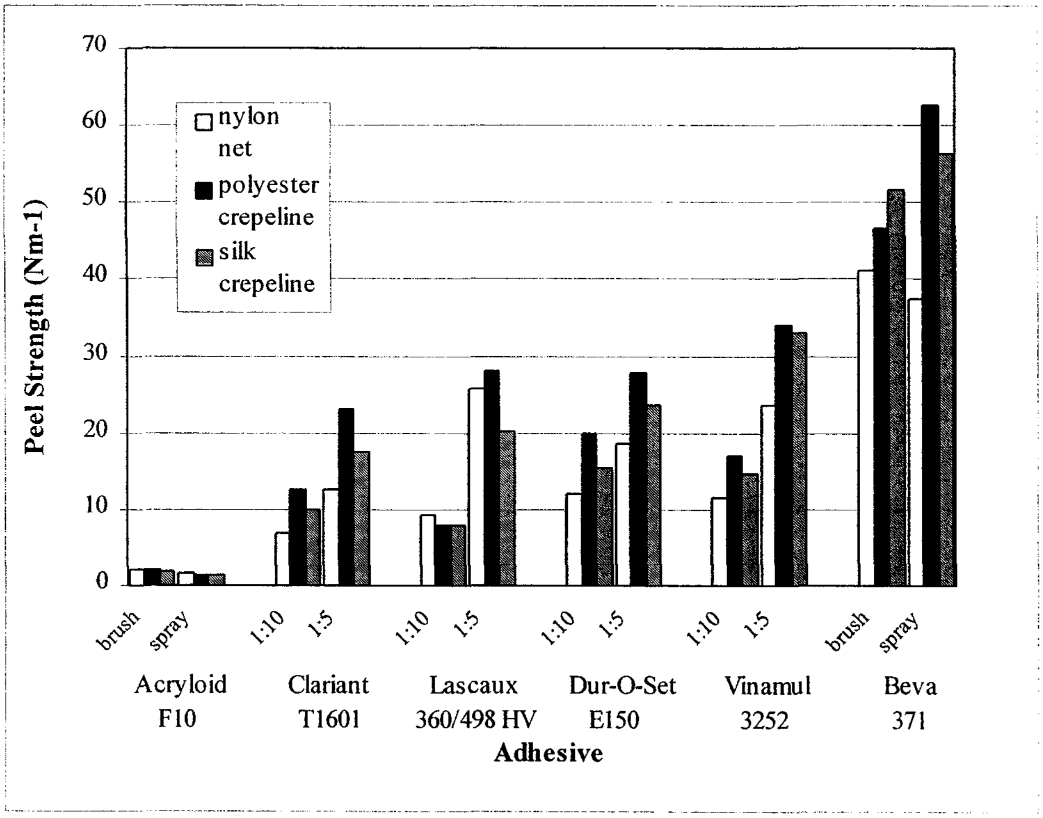


Figure 2.6 Peel strength (N m^{-1}) of laminates having nylon net, polyester crepeline, and silk crepeline supports adhered with Acryloid F10, Beva 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252.

and a 1:10 v/v solution of Lascaux to the three support fabrics could not be statistically distinguished when artifact fabric and application technique were held constant.

Effect of adhesive type

Examining the results of the multiple comparison tests (Appendix C, Table C.2) and the values for mean peel strength (Table 2.4) permits ranking the adhesives from weakest to strongest while indicating which differences are significant (Table 2.5). Acryloid F10 produced the weakest bonds (1-3 N m^{-1}) and Beva 371 the strongest (33-72 N m^{-1}). Bonds produced with dispersion adhesives were of moderate strength (4-39 N m^{-1}), falling between those of Acryloid F10 and Beva 371. These distinctions were statistically significant for both silk and nylon artifact fabrics and for all three support fabrics regardless of application technique.

Table 2.5 Significant differences between the peel strength of laminated fabric specimens by adhesive type and artifact fabric or support fabric.

Fabric	Dispersion Concentration (v/v)	Adhesive		
Artifact Fabrics[a]			*Dispersions*	
nylon taffeta	1:10	$A <$	$(C \cong L < D \cong V)$	$< B$
	1:5	$A <$	$(C < D < L < V)$	$< B$
silk habutae	1:10	$A <$	$(L < C < V \cong D)$	$< B$
	1:5	$A <$	$(C \cong L, L \cong D, D \cong V)$	$< B$
Support Fabrics[b]				
nylon net	1:10	$A <$	$(C < L \cong D \cong V)$	$< B$
	1:5	$A <$	$(C < D < L \cong V)$	$< B$
polyester crepeline	1:10	$A <$	$(L < C < V \cong D)$	$< B$
	1:5	$A <$	$(C \cong D, D \cong L \cong V)$	$< B$
silk crepeline	1:10	$A <$	$(L \cong C < V \cong D)$	$< B$
	1:5	$A <$	$(C \cong L, L \cong D, D < V)$	$< B$

Note: Adhesives are Acryloid F10 (A), Beva 371 (B), Clariant T1601 (C), Dur-O-Set E150 (D), Lascaux 360/498 HV (L), and Vinamul 3252 (V)

[a]averaged over support fabrics [b]averaged over artifact fabrics

The distinctions between the bonds produced by the dispersion adhesives depended on the particular artifact or support fabric and on whether the adhesive was applied as a 1:10 or 1:5 v/v solution. In general, however, Clariant T1601 produced bonds that were consistently weaker than Dur-O-Set E150 and Vinamul 3252. On average, Vinamul 3252 bonds were stronger than Dur-O-Set E150 bonds, although these were often not statistically distinguishable. The bonds produced with Lascaux 360/498 HV were the most variable. For 1:10 v/v solutions, the Lascaux bonds were usually weaker or equivalent to Clariant bonds, while for 1:5 v/v solutions, they were stronger than or equivalent to Dur-O-Set bonds.

Bond failure

The peeling behaviour of the adhesives was classified according to whether the adhesive transferred to the artifact fabric during peeling or remained on the support fabric (Table 2.6). All adhesives exhibited some transfer except the one that formed the weakest bonds, Acryloid F10. Transfer was observed on Clariant T1601 and Dur-O-Set E150 specimens only when the support fabric was nylon net. Lascaux 360/498 HV and Vinamul 3252 showed transfer when the artifact fabric was nylon taffeta or when the support was nylon net. Beva 371 exhibited substantial

Table 2.6 Amount of adhesive transferred to the artifact fabric during peeling according to the type of fabrics and the application technique used to make the laminate. Observations were classified as none (N/dark), slight (S/light), or lots (L/white) with the shading indicating the majority of cases when more than one classification occurred.

Adhesive	Pretzel 1997a,b*	Present Study											
		nylon taffeta						silk habutae					
		nylon		polyester		silk		nylon		polyester		silk	
		brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5
Paraloid F10 / Acryloid F10	A	■	■	■	■	■	■	■	■	■	■	■	■
Beva 371	L	S	L	■	L	■	L	S	L	■	L	■	L
Mowilith DMC2 / Clariant T 1601	■	S/N	S	■	■	■	■	■	S/L	■	■	■	■
Dur-O-Set E150	n/a	S/N	S	■	■	■	■	■	S	■	■	■	■
Lascaux 360/498 HV (1:1)	■	S	L	■	■	■	■	■	L	■	■	■	■
Vinamul 3252	■	S	L	■	■	■	■	S/N/L	L	■	■	■	■

Note: The classification "A" stands for Pretzel's classification "no adhesive apparent".

*silk laminates supported with polyester crepeline

transfer when the coating was sprayed and slight transfer when it was brushed onto nylon net or adhered to nylon taffeta. Observation of the peel front during peel testing indicated differences in how this transfer occurred. Coatings of three adhesives, Beva 371, Lascaux 360/498 HV, and Vinamul 3252, were stretched into fibrils when subjected to peel force (Figure 2.7). Transfer occurred with Clariant T1601 and Dur-O-Set E150 when the coating broke away from fabric interstices (Figure 2.7). Observations of peel transfer for silk laminates adhered to polyester crepeline corresponded to Pretzel's (1997a; 1997b) results in most cases (Table 2.6).

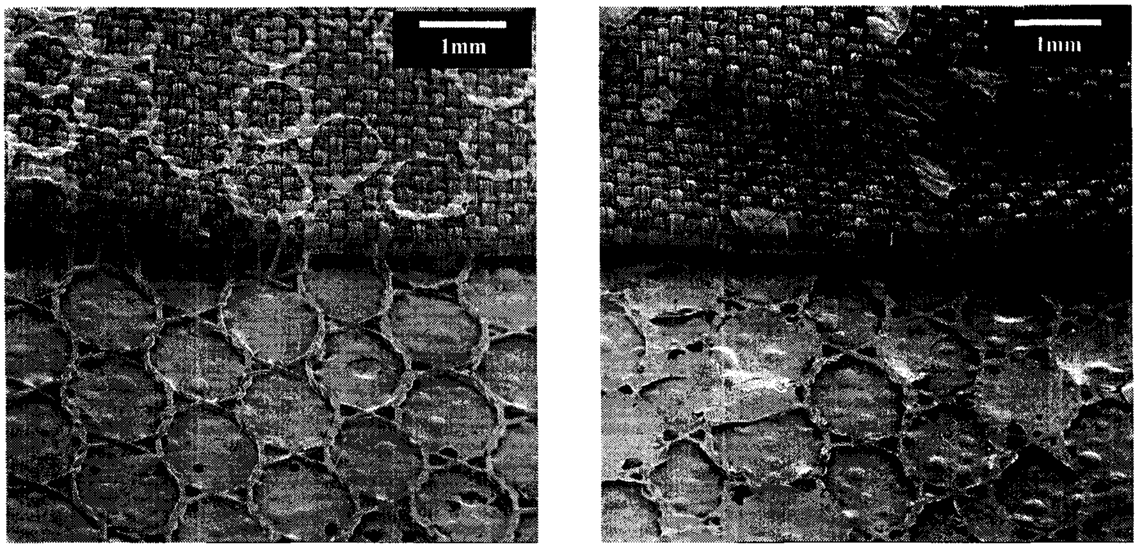


Figure 2.7 Peel behaviour of Lascaux 360/498 HV (left) and Clariant T1601 (right) brushed as a 1:5 v/v solution in distilled water onto nylon net and adhered to silk habutae. Lascaux 360/498 HV exhibits adhesive stretching and transfer to artifact fabric while Clariant T1601 shows adhesive transfer from the interstices of the coated net. (Note: carbon tape is visible through most of the nylon net interstices.)

Discussion

Assessment of Pretzel's scoring system for bond strength

One objective of this study was to assess the validity of the system used by Pretzel (1997a; 1997b) to classify the bond strength of adhesives that might be chosen by textile conservators for adhesive support treatments. The peel strength results indicate that all materials used to produce the textile laminates, as well as the methods used to apply the adhesives significantly affect peel strength results. Variation in laminate preparation techniques among the six adhesives means that the effects of adhesive formulation cannot be totally distinguished from the effects of adhesive application technique. Nevertheless, the results indicate clearly that peel results for a single set of textile materials and adhesive application techniques would not be replicated if any of the fabrics or application techniques were altered. A classification system derived from such a single set of peel tests like Pretzel's is, therefore, misleading if the conservator uses application techniques and fabrics that differ markedly from those used to prepare the specimens in the original peel tests. The importance of considering application techniques and fabric type is illustrated when the results of the present study are classified by

Pretzel's system (Table 2.1) and compared with Pretzel's results (Table 2.7). In every case, other than some of the specimens adhered with Beva 371, the peel strength received a poor rating (< 50 N m^{-1}). Two adhesives, Mowilith DMC2, the equivalent of Clariant T1601, and Lascaux 360/498 HV merited an acceptable rating (50-100 N m^{-1}) in Pretzel's study. The Beva 371 exceptions received acceptable scores. In Pretzel's study, the peel strength of Beva 371 merited a good score (> 100 N m^{-1}). No adhesive produced peel strengths in the "good" category in this study. Nevertheless all specimens except the Acryloid F10 specimens were well adhered. The Beva 371 specimens in particular were so strongly adhered that the fabrics stretched and distorted considerably during peel testing. That a stronger bond, i.e. one that would be classified by Pretzel as "good", could be necessary for adhesive support treatments is questionable, since the treated artifact would not likely be exposed to such mechanical stress.

Table 2.7 Classification of peel strength results according to the system proposed by Pretzel (1997a; 1997b): good (> 100 N m^{-1}), acceptable (50-100 N m^{-1}), or poor (< 50 N m^{-1}).

		Present Study											
		nylon taffeta						silk habutae					
		nylon		polyester		silk		nylon		polyester		silk	
Adhesive	Pretzel 1997 a,b	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5	brush or 1:10	spray or 1:5
Paraloid F10 / Acryloid F10	P	P	P	P	P	P	P	P	P	P	P	P	P
Beva 371	A	P	P	P	A	P	P	P	P	A	A	A	A
Mowilith DMC2 / Clariant T 1601	A	P	P	P	P	P	P	P	P	P	P	P	P
Dur-O-Set E150	n/a	P	P	P	P	P	P	P	P	P	P	P	P
Lascaux 360/498 HV (1:1)	A	P	P	P	P	P	P	P	P	P	P	P	P
Vinamul 3252	P	P	P	P	P	P	P	P	P	P	P	P	P

Note: dark = good (G), light = acceptable (with care) (A), white = poor (P)

Stronger evidence for the lack of validity of the Pretzel matrix (1997a; 1997b) might be found in ranking the relative strength of the adhesives. If all adhesives still ranked in the same way, the overall lowering of the peel strength values might be due to differences in testing conditions or techniques or to the effects of the artificial ageing regime that Pretzel used. But this is not the case. Pretzel's results are in general consistent with those of this study. Pretzel also found that Beva 371 had the strongest bonds (120 N m^{-1}) and Acryloid F10 the weakest (10 N m^{-1}), while the dispersion adhesives produced bonds of intermediate strength (30 to 100 N m^{-1}). Lascaux 360/498 HV, a relatively strong adhesive in Pretzel's study (100 N m^{-1}), however, was a weak adhesive in the present study (9.9 N m^{-1} for the corresponding laminate of silk habutae adhered to polyester crepeline). At times it was the weakest adhesive next to Acryloid F10 (Table 2.5). Similarly Clariant T1601 was almost always the weakest of the dispersion adhesives while its equivalent, Mowilith DMC2, gave bonds of intermediate strength, bonds stronger than those of Vinamul 3252, in Pretzel's study. Vinamul 3252 was consistently one of the strongest dispersion adhesives in this study. The actual peel strength values for silk habutae/polyester crepeline laminates in both studies were fairly consistent when the degree of variation is considered. Clariant T1601 gave peel strengths of 33.3 ± 3.2 N m^{-1} for a brushed 1:5 v/v solution while the corresponding value for Mowilith DMC2 was 50 ± 10 N m^{-1}. The results for Vinamul 3252 were very close (39.2 ± 8.2 N m^{-1} versus 30 ± 10 N m^{-1}). Nevertheless, the present study gave a very different impression of the relative strength of these adhesives.

Comparing the extent of adhesive transfer in this study with that observed by Pretzel (1997a; 1997b) as presented in Table 2.6, reveals further problems with that system. Silk habutae laminates adhered to polyester crepeline with Clariant T1601, Lascaux 360/498 HV, and Vinamul 3252 exhibited no adhesive transfer, matching the results for the equivalent adhesives in Pretzel's study. Pretzel's description of the Acryloid (Paraloid) F10 specimens as showing no adhesive at all was probably due to the transparency or fragmentary nature of the coating and not to absorption into the fabrics as tentatively suggested. Scanning electron microscopy has shown clearly that the adhesive coating remains on the support fabric (Figure 2.8). Beva 371 exhibited substantial transfer during peeling in this study but only when the adhesive was sprayed. What the Pretzel matrix does not reflect is the amount of transfer that can be expected from coatings on nylon net from every adhesive except Acryloid F10, particularly when adhered to nylon taffeta. Clearly the Pretzel system does not necessarily predict correctly the peel strength and adhesive transfer results for adhesives used in the types of treatments examined in this study.

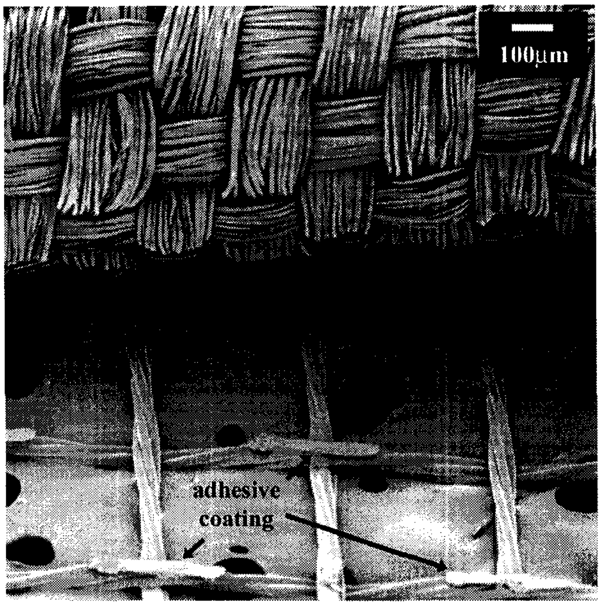


Figure 2.8 Peel behaviour of Acryloid F10 (1:8 v/v in toluene) brushed onto polyester crepeline and adhered to silk habutae. The adhesive coating is visible as short strips on the weft yarns. No adhesive transferred to the silk habutae. (Note: carbon tape is visible through support interstices.)

Adhesive behaviour

Effect of adhesive distribution

Some of the differences in peel strength observed for the specimens in this study and those in the Pretzel (1997a; 1997b) study can be attributed to differences in the amount and distribution of adhesive applied to the support fabric. The significant increase in peel strength of laminates adhered with the dispersion adhesives when the adhesive concentration was doubled illustrates this effect unequivocally. Doubling the concentration of the adhesive solution resulted in adhesive coatings of almost twice the mass of those produced by the more dilute solution (Table 2.4); for example, the mean adhesive add-on of polyester crepeline supports coated with 1:10 and 1:5 v/v solutions of Clariant T1601 was 0.0127 g and 0.0251 g respectively. Moreover, the adhesive that gave the strongest bonds, Beva 371, also had the highest adhesive add-on, while Acryloid F10, which gave the weakest bonds, had the lowest adhesive add-on (Table 2.4). Comparing adhesive add-on and peel strength while disregarding adhesive type shows a broad, positive correlation (Figure 2.9, $R^2 = 0.67$). The relationship was not strong enough, however, for adhesive add-on to function as a significant covariate in the statistical analysis of the peel strength data. Considerable scatter, particularly in the results for Acryloid F10 (all values close to the x-axis) and for a brushed coating of Beva 371 (values on the right in Figure 2.9), indicate that considering the mass of adhesive coating alone is not sufficient to understanding how the nature of the adhesive coating affects peel strength.

To a point, increased adhesive add-on appears to affect peel strength through its effect on the surface area of the adhesive film. The high mass of a brushed Beva 371 coating corresponded to a continuous film of adhesive over the support fabric whereas the low mass of a brushed Acryloid F10 coating did not quite fully coat the yarns of the support fabrics (Table 2.8). Similarly, a 1:5 v/v dispersion solution was more likely than a 1:10 v/v solution of the same adhesive to produce a coating that partially filled the interstices of the support fabrics (Table 2.8). The increase in peel strength can be attributed in part, therefore, to an increased surface bonding area. That specimens adhered with Mowilith DMC2 in Pretzel's study gave a higher average peel strength than the corresponding specimens adhered with Clariant T1601 may be due to the difference between a continuous coating in the previous study compared to a coating covering the yarns in this study. Vinamul 3252 did not form a continuous film in either study.

Exceptions to this pattern may, when considered more closely, actually provide additional support. The sprayed coatings of Acryloid F10 coated the yarns with a higher adhesive add-on

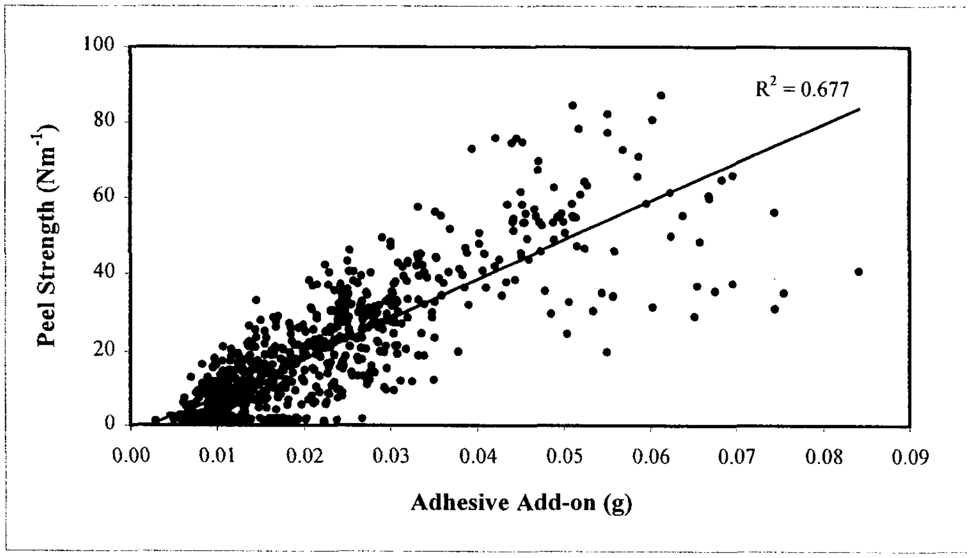
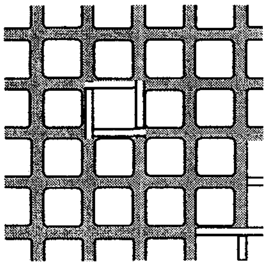
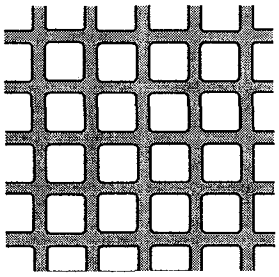
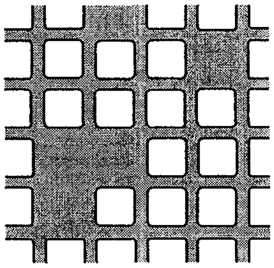
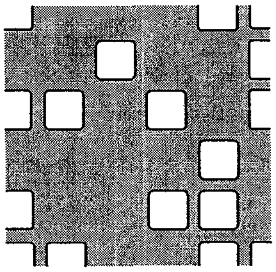
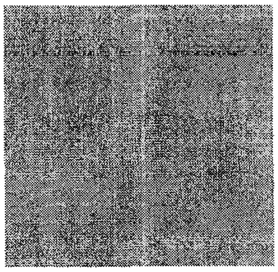


Figure 2.9 The relationship between adhesive coat mass (add-on) and peel strength for all specimens.

Table 2.8 Classification of adhesive coatings by the degree to which the adhesive coats the support fabrics, nylon net (N), polyester crepeline (P), and silk crepeline (S).

Coating Description	Adhesive	Application	Support
 *yarns almost coated*	Acryloid F10	brush	N, P, S
	Clariant T1601	1:10	P, S
		1:5	P, S
	Dur-O-Set E150	1:10	P, S
 *yarns coated*	Acryloid F10	spray	N, P, S
	Clariant T1601	1:10	N, P, S
		1:5	P, S
	Dur-O-Set E150	1:10	N, P, S
	Vinamul 3252	1:10	P, S
	Beva 371	spray	N, P, S
 *few interstices filled*	Clariant T1601	1:10	N
		1:5	N
	Lascaux 360/498 HV	1:10	N, P
		1:5	P
	Dur-O-Set E150	1:10	N
		1:5	P, S
	Vinamul 3252	1:10	N, P, S
		1:5	N, P, S
 *many interstices filled*	Clariant T1601	1:5	N
	Lascaux 360/498 HV	1:10	S
		1:5	N, P, S
	Dur-O-Set E150	1:5	N
	Vinamul 3252	1:5	N, P, S
 *all interstices filled*	Beva 371	brush	N, P, S

but gave significantly weaker peel strengths than the corresponding brushed coatings, which did not fully coat the support yarns. When sprayed, the dilute adhesive solution conformed to the shape of the fibres; when brushed the adhesive coating conformed to the flat Teflon-coated glass cloth underneath the support fabric swatch (Figure 2.10). Even if the brushed coating is not securely anchored to the support fabric yarns in all places, a brushed coating will provide a greater surface area of accessible adhesive than a sprayed coating that follows the texture of the support weave (Figure 2.11a and b). The sprayed coatings of Beva 371 produced bonds exhibiting peel strengths as high as a brushed coating because the adhesive was deposited as fine particles (Figure 2.12) that protruded from the surface of the support fabric (Figure 2.11c). If a more dilute solution of Beva 371, dissolved in a solvent that evaporated more slowly, had been sprayed more closely to the fabric surface, a coating that more closely resembled the sprayed Acryloid F10 coating might have resulted (Nicky Yates, textile conservator, personal communication, February 5, 2001). Unlike the sprayed Acryloid coatings tested in this study, however, such Beva 371 coatings can produce substantial bond strength (Zenzie Tinker, textile conservator, personal communication, February 7, 2001).

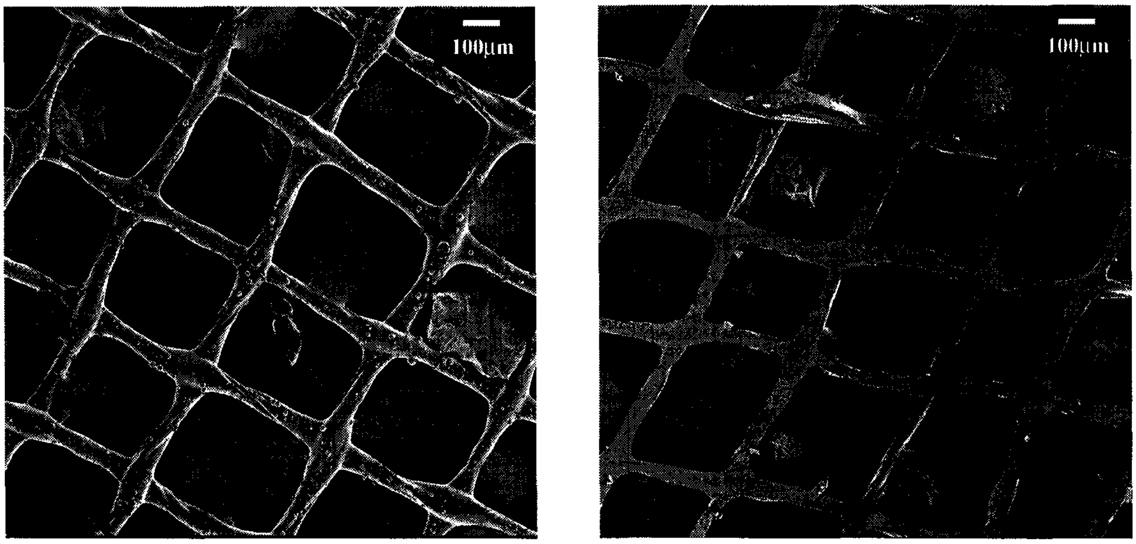
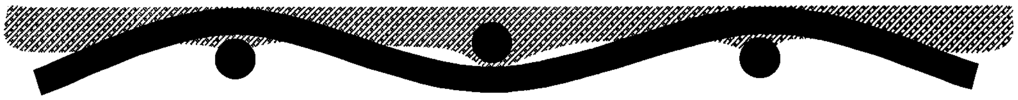
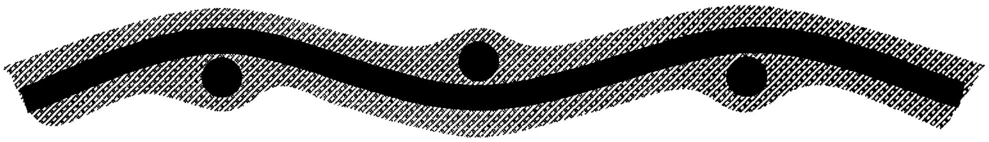


Figure 2.10 Coating of Acryloid F10 (1:8 v/v in toluene) on silk crepeline applied by spray (left) and brush (right).



a) brushed solution



b) sprayed dilute solution

c) sprayed concentrated solution

Figure 2.11 Adhesive coating types produced by solvent adhesives applied by (a) brush or sprayed as a (b) dilute or (c) concentrated solution.

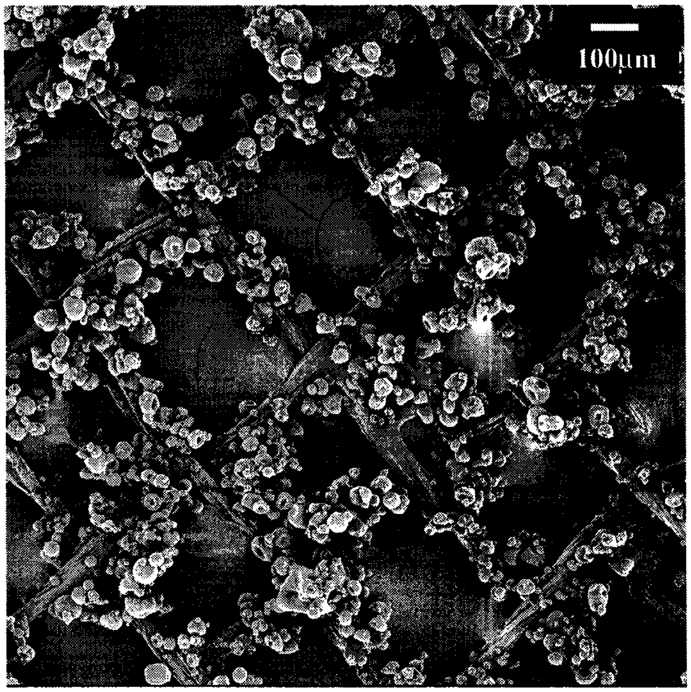


Figure 2.12 Sprayed coating of Beva 371 (1:1 v/v in toluene) on silk crepeline.

The low peel strength results for Lascaux 360/498 HV relative to the other dispersion adhesives also appears anomalous given the degree to which this adhesive can fill the interstices of support fabrics. Microscopic analysis of Lascaux coatings, however, revealed that they were substantially different from those produced by the other adhesives (Figure 2.13). The adhesive film filled many interstices but only partially. The adhesive coating appeared to be poorly anchored to the support fabric yarns, attached to small sections of yarn and then stretching across the interstices in a manner independent of the fabric structure. In contrast, brushed coatings of the other dispersion adhesives followed the structure of the fabrics closely. As the adhesive add-on increased for Lascaux 360/498 HV and the number of interstices that appear filled increased, the peel strength of laminates increased substantially (Table 2.4). The peel strength of laminates produced with a 1:5 v/v solution was three to four times as high as that produced with a 1:10 v/v solution. By comparison, the other dispersion adhesives exhibited a two-fold increase. This suggests that with an even more continuous film, Lascaux 360/498 HV might produce fabric bonds of relatively high peel strength. This may account for the high peel strength for Lascaux 360/498 HV observed by Pretzel (1997a; 1997b). In that study, the Lascaux solution was applied

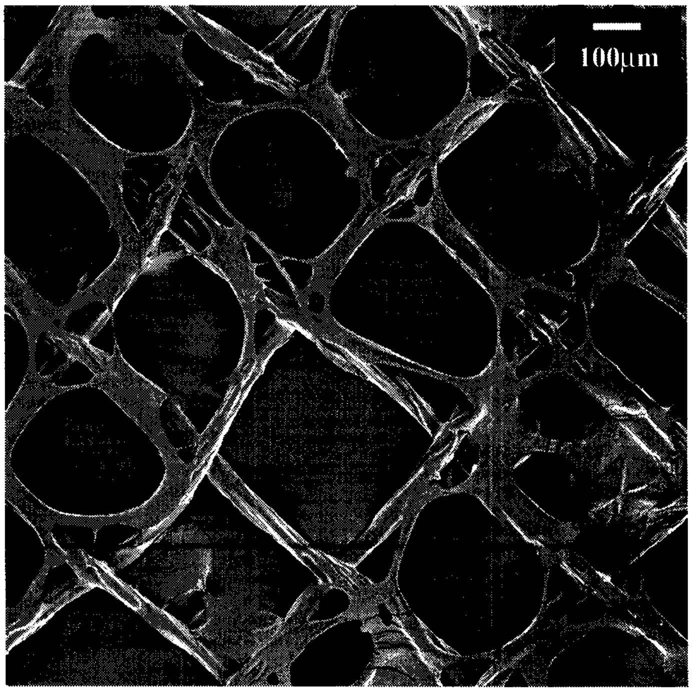


Figure 2.13 Coating of Lascaux 360/498 HV brushed as a 1:5 v/v solution in distilled water onto silk crepeline. Lascaux 360 HV and 498 HV were mixed in a 1:1 mass ratio before dilution.

in a manner that resulted in a more continuous film of adhesive on the support fabric than was produced in this study.

The effect of the support fabrics on the peel results provides further evidence of the influence of adhesive surface area on peel strength. The difference in the peel strength of laminates supported on nylon net and the corresponding laminates supported on polyester or silk crepeline can be attributed to differences in the surface area of adhesive available when coatings for the most part just coat the support fabric yarns. The count of nylon net (9-10 yarns/cm) is one half to one third that of polyester (23 yarns/cm) and silk crepeline (20-30 yarns/cm), respectively, while the diameter of its yarns is similar (about 50-60 μm) (see Table 2.10). Since the adhesive coated mainly the yarns of the support fabrics in most of the specimens tested, surface area of available adhesive would be proportional to that of the support fabrics. Assuming that the surface area of the yarns corresponds to their diameter times their length, the surface area of available adhesive per square centimetre of fabric can be estimated from the yarn diameter and fabric count. Silk crepeline has a slightly higher area available (0.28 cm^2) than polyester crepeline (0.25 cm^2). The area available for nylon net (0.14 cm^2) is considerably less than both crepelines.

This distinction among the support fabrics is paralleled by the amount of adhesive picked up by the fabrics (Figure 2.14). The adhesive add-on was significantly less for nylon net when the adhesive was Acryloid F10, Beva 371 applied by spray, or the dispersion adhesives, Clariant T1601, Dur-O-Set E150, and Vinamul 3252, applied as a 1:10 v/v solution. When these dispersions were applied with a more concentrated solution, the adhesive was more likely to fill the interstices of nylon net than those of polyester or silk crepeline (Table 2.8), reducing the differences in add-on to a non-significant level. As previously discussed, the structure of Lascaux 360/498 HV coatings was relatively independent of that of the support fabrics (Figure 2.13). Lascaux 360/498 HV was better able to fill fabric interstices at low concentrations (Table 2.8), such that the add-on for nylon net was never significantly less than that for polyester crepeline. When the adhesive was applied in a manner that produced a continuous film, as with a brushed coating of Beva 371, the adhesive surface area and adhesive add-on for the three support fabrics no longer differed significantly; neither did the peel strength of the corresponding laminates for a particular artifact fabric.

Bond failure mechanisms

Whether or not adhesive is transferred to the artifact fabric during peeling appears to be related to the mechanical properties of the adhesives. Failure is adhesive in nature (i.e., at the interface) when the adhesive is relatively stiff under the test conditions (20 ± 2°C and 65 ± 2%

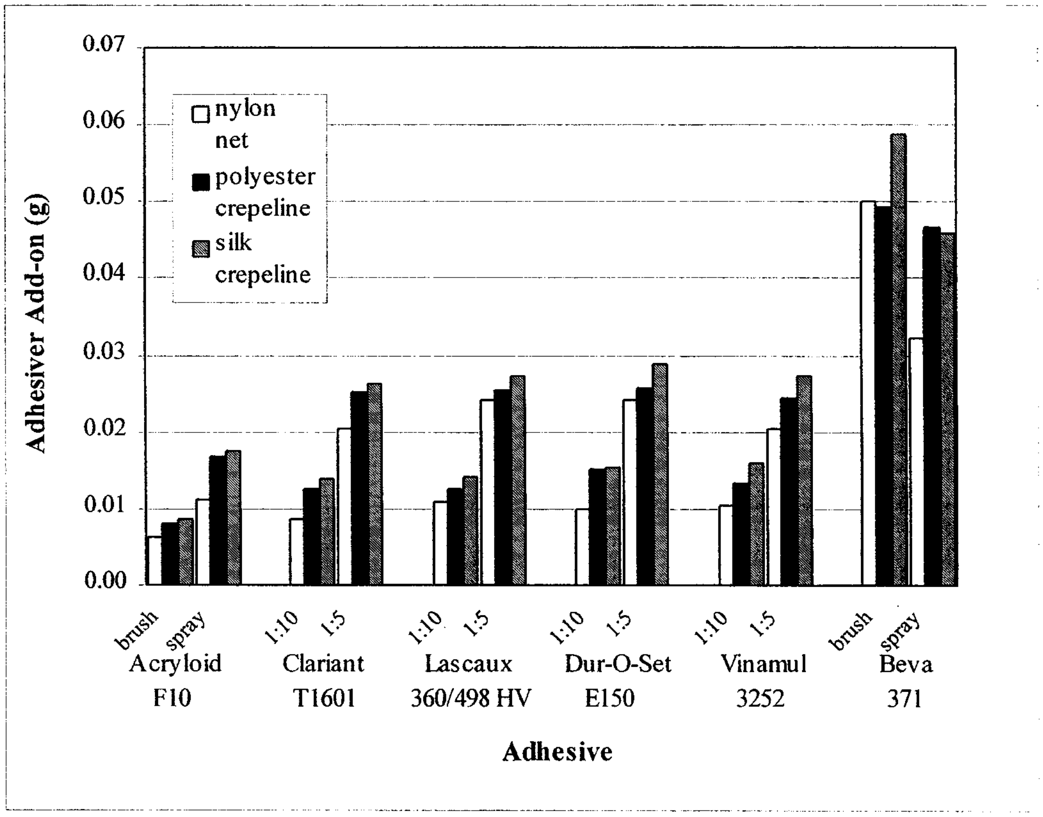


Figure 2.14 Adhesive add-on (g) of Acryloid F10, Beva 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252 coatings on nylon net, polyester crepeline, and silk crepeline supports.

RH). When, by contrast, the adhesive is relatively flexible and extensible, failure is cohesive within the adhesive layer with the attendant transfer of adhesive residue to the artifact fabric on peeling. Although data on the tensile properties of all the adhesives examined in this study are not available, the work of Down and colleagues (Down et al., 1996; Down, 1999) provides tensile data on three of the adhesives, Acryloid F10, Beva 371, and Dur-O-Set E150, along with data on an adhesive equivalent to Clariant T1601, Mowilith DMC2 (Table 2.9). Of these adhesives, the two stiffest as indicated by high values for modulus, Acryloid F10 and Clariant T1601, exhibited little adhesive transfer during peeling. Beva 371, a fairly flexible adhesive with low modulus, exhibited substantial transfer from a sprayed coating or a brushed coating on nylon net (Figure 2.15). Lascaux 360 HV was also studied by Down et al. (1996) but not Lascaux 498 HV or their mixture. Lascaux 360 HV, with a Tg of about -8°C, exhibited the typical tackiness and extreme extensibility of pressure sensitive adhesives. Down et al. were unable to measure the tensile

Table 2.9 Tensile properties of adhesives (tested as unsupported films). (Source: Down et al., 1996; Down, 1999)

Adhesive	Tensile Strength (MPa)	Elongation at Break (%)	Modulus (MPa)
Acryloid F10	5.08 ± 0.13	211 ± 4.88	204 ± 12.3
Beva 371	3.78 ± 0.12	347 ± 15	58.1 ± 0.60
Mowilith DMC2[a]	7.30 ± 0.21	274 ± 9.86	305 ± 86.5
Lascaux 360 HV[b]	>0.202	>768	1.90 ± 0.879
Dur-O-Set E150	4.96 ± 1.1	579 ± 86.1	14.09 ± 3.57

[a] equivalent to Clariant T1601

[b] after 4 years of dark ageing

properties of unaged films of this adhesive but its modulus remained very low after four years of ageing in the dark (Table 2.9). The tackiness of the Lascaux 360/498 HV mixture suggests that the Tg of this mixture is still very low (it would be below the Tg of Lascaux 498 HV which is about 13°C), and that a low modulus and high degree of extensibility could be predicted for this adhesive mixture. Similar tensile results would be expected for Vinamul 3252.

The cohesiveness of the adhesive coating and the strength of its attachment to the support fabric must also affect how the bond fails. Relative modulus does not reliably predict adhesive

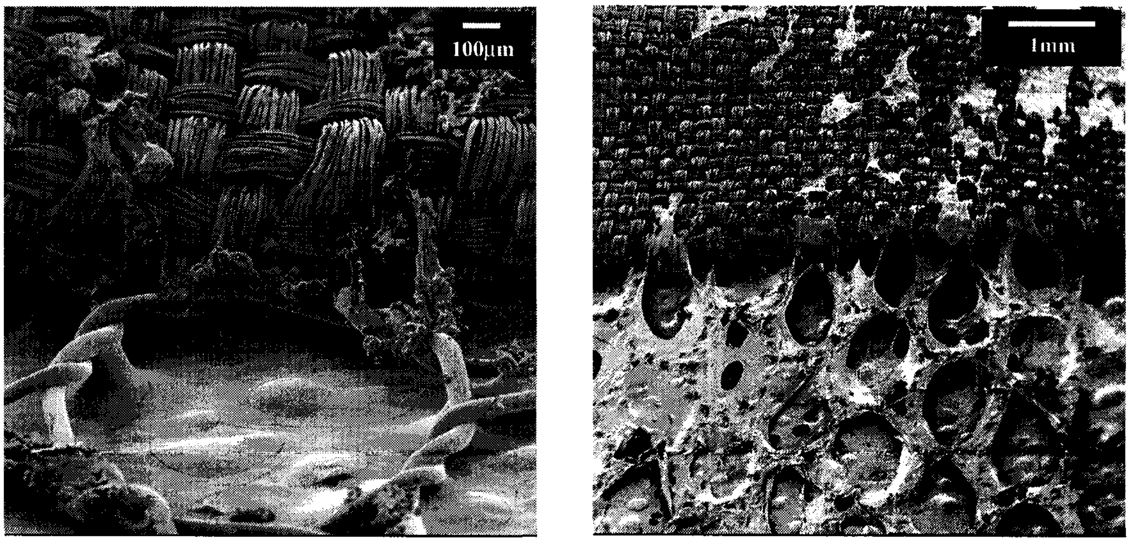


Figure 2.15 Peel behaviour of Beva 371 sprayed (left) and brushed (right) as a 1:1 v/v solution in toluene onto nylon net and adhered to silk habutae showing adhesive stretching and transfer to artifact fabric. (Note: the layer under the nylon net is carbon tape.)

transfer during peeling. Dur-O-Set E150 has a lower modulus than Beva 371; yet it exhibited almost no adhesive transfer during peeling. Beva 371 brushed onto polyester or silk crepeline to form a continuous film also exhibited little adhesive transfer during peeling (Table 2.6). Extending and breaking bits of adhesive from a continuous film that is securely attached to the support fabric yarns would require more force than stretching the tiny particles of adhesive deposited during spraying: the continuous film has more cohesive strength than an agglomeration of particles. Coatings of Lascaux 360/498 HV and Vinamul 3252 on polyester or silk crepeline showed little transfer (Table 2.6), an observation also recorded by Pretzel (1997a; 1997b). Adhesive coatings on net, on the other hand, exhibited greater degrees of transfer regardless of adhesive modulus (Table 2.6, Figure 2.7). Both the large size of the interstices and its construction from monofilament yarns may predispose nylon net to adhesive transfer during peeling. Adhesive coatings are anchored onto polyester and silk crepeline through mechanical interlocking when the adhesive solution that penetrates between the fibres in the yarns solidifies. This can occur to only a minor degree on nylon net, in which the filaments twist around each other only occasionally.

Using an adhesive that stretches easily when subjected to stress is both advantageous and problematic for adhesive support treatments for textile artifacts. The ability of the adhesive to stretch into filaments is often related to high peel strengths, since force is dissipated in deforming the adhesive and is not concentrated at the interface where it would break the adhesive-fibre bond. Higher peel strength means that the treated artifact can be handled and manipulated to a greater degree without fear of bond failure. Adhesives such as Beva 371 and Vinamul 3252 are probably more appropriate for three-dimensional textile artifacts such as clothing or for flat artifacts that will be rolled for storage. Keyserlingk (1993) recognized that Acryloid F10 applied as a 1:8 solution in toluene does not produce bonds sufficiently strong to withstand handling or rolling. Accidental delamination of two Acryloid F10 specimens before peel testing during this study confirmed that artifacts adhered with this adhesive in the manner applied would have to be handled very carefully to prevent bond failure.

If an adhered support needs to be removed, however, an extensible adhesive that tends to transfer to the artifact makes the task more difficult. Conservators often use heat or solvent vapour to reduce the bond strength if using a peeling technique to remove the support (Boersma, 1998; Cruickshank, Lee, & Potter, 1998; Foskett & McClean, 1998; Himmelstein & Appelbaum, 1977; Landi, 1992; Lord, 1997; Mailand, 1998). Both heat and solvent vapour increase the flexibility and extensibility of the adhesive, making adhesive transfer more likely. Thus Pretzel (1997a; 1997b) observed adhesive transfer for Lascaux 360/498 HV during a hot peel test but not during a peel test under ambient conditions (Table 2.2). Cohesive failure within the adhesive is also more likely at slow peel rates (Derail et al., 1998), which textile conservators use instinctively in order to protect the relatively weak fibres of the artifact. If removability of an adhered support is important for a particular artifact, a relatively stiff adhesive, such as Acryloid F10 or Clariant T1601, and a rigid mount may be the best alternative.

Fabric Effects

Artifact fabrics

That silk habutae laminates had stronger peel strengths than the corresponding nylon taffeta laminates was expected given the relative polarity of the two fibre polymers. Both fibres contain amide linkages and thus C═O and N—H polar bonding sites. These are more numerous in silk than in nylon, where aliphatic chains of —CH_2 groups (six in nylon 6,6) separate the amide groups. The presence of additional polar groups on amino acid side chains of the protein fibre, silk, such as the hydroxyls of serine (—CH_2OH), adds to its polarity. As a result, silk fibres have a higher moisture regain at 20°C and 65% RH (10%) than nylon fibres (4.1%) (Morton & Hearle, 1993, p. 170). Polar groups provide sites for potential acid-base interactions and hydrogen bonding with polar groups on the adhesive polymer molecules that contribute to bond strength.

Fabric structure and mechanical properties also influenced the peel test results. Since the fabrics were bent and, to some degree, stretched during peeling, the greater the force expended in this manner, the greater the peel strength, all else being equal. Given its fabric mass and structure, more force would probably be expended to bend and stretch nylon taffeta than silk habutae (Table 2.10). With a slightly higher initial modulus (23.3 versus 20.9 N mm^{-1}), nylon taffeta is stiffer than silk habutae, requiring more force to be bent into the T-peel configuration. The yarns of nylon taffeta are larger than those of silk habutae and thus more difficult to bend. The circular fibre cross-section of its fibres requires more force to bend than the flatter, triangular silk fibres (Morton & Hearle, 1993, p. 401). Since the nylon laminates were adhered more weakly than the silk laminates, the contribution to the total peel force of the force required to bend the artifact fabrics must have been outweighed by that required to break intermolecular bonds. The relative strength of Acryloid F10 bonds to the artifact fabrics is a good test case for this idea since the fabrics were not bent sharply or stretched at all during peeling. Nevertheless, Acryloid F10 bonds to silk habutae (2-3 N m^{-1}) were twice as strong as those to nylon taffeta (1-1.5 N m^{-1}). In addition, the triangular cross-sectional shape of the silk fibres, their slightly rough surfaces, and their relatively loose packing in the habutae yarns may have optimised the

Table 2.10 Characteristics of the artifact and support fabrics.

		Fabric				
		Artifact		Support		
Fabric Property		nylon taffeta	silk habutae	nylon net[a]	polyester crepeline	silk crepeline
Weave		plain	plain	bobbinet	plain	plain
Mass (gm^{-2})		63.5	33.9	8.7	12.3	9.6
Count (yarns/cm)	warp	41	50	10	23	30
	weft	34	44	9	23	28
Linear Density (tex, g/km)	warp	7.9	3.7	3.6	2.6	1.5
	weft	8.1	3.7	2.2	2.7	1.6
Yarn Diameter (μm)	warp	245	200	62	56	52
	weft	294	227	49	58	51
Yarn Twist	warp	minimal	minimal	n/a	S	Z
	weft	minimal	minimal	n/a	S	Z
Fibres per Yarn	warp	34	c. 30	1	4	c. 10
	weft	34	c. 30	1	4	c. 10
Fibre Cross-sectional Shape		circular	triangular	circular	circular	triangular
Tensile Strength (N)	warp	355.5 ± 4.3	132.5 ± 4.7	46.3 ± 0.9	73.6 ± 1.5	32.3 ± 0.5
Extension at Break (%)	warp	38.3 ± 1.0	13.6 ± 0.9	32.0 ± 1.6	19.1 ± 1.6	14.2 ± 0.6
Initial Modulus (Nmm^{-1})	warp	23.3 ± 0.3	20.9 ± 0.8	2.4 ± 0.1	8.1 ± 0.9	8.5 ± 0.7

[a] for this fabric, yarns running parallel to the length of the fabric are called warp yarns, while those running diagonally to the warp yarns are labelled weft yarns

surface area available for bonding when compared to the relatively smooth, circular, densely packed nylon fibres in the taffeta yarns (Figure 2.16).

The clear difference in the peel strengths of silk habutae and nylon taffeta laminates has implications for adhesive choice. If a certain level of resistance to peel forces is required for a particular treatment, a "stronger" adhesive may be needed if the artifact is made of nylon, even if the weave and structure of the fabric is similar to silk fabrics that are more frequently given adhesive treatments. For example, to get bonds as strong as silk crepeline coated with Clariant T1601 adhered to silk habutae (14-25 N m^{-1} depending on concentration), a conservator would probably have to use a similar solution of Vinamul 3252 on silk crepeline for nylon taffeta (12-30

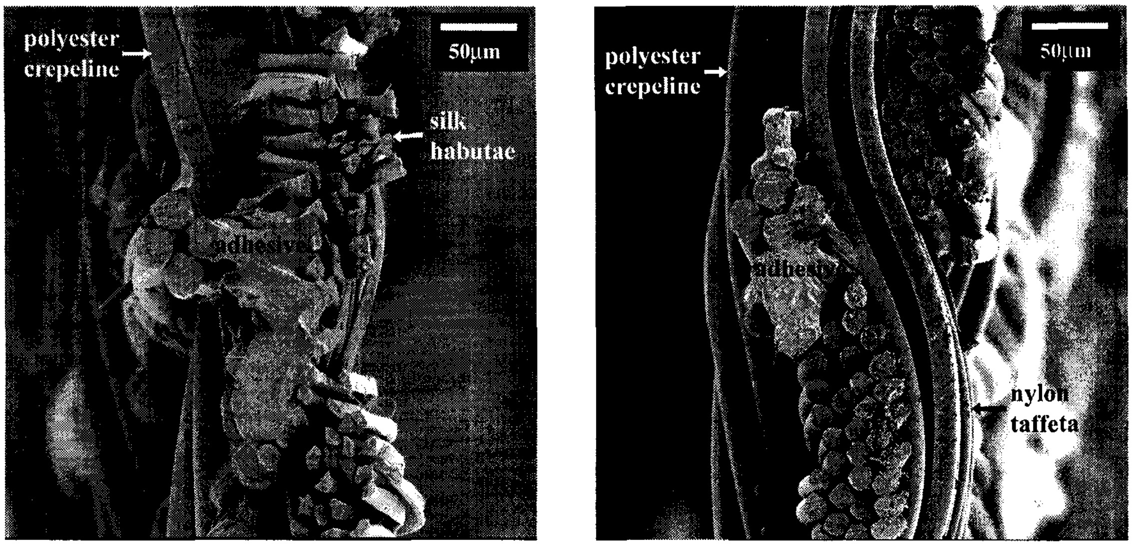


Figure 2.16 Silk habutae (left) and nylon taffeta (right) adhered to polyester crepeline with a sprayed coating of Beva 371 in toluene (1:1 v/v) showing how the difference in fibre cross-section and yarn structure may optimize bonding to silk habutae.

N m^{-1}) rather than Clariant T1601 (6-11 N m^{-1}). Although few adhesive support treatments of nylon artifacts have been described in the literature, the tendency for nylon to embrittle when exposed to light in a manner similar to silk suggests that adhered supports might be considered for such textiles in the future.

Support fabrics

The tensile properties of the support fabrics may have contributed to their peel strength differences in addition to the amount of adhesive they could carry as already described. The relative flexibility of nylon net in comparison to polyester or silk crepeline may also contribute to the lower peel strength of laminates supported with it. The initial modulus of nylon net (2.4 N mm^{-1}) is less than a third that of polyester crepeline (8.1 N mm^{-1}) and silk crepeline (8.5 N mm^{-1}). Little force is required to bend the net relative to the crepelines. Nylon net is also easily stretched (Table 2.10). Some force may be dissipated when peeling net-supported laminates, particularly when the adhesive bond is quite strong. If so, the force expended is not sufficient to negate the effect of less available adhesive. The peel strength of laminates adhered with the strongest adhesive, Beva 371, was significantly less when applied by spray on nylon net (33-42 N m^{-1}) than when sprayed onto polyester (53-72 N m^{-1}) or silk crepeline (49-63 N m^{-1}).

The lack of distinction between the peel strengths of laminates supported on silk or polyester crepeline contradicts the findings of a previous study comparing Appretan MB extra and Lascaux Hot-seal Adhesive 371 (Karsten, 1998). In that study, polyester crepeline produced significantly higher peel strengths than silk crepeline. If this study focussed on the comparable laminates, Clariant T1601 applied at a 1:10 v/v concentration and Beva 371 applied by spray, that statistical result might have been replicated, as were the peel strength values. The peel strength of the silk habutae laminates adhered with Clariant T1601 was 18.2 ± 3.4 N m^{-1} when supported on polyester crepeline but only 13.8 ± 3.8 N m^{-1} when supported with silk crepeline. The corresponding values for Appretan MB extra were 17.8 ± 7.3 N m^{-1} for polyester crepeline and 11.3 ± 4.9 N m^{-1} for silk crepeline. Sprayed Beva 371 adhered to silk habutae gave peel strengths of 72.1 ± 9.5 N m^{-1} when supported on polyester crepeline but 63.2 ± 13.2 N m^{-1} when supported on silk crepeline. The corresponding values for Lascaux Hot-seal Adhesive 371 were 51.9 ± 11.5 N m^{-1} for polyester crepeline and 48.1 ± 7.6 N m^{-1} for silk crepeline. The lack of significance in the present study is rooted in an analysis that included values for nylon taffeta, which exhibited smaller differences between polyester and silk crepeline; for example, the Clariant T1601 results that correspond to the silk habutae values given above are 7.1 ± 1.3 N m^{-1} for polyester crepeline and 6.1 ± 1.8 N m^{-1} for silk crepeline. In addition, silk and polyester crepeline exhibited almost no difference for Acryloid F10 and a 1:10 v/v solution of Lascaux 360/498 HV, while silk crepeline gave higher peel strengths on average than polyester crepeline for a brushed coating of Beva 371 (Figure 2.4). In general, this study suggests that any distinction between polyester and silk crepeline is not significant enough to be worth considering with regards to the desired peel strength of the treated artifact. Lower bond strengths can be expected from nylon net, however, when the adhesive coating does not form a continuous film over the fabric interstices.

Conclusions

This study has shown that the materials (adhesives, artifact fabrics, and support fabrics) and application techniques, used in adhesive support treatments for textile artifacts significantly affect the peel strength of the laminated textile. Doubling the concentration of a dispersion adhesive solution doubled the peel strength of the laminates. Spraying rather than brushing produced significantly weaker peel strength when the adhesive was Acryloid F10 but did not significantly affect the results of Beva 371. The effect of spray versus brush application appears to depend in part on the concentration of the adhesive solution. Bonds to silk habutae were stronger than those to nylon taffeta. Laminates supported with nylon net were weaker than those on polyester and silk crepeline. The type of adhesive used clearly influenced peel strength as well, although variations in application technique made a single ranking by peel strength impossible. Many of the differences in peel strength can be attributed to differences in the surface area of adhesive available for bonding, although the artifact fabric differences are probably due to differences in fibre chemistry. The results indicated that a scoring system that compares the bond strength of adhesives based on a single set of peel tests using one artifact and support fabric and adhesive solutions of varying concentration for the purposes of selecting an adhesive for a variety of artifacts (Pretzel, 1997a, 1997b) is not valid.

An instrument to aid textile conservators in choosing an adhesive would, nevertheless, be very useful. If it is to include an assessment for bond strength, which it should since the success of the treatment depends on an adequate bond, further research is required. Because this study employed application techniques recommended by textile conservators, much as the Pretzel (1997a; 1997b) study did, the results cannot be used to rank the adhesives from weakest to strongest even as they show that Pretzel's attempt to classify the adhesive along these lines is invalid. Carefully designed experiments with adhesive coatings of equal surface area and thickness would be necessary to better compare the bond strengths of the adhesives that textile conservators might use. Heat-sealing temperature would need to be controlled in order to give the maximum peel strength for each adhesive. Different fabrics would again need to be tested to ensure that patterns for one can be generalized to others. Without such careful study, conservators must rely on their experience to glean from Pretzel's matrix and the results of this study information that will help them make good treatment decisions with regard to the bond strength needed for the support of textile artifacts.

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CHAPTER 3

CONTACT ANGLES, SURFACE FREE ENERGY COMPONENTS, AND WORK OF ADHESION[2]

Introduction

When supporting fragile textiles using adhesives, textile conservators want an effective bond to the support fabric with little adhesive penetration into the artifact fabric in order to enhance treatment reversibility. The resultant superficiality of the adhesive bond contributes to bond weakness, a weakness that is ideal as long as the bond provides effective support to the artifacts under conditions of display and handling. One way to increase bond strength without increasing artifact penetration and, thus, optimize bond strength, is to choose an adhesive that forms strong molecular interactions with fibre surfaces (Bede, 1993). Conservation science research has not characterized the adhesives used by textile conservators according to their surface properties. Few adhesive formulations, even adhesives used in industrial applications, have been considered in research on the surface properties of polymeric solids. Given the importance of molecular interactions to the formation of bonds between adhesives and solids, characterization of adhesive/fibre surface interactions is important to understanding how the bonds in fabric laminates function. Using the van Oss-Chaudhury-Good (vOCG) approach (Good, Chaudhury, & van Oss, 1991), this study will characterize the surface free energies of six adhesives used by textile conservators and of silk and nylon fabrics similar to fabrics found in textile artifacts. The relative strength of molecular interactions for fabric/adhesive pairs will be ascertained through calculation and comparison of work of adhesion, W_{FA}. Work of adhesion results will be compared to peel strength results for corresponding fabric laminates in order to assess the importance of adhesive/adherend surface interactions relative to the effects of joint design and adhesive mechanical properties towards the provision of an adequate bond. Comparing the results of these two approaches to examining the bond in textile artifact/adhesive/support fabric laminates will also permit assessment of the usefulness of this surface science approach towards the goal of improving adhesive treatments for textile artifacts.

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[2] A version of this chapter, based on preliminary results, has been published. Karsten, I.F., & Kerr, N. (2003). Comparing the bond strength of adhesive support treatments for textiles: peel strength versus work of adhesion. In J.H. Townsend, K. Eremin, & A. Adriaens (Eds.), *Conservation Science 2002* (pp. 107-114). London: Archetype.

Interfacial Interactions

Textile layers cannot be adhered without the activation of interfacial forces between the textile fabrics and the adhesive used to join them together. At the microscopic level, this requires that the adhesive liquid wets and maintains a reasonably strong attraction for both the fibres of the textile artifact and those of the support fabric. The interactions at these interfaces can be studied in terms of the thermodynamics of surfaces. For this study, the interface between textile artifact fibres and the adhesive will be the focus since it is simpler to model and is often the site of delamination. Adhesion at this interface takes place between a softened adhesive polymer and the solid fibre during heat-sealing. In contrast, adhesion at the adhesive-support fabric interface is initiated when the adhesive polymer is dissolved or suspended in a solvent. This complicates the thermodynamics of the interface considerably (Gutowski, 1991).

Wetting parameters

Surface science offers several parameters by which the interfacial interaction of adhesive bonds can be characterized (Connor, Bidaux, & Månson, 1997). The simplest parameter, and one which can be measured directly for some liquid-solid systems, is the contact angle, θ, formed by a liquid droplet against the solid surface (Figure 3.1). Other parameters are usually calculated, often using measured contact angle values. Work of adhesion, W_{SL}, or the reversible work necessary to separate a unit area of the interface between a solid and a liquid into two new surfaces, can be defined as the sum of the surface free energies of the two materials less their interfacial free energy:

$$W_{SL} = \gamma_{SV} + \gamma_{LV} - \gamma_{SL} \tag{3.1}$$

wherein γ_{SV}[3], γ_{LV} and γ_{SL} are interfacial free energies of the solid-vapour, liquid-vapour and solid-liquid interfaces, respectively.

Although the surface free energy of liquids can be measured directly in a variety of ways, the surface free energy of solids and the interfacial free energy between liquid and solid can only be estimated through the measurement of the contact angle of liquids of known surface free energy on the solid surface. The Young equation, which describes the relationship between

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[3] For the purposes of this paper, γ_{SV} is considered equivalent to the actual surface free energy of the solid, γ_S. In fact, the solid surface free energy in a vacuum is equal to the surface free energy of the solid-vapour interface plus the spreading pressure, $\gamma_{SV} + \pi_e$. The spreading pressure is considered negligible for low energy surfaces such as polymers, making this a reasonable assumption (Hiemenz & Rajagopalan, 1997).

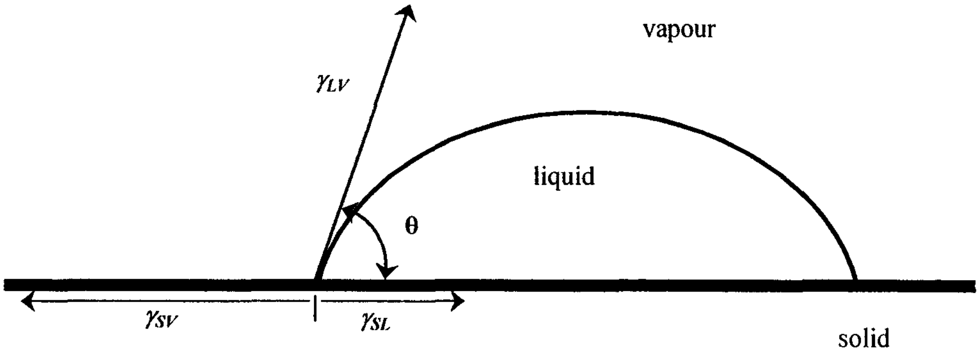


Figure 3.1 Contact angle, θ, and the forces between a drop of liquid and a solid surface at the solid-vapour (γ_{SV}), solid-liquid (γ_{SL}), and liquid-vapour (γ_{LV}) interfaces.
Note. Adapted from Gutowski (1991, p. 117).

contact angle and the surface free energies of a solid and liquid,

$$\gamma_{SV} - \gamma_{SL} = \gamma_{LV}\cos\theta \tag{3.2}$$

combined with equation 3.1 gives

$$W_{SL} = \gamma_{LV}(1 + \cos\theta) \tag{3.3}$$

Thus the work of adhesion between a liquid and a solid can be calculated if the surface free energy of the liquid and the contact angle between the liquid and the solid are known.

Van Oss-Chaudhury-Good approach

A frequently used, though not undisputed, technique for deriving the solid surface free energy and its components is the van Oss-Chaudhury-Good (vOCG) approach. This theoretical approach models the surface interactions through two components: dispersion or Lifshitz-van der Waals (γ^{LW}) and acid-base (γ^{AB}) (Good et al., 1991; Good & van Oss, 1992; Good & Chaudhury, 1991; Good, 1993). The acid-base component is further characterized through two parameters describing the acidic (γ^+) and basic (γ^-) properties of a surface. Substances can be apolar (dispersion component only), monopolar acidic or basic, or bipolar to varying degrees. The surface free energy of a material is described as the sum of the dispersion and acid-base components:

$$\gamma = \gamma^{LW} + \gamma^{AB} = \gamma^{LW} + 2(\gamma^+\gamma^-)^{1/2} \tag{3.4}$$

The interfacial interaction between a solid and a liquid is then determined as follows:

$$\gamma_{SL} = \gamma_S^{LW} + \gamma_L^{LW} + 2[(\gamma_S^+\gamma_S^-)^{1/2} + (\gamma_L^+\gamma_L^-)^{1/2} - (\gamma_S^{LW}\gamma_L^{LW})^{1/2} - (\gamma_S^+\gamma_L^-)^{1/2} - (\gamma_S^-\gamma_L^+)^{1/2}] \quad (3.5)$$

Combining equation 3.5 with equations 3.1, 3.3, and 3.4 gives:

$$\gamma_{LV}(1 + cos\theta) = 2[(\gamma_S^{LW}\gamma_L^{LW})^{1/2} + (\gamma_S^+\gamma_L^-)^{1/2} + (\gamma_S^-\gamma_L^+)^{1/2}] \quad (3.6)$$

The Lifshitz-van der Waals and acid-base components of the solid are estimated through measuring the contact angle with three liquids of known surface free energy components, one of which is apolar (negligible acidic and basic character), and solving the system of equations for the unknowns (Good, 1993). The work of adhesion between a fabric and an adhesive can also be estimated using equation 3.6 if the surface free energy components of both fabric and adhesive surfaces are known. The usefulness of the results of such calculations depends on the accuracy of the underlying theory as well as precise measurement and interpretation of contact angles on fabrics and adhesive polymers using the available techniques.

Although alternative approaches, such work of adhesion calculations based on the geometric or harmonic mean of dispersion and non-dispersion free energy components or Neumann's equation of state approach, have been shown to be incorrect in some cases (Fowkes, Riddle Jr., Pastore, & Weber, 1990; Xu, Liu, & Ling, 1995), the vOCG approach has equally been found inadequate. Kwok (1999) summarized a number of studies testing the ability of the vOCG approach to predict surface free energy components of fluorocarbon, poly(styrene), and poly(methyl methacrylate) solid surfaces, as well as the interfacial free energy of a number of liquid pairs. Kwok reported considerable variation in the results depending on which three liquids were chosen for testing contact angles. There was also considerable discrepancy between experimental and calculated interfacial free energy although there was a positive correlation in the results. Della Volpe and Siboni (2000) dismissed this criticism on the basis that certain liquid triplets—one apolar and two polar of distinct acid-base character, as recommended by van Oss (2002)—give optimal results while others should simply not be used. Le, Ly, and Stevens (1996) found a similar but slight variability in surface free energy values for wool fibres depending on the set of three liquids used, but the variability was far less than that observed by using the equation of state approach or the geometric mean equation.

Tate, Kamath, Wesson, and Ruetsch (1996) also questioned the ability of the vOCG approach to provide meaningful results for their study of nylon 6,6 fibres. They found that this approach predicted unreasonably low nondispersive components to the surface free energy and that it characterized nylon 6,6 as basic when other tests showed it to be bipolar. They rejected the explanation given by Good et al. (1991, 1992) for similar results on other materials: that the basicity is caused by removal of acid functionality from the surface through internal hydrogen bonding. Instead they suggested that dispersive and nondispersive components of surface free energy do not act concurrently for strongly hydrogen bonding substances such as nylon. They recalculated the acid-base components with the following equation based on the assumption that the entire work of adhesion results from hydrogen bonding:

$$\gamma_{LV}(1 + \cos\theta) = 2[(\gamma_S^+\gamma_L^-)^{1/2} + (\gamma_S^-\gamma_L^+)^{1/2}] \tag{3.7}$$

Whether such an assumption is thermodynamically appropriate is not clear. The microfluorometric data that Tate et al. use to support their argument depended on the occupation of acidic and basic sites on the fibres by dyes during a 30-minute period of immersion in an aqueous solution, during which it is likely that a certain degree of surface reorganization could have occurred. Fluorescence intensities of fibres drawn in aqueous environments were greater than those of fibres drawn in air. The microfluorometric data thus support the interpretation that the surfaces of the fibres in the two environments are not identical.

Another weakness in the vOCG approach may lie in one of its underlying assumptions. This approach is predicated on the premise that the acid/base ratio of water equals one (Good, 1993; Good et al., 1991; Good & van Oss, 1992). This ratio affects the acid-base parameters of all reference liquids used as probes. Shen (2000) demonstrated clearly that changing the ratio results in significant changes in the acid-base components of the surface free energy. The greatest changes occur amongst ratio values from one to three. The changes that Shen reported were a fairly large decrease in basicity and a slight increase in acidity as the acid/base ratio increased. Thus the high basicity of many substances studied through the vOCG approach may be due to the postulated acid/base ratio for water. Shen suggested using a value of 2.42 for the acid/base ratio, a value averaged from the results of several binary approaches to the acid-base properties of water reported in the literature. Similarly, Lee (1996) obtained an acid/base ratio of 1.8 from solvatochromatic parameters. Lee found that this ratio increased the value of γ^+ relative to γ^-, but not sufficiently to account for the acidity of polymers like poly(vinyl chloride). Van Oss (2000) has demonstrated clearly, however, that the concern over the accuracy of the acid/base ratio in water is misplaced, since the value of the acid-base component, γ^{AB}, is independent of that ratio. Nevertheless, Della Volpe and Siboni (2000) have stated emphatically that the tendency for the vOCG approach to characterize solid surfaces as basic does not correspond to reality and is an artifact of the characterization of water as having equal acidic and basic components. They concluded that the vOCG approach should only be used to determine relative acid-base values until accurate values for a reference material such as water can be determined.

Determining contact angles on solids

The use of the vOCG approach requires techniques for determining accurate contact angles of liquids on solid surfaces. For flat, rigid, nonporous solids, such as polymer films, contact angles of actual drops can be measured using a goniometer. For fibrous materials or porous solids, contact angles measured in such a manner will be inaccurate due to the effects of surface deformation or roughness and capillary wicking on the shape of the drop. Fabrics are both fibrous and porous.

Washburn technique

A variation of the Washburn technique, most often used for porous or powdered solids, has been used to determine the contact angles of liquids on fabric specimens (Rulison, 1996; Park & Kim, 2001). In the Washburn technique, contact angles are related to the rate of liquid wicking into the specimen. The rate of liquid flow through a capillary is given by the Poiseuille equation (Hiemenz & Rajagopalan, 1997; Washburn, 1921):

$$\frac{V}{t} = \frac{(\rho g l + \Delta p)\pi R^4}{8\eta l} \qquad (3.8)$$

where V/t is the rate, ρ is the liquid density, g is the force due to gravity, l is the length of the capillary, Δp is the pressure difference across the end of the capillary, R is the capillary radius, and η is the liquid viscosity. The Poiseuille equation can be simplified by equating the volume rate of flow to $d(\pi R^2 h) / dt$, where h is the penetration height of the liquid into the specimen:

$$\frac{dh}{dt} = \frac{pR^2}{8\eta h} \qquad (3.9)$$

The pressure term, p, can be eliminated from this equation by modeling the porous solid as a bundle of capillaries and applying the Laplace equation,

$$p = 2\, \gamma_L \cos\theta / R \qquad (3.10)$$

to give the Washburn working equation:

$$\frac{dh}{dt} = \frac{\gamma_L R \cos\theta}{4\eta h} \qquad (3.11)$$

By integrating equation 3.11 and substituting mass of the liquid absorbed for its height through the relation, $m = \rho C$, where ρ is the density of the liquid, and C is a constant that characterizes the capillary volume of the specimen, the equation takes the form:

$$\frac{m^2}{t} = \frac{\gamma_L \cos\theta\, \rho^2 C}{2\eta} \qquad (3.12)$$

which, if solved for $\cos\theta$, gives

$$\cos\theta = \frac{m^2}{t}\,\frac{2\eta}{\gamma_L \rho^2 C} \tag{3.13}$$

The slopes of graphs of tensiometric data—mass squared (g^2) versus time (seconds)—can be substituted into equation 3.13. The material constant, C, is determined by using a low energy liquid that fully wets the solid, giving a contact angle of zero. Once the material constant is known, the contact angle for other liquids of known surface free energy (mJ m^{-2}), viscosity (mPa s), and density (g cm^{-3}) can be calculated.

Factors Affecting Contact Angle Measurements

Many factors may affect the value and interpretation of the contact angle and in turn its usefulness for calculating other parameters. The contact angle itself can denote three distinct angles (Adamson & Gast, 1997, pp. 372-373): the microscopic angle between the liquid and an actual solid, θ_m, the thermodynamic contact angle found in Young's equation, θ_{th}, which assumes a smooth, homogeneous, incompressible solid surface and a liquid drop at equilibrium, and the apparent contact angle, θ_{app}, which is measured experimentally. The apparent angle, moreover, may be designated as an advancing angle, θ_a, measured when liquid is being added, or as a receding angle, θ_r, measured when liquid is extracted. It may not be possible to measure an equilibrium contact angle, on which the thermodynamic equations given above are premised, with some of the experimental techniques used. Whether angles other than the true equilibrium angles can be used in equations derived from Young and Dupré's thermodynamic equations without introducing a source of error does not appear to have been addressed directly in recent literature. Certainly the surface free energy results obtained using advancing angles differ from those using receding angles, if those angles differ (Good, Shu, Chiu, & Yeung, 1997). Receding angles may better characterize the polar component of the surface free energy (Della Volpe & Siboni, 2000). Using both angles permits fuller characterization of the surface.

Contact angles are, moreover, affected by physical and chemical surface heterogeneity, resulting in contact angle variability (Adamson & Gast, 1997; Hiemenz & Rajagopalan, 1997; Shaw, 1992). Surface roughness can result in angles that are greater or less than the true contact angle depending, respectively, on whether the liquid wets the solid well or poorly (Wenzel, 1936). Soft solids, such as elastomers, may deform at the edge of a liquid drop, creating a wetting ridge that, like surface roughness, obscures the true contact angle (Shanahan & Carré, 2002; Carré, Gastel, & Shanahan, 1996). Variability in the manner in which specimens of porous solids are prepared for testing using the Washburn technique introduces error since the technique involves determining the material constant on specimens different from those used for contact angle measurement. Depending on the nature of the solid, consistent packing or preparation may be challenging (Rulison, 1996).

Contact angle variability may also be due to chemical heterogeneity of the polymer surface. Surface contaminants or finishes, such as sizes, surfactants, or exuded, low energy additives, affect contact angle measurements (Kamath, Dansizer, Hornby, & Weigmann, 1987; Rhee, Young, & Sarmadi, 1993; Sarmadi, Kwon, & Young, 1993a; Sarmadi, Kwon, & Young, 1993b; Wu, 1982, p. 84); therefore, careful specimen preparation is required. The manner in which a polymer is processed may change the type and orientation of functional groups at the surface, which would affect surface free energy measurements in turn. The percent content of a copolymer alters the surface free energy in a linear manner if polymerization is random (Erbil, 1996; Wu, 1982, p. 81). Drawing of polymer fibres has been found to change the nondispersive surface free energy components of nylon 6,6 (Tate et al., 1996) and poly(ethylene terephthalate) (PET) (Okamura, Tagawa, Gotoh, Sunaga, & Tagawa, 1996) fibres. Heat treatments above certain temperatures may also affect surface free energy components of PET fibres by causing partial melting or disorder in the surface region (Okamura et al., 1996). The presence of a reactive dye, Procion Blue HB, has been shown to alter the adhesion efficiency of nylon 12 particles (Tagawa, Gotoh, Yokokura, Syutoh, & Takechi, 1989), suggesting that the surface of dyed fibres might differ in important ways from that of undyed fibres. The substrate against which a polymer is cast can alter its acid-base interactions (Smith & Pitrola, 2000).

Contact angles on polymer solids are also sensitive to molecular reorientation of the polymer resulting from the testing environment. Exposure to elevated relative humidity or liquid water can substantially increase the concentration of polar groups at the surface and cause a decrease in contact angle on a variety of polymers (Yasuda, Okuno, Tsuji, & Yasuda, 1996; Yasuda, Miyama, & Yasuda, 1994; Yasuda, Okuno, Sawa, & Yasuda, 1995). Wetting liquids can react with or swell the polymer surface. When sorption rate is being measured, such swelling can reduce the size of the solid's capillaries and alter the sorption rate (Pezron, Bourgain, & Quéré, 1995). Liquids may extract low molecular weight components from the polymer, which alter the surface free energy of the liquid and further lead to dubious results (Kamath et al., 1987; Kwok, 1999). Changes in the surface due to the wetting liquids may be observed as whitish bloom on transparent adhesive films (Karsten, 2000), contact angle hysteresis or the difference between advancing and receding angles (Karsten, 2000; Schmitt, Park, Simon, Ringsdorf, & Israelachvili, 1998), or changes in contact angle with time (Karsten, 2000; Ruckenstein & Gourisankar, 1985; Ruckenstein & Lee, 1987).

The above description of the numerous factors that may influence the results of contact angle measurements on polymer surfaces suggests that caution is warranted if contact angle values are used to determine surface free energy components. Subsequent calculations with dubious results may only compound the error. Gutowski (1991) showed how a technique with an accuracy of ± 0.2° to ± 0.3° is needed to give reasonable values for $cos\theta$ when the contact angle is between 70° and 110°. The use of surface free energy components determined from liquid contact angle values for two solids, fabric and adhesive film, to calculate fabric-adhesive work of adhesion may be questionable, since it relies on the untested assumption that thermodynamic equations developed for liquid-solid systems apply equally once the adhesive liquid has solidified (Allen, 1984; Wake, 1982, p. 55). Nevertheless, these surface characterization techniques are relatively simple to use and produce results that are useful for comparing adhesive and fabric surfaces and for estimating their interaction.

Comparison of work of adhesion and peel strength

Theoretically, work of adhesion and peel strength should be related. The work expended to peel an adhered structure, W_P, can be roughly modelled as the sum of work of adhesion, W_A, work of bending, W_B, and work of deformation, W_D:

$$W_P = W_A + W_B + W_D \qquad (3.14)$$

The work of adhesion is the thermodynamic parameter, W_{SL}, described above. The work of bending and deformation depend on the mechanical properties of the adhesive and adherend layers. According to equation 3.14, work of adhesion is proportional to work of peel if the work due to bending and deformation is held constant. In fact, work of bending and deformation are altered when different fabrics are adhered. If the adhesive bond fails within the adhesive layer—failure known as cohesive failure—the mechanical properties of the adhesive also contribute to the work of peel. Specimens that fail within the adhesive layer do not necessarily provide information about the strength of the interfacial bond (Kaelble, 1971, p. 465). Such peel tests can be better correlated to the mechanical properties of the adhesive, such as storage and loss modulus (Derail, Allal, Marin, & Tordjeman, 1997) than to work of adhesion (Gibert, Allal, Marin, & Derail, 1999; Kano, Ushiki, & Akiyama, 1993). Since peel strength is determined per unit width of fabric, differences in the amount of adhesive per unit width of fabric would also affect peel strength independent of relative work of adhesion. A high degree of correlation between work of adhesion and peel strength would, therefore, strongly suggest that the interfacial interaction between adhesives and fibres is a major contributor to the peel strength of fabric/adhesive laminates. If ranking the adhesives by work of adhesion shows no similarities to ranking by peel strength, it is likely that the effects of treatment techniques or adhesive mechanical properties outweigh those of interfacial interactions.

Experimental Procedures

Specimen preparation

Adhesive films

Adhesive films for contact angle measurement were prepared by spin coating six adhesives onto silicon wafers, the same six adhesives used to prepare fabric laminates for peel testing (see Table 2.3). The dispersion adhesives Clariant T1601, Dur-O-Set E150, and Vinamul 3252 were applied undiluted. Acryloid F10 and Beva 371 were thinned slightly with toluene by mixing 2 g adhesive resin with 2 mL solvent. Beva 371 solutions were warmed in a water bath at 45°C to ensure proper mixing. Lascaux 360 HV and 498 HV were combined in a 1:1 mass ratio (2 g each) and diluted slightly with 2 mL distilled water. A thin layer of adhesive was coated onto 2 x 2 cm pieces of silicon wafer using a Spincoater, Model P6700. Specimens were spun at 2000-2500 rpm for a total of 20 seconds for all adhesives except Vinamul 3252, which was spun for 60 seconds. After the specimens air-dried, they were annealed in a vacuum oven for one hour at 45°C (Acryloid, Beva, and Lascaux) or 75°C (Clariant, Dur-O-Set, and Vinamul). Annealing permitted full coalescence of the dispersion adhesive films, which remained slightly cloudy after spin coating.

Fabrics

The surface free energy components were determined for the two plain weave fabrics used to represent the artifact fabric in peel tests: a light-weight, degummed, *Bombyx mori* silk habutae and a semi-dull nylon taffeta (see Table 2.10). Specimens measuring 190 x 30 mm (warp x weft) were cut and ravelled to 185 x 25 mm. An equal number of cover cloths measuring 50 x 60 mm were cut from the same fabrics and ravelled slightly. The cover cloths were needed to help give the fabric specimens a rolled, cylindrical shape for testing, as will be described below. Fabric specimens and cover cloths were cleaned by immersion and occasional agitation in distilled water at 50°C for 30 minutes and then rinsed in distilled water at 50°C. Aqueous cleaning was followed by solvent extraction using carbon tetrachloride (CCl_4, BDH, analytical grade). Specimens were placed in a soxhlet extractor and flushed with solvent ten times. Specimens were air dried in a fume hood overnight. Silk habutae and nylon taffeta specimens and cover cloths were cleaned and extracted in separate batches. To remove wrinkles formed during the cleaning process, cover cloths were wet out with distilled water and spread out on a clean glass plate to air dry.

Fabric specimens were prepared for testing by trimming, wetting, and drying in a rolled state. The ravelled edge of the two short sides and one long side of the 190 x 30 mm specimens was trimmed to within 0.5 mm of the weave using embroidery scissors. Once trimmed, the specimens were wet out with distilled water and rolled evenly and tautly without stretching around clean cross-linked polyethylene (PEX) rollers (8 cm lengths cut from 1 cm diameter tubing). A cover cloth of the same fabric was then wet out and rolled tightly around the specimen such that the ends of the cover cloth extended beyond the fabric specimen. Plastic electrical ties were slipped over each end of the roller and cover cloth (but not over the specimens under the cover cloth) and tightened to hold the fabric on the roller while drying. Rolled specimens were set upright on pegs and air-dried using a fan. Drying in this configuration ensured that the fabric specimens maintained a tightly rolled configuration during testing.

Contact angle measurement

Measuring contact angles on adhesive films

Advancing contact angles of drops of four probing liquids, water (H_2O), formamide (CH_3NO), 1-bromonaphthalene ($C_{10}H_7Br$) and diiodomethane (CH_2I_2), were determined using a Krüss Drop Shape Analysis System DSA 10. Deionized water was purified with a Millipore-UV unit (Millipore, Canada). Formamide (Acros, Spectro grade), 1-bromonaphthalene (Aldrich, 99%) and diiodomethane (Fisher, lab grade) were used as supplied. A small drop of the liquid was placed on the adhesive film using a 0.73 mm diameter needle. With the needle still penetrating the top surface of the drop, three doses of liquid sufficient to cause the drop to advance over the surface of the film (usually 20 μl) were added using the automated dosing system. The image of the drop was videotaped while liquid was added. Still images of the drop were obtained from the video recording at moments when the drops had just stopped advancing during each dose (van Oss, 2002). The advancing contact angle was determined manually from prints of these still images (Figure 3.2). Automated angle calculation through image analysis, provided by the Krüss system, could not properly interpret the images of several liquid/adhesive combinations because of the presence of the needle in the image. Comparison of manually

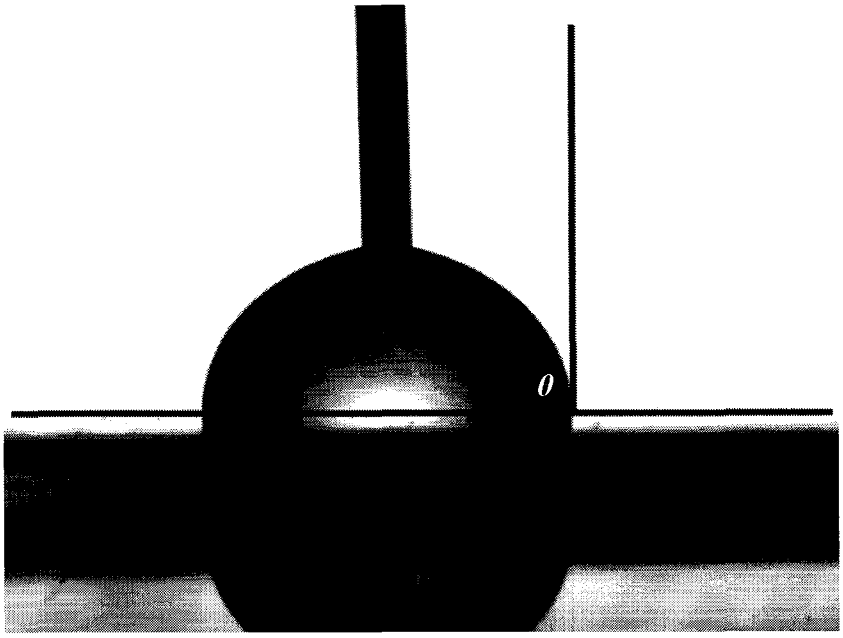


Figure 3.2 Still image of water drop on silicon wafer coated with Acryloid F10 showing lines used to measure advancing contact angle, *θ*.

measured angles with those for which good image analysis was possible shows that manual measurement provides good agreement with automated techniques (Figure 3.3). Each angle was marked and measured with a protractor three times, and the results averaged. These repeated measurements varied by no more than ±2 degrees from the mean. The contact angle for a liquid on a specimen was averaged from the angles of at least two still images for that specimen. Three specimens prepared on separate occasions were tested for each adhesive-probing liquid combination.

Determining contact angles for fabric specimens

The Washburn method was used to determine the contact angles of three probing liquids, water, formamide, and 1-bromonaphthalene on fabric specimens. The rolled fabric specimens were released from the PEX rollers and cover cloths, and rolled onto the end of an aluminum specimen holder, trimmed edge down (Figure 3.4). The specimen was fixed to the holder with an electrical tie at the top of the specimen. Fibres protruding from the bottom edge of the specimens were cut away using sharp embroidery scissors. Specimens were set into a Krüss K12 tensiometer equipped with the software LabDesk 2.0. Using the program for measuring contact

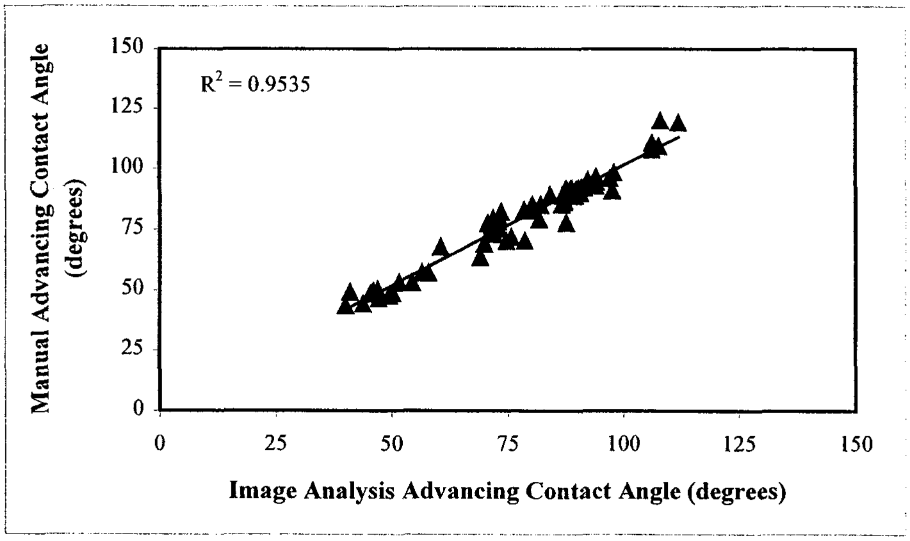


Figure 3.3 Correlation of advancing contact angles measured manually versus angles measured using image analysis, showing good agreement between the two methods.

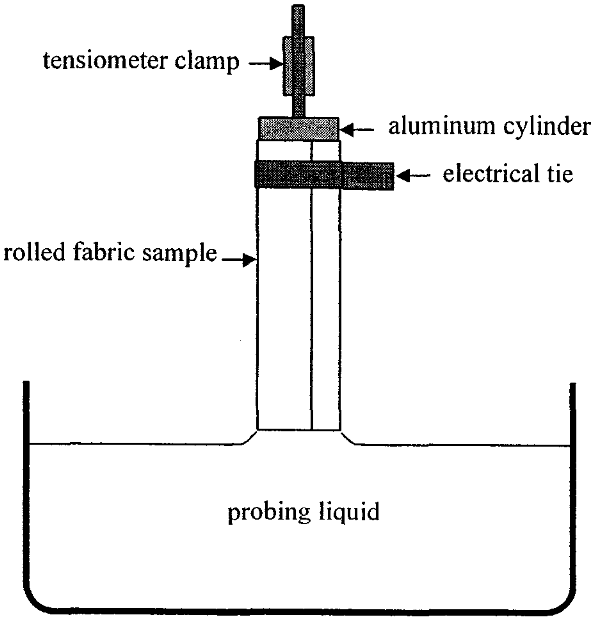


Figure 3.4. Fabric specimen structure for tensiometric sorption tests.

angles, the tensiometer was programmed to raise the liquid at 1 mm per minute until it touched the lower edge of the specimen (surface detected at a mass of 0.01 g) and then to hold the specimen in place for 150 seconds while gathering data of force versus time. Graphs of mass^2 (g) versus time (seconds) were produced from the collected data. The slope was determined for the linear section of each graph just before the graph levelled off indicating specimen saturation. The slopes of this secondary wetting were more reliable than those of primary wetting, which occurs on first contact with the liquid and is usually used for the calculation of the contact angle (Figure 3.5). Since primary wetting occurred very quickly and the Krüss tensiometer software tared out the measured force when liquid contact with the specimen was detected, data points characterizing primary wetting were probably lost. The contact angle for each graph was calculated using the modified Washburn equation (Equation 3.13). The values for *C*, the fabric material constants, were calculated from equation 3.13 using the slopes of absorption graphs for the probing liquid hexadecane (Fisher, 99.9%) and assuming zero contact angle ($cos\theta = 1$). At least six specimens were analysed for each probing liquid/fabric combination.

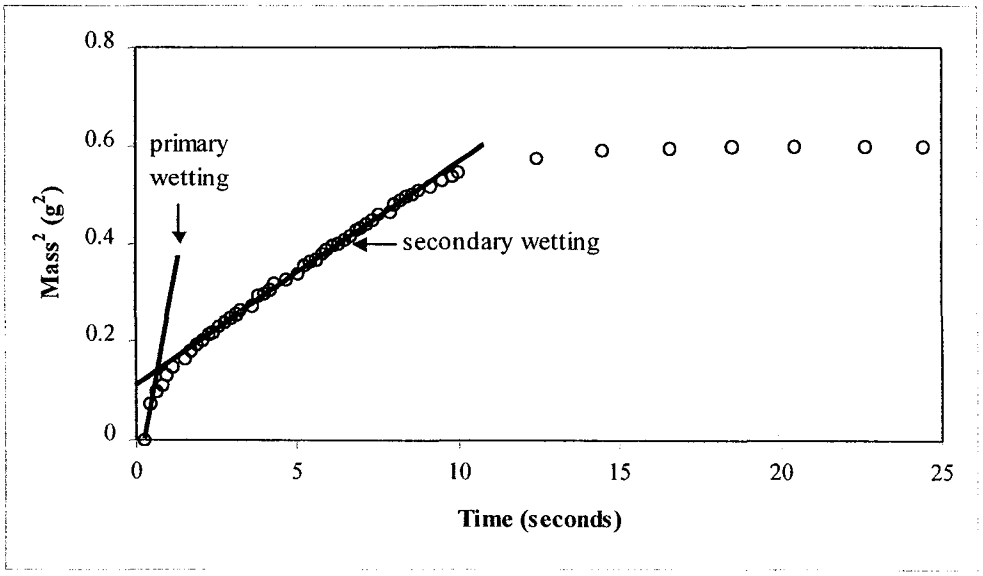


Figure 3.5 Typical fabric sorption graph showing primary wetting followed by secondary wetting before full saturation of the specimen by the liquid. The two levels of wetting correspond to absorption into different sizes of capillaries, such as those between fabric layers versus those within the yarns. The secondary wetting slopes were used in the calculations for this study.

Calculating surface free energy components and work of adhesion

The Lifshitz-van der Waals and acid-base components of the surface free energy were calculated for the adhesive films and fabrics using the vOCG approach. The surface free energy components of adhesives and fabrics were calculated by solving a system of three equations (Appendix D). Surface free energy components of the liquids were drawn from the literature and are given in Table 3.1. Since it provided consistently complete wetting of the fabric specimens and showed no interaction with the fewest adhesive films, 1-bromonaphthalene was used as the apolar liquid in most cases. Diiodomethane results were reported for two adhesives, Beva 371 and Dur-O-Set E150, which were affected detrimentally by 1-bromonaphthalene (see Table 3.4).

Work of adhesion between nylon taffeta or silk habutae and each adhesive was determined by substituting the surface free energy components of each adhesive (A) and fabric (F) into the following equation:

$$W_{FA} = 2[(\gamma_F^{LW}\gamma_A^{LW})^{1/2} + (\gamma_F^{+}\gamma_A^{-})^{1/2} + (\gamma_F^{-}\gamma_A^{+})^{1/2}] \qquad (3.15)$$

The results for work of adhesion were ranked from highest to lowest by fabric type and compared with the results of peel tests for fabric laminates made from the same materials (Chapter 2).

Table 3.1 Properties of probing liquids. (Surface free energy values are from van Oss (1994). Density and viscosity values are from the Krüss database, Labdesk 2.0.)

Liquid	Surface Free Energy Component (mJ/m^2) Dispersion γ_L^{LW}	Polar γ_L^{AB}	Acid γ_L^{+}	Base γ_L^{-}	Total γ_L	Density (g cm^{-3})	Viscosity (mPa s)
water	21.8	51.0	25.5	25.5	72.8	0.998	1.002
formamide	39.0	19.0	2.28	39.58	58.0	1.133	3.602
1-bromonaphthalene	44.4	~ 0	~ 0	~ 0	44.4	1.483	5.107
diiodomethane	50.8	~ 0	~ 0	~ 0	50.8	3.325	2.762
hexadecane	27.6	0	0	0	27.6	0.773	3.34

Results

Contact angles

Adhesive films

Advancing contact angles were determined from digital images of probing liquid drops on the adhesive films (Table 3.3). The mean contact angle for the three specimens of each liquid/adhesive combination is given in Table 3.2. The results for certain liquid/adhesive combinations showed considerable variation, with coefficients of variation averaging 3% but reaching 7% in one case. The effect of the liquids on the surface of the adhesive films was also noted (Table 3.4). Contact with water created a white bloom on the surface of the three poly(vinyl acetate) copolymer dispersion adhesives, Clariant T1601, Dur-O-Set E150, and Vinamul 3252. No change in the clarity of the water drops was apparent. A slight, white halo appeared around the perimeter of drops of diiodomethane on Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252.

Table 3.2 Advancing contact angles (mean and standard deviation in degrees, n = 3) of probing liquids on adhesive films.

	Advancing Contact Angle of Probing Liquid (degrees)		
Adhesive	water	formamide	1-bromonaphthalene / diiodomethane
Acryloid F10	92 ± 2	80 ± 1	42 ± 2 (B)
Beva 371	96 ± 1	85 ± 1	42 ± 1 (D)
Clariant T1601	96 ± 2	84 ± 3	53 ± 2 (B)
Dur-O-Set E150	77 ± 1	59 ± 1	51 ± 2 (D)
Lascaux 360/498HV	93 ± 2	87 ± 3	55 ± 1 (B)
Vinamul 3252	55 ± 4	57 ± 2	45 ± 1 (B)

Table 3.3 Representative still images of drops of water, formamide, and 1-bromonapthalene (B) or diiodomethane (D) on adhesive films.

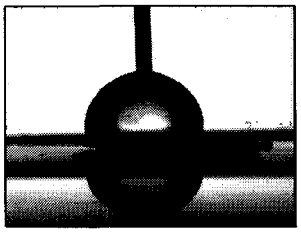
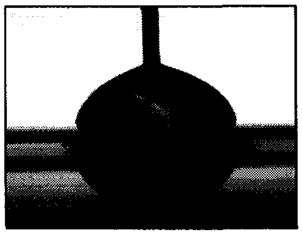
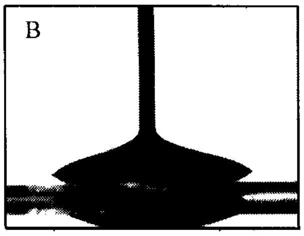
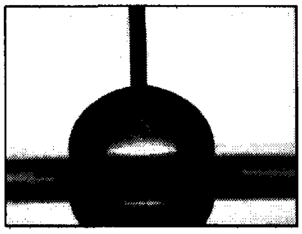
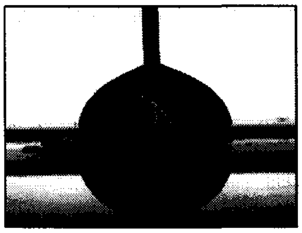
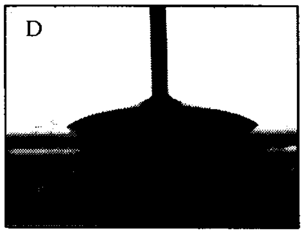
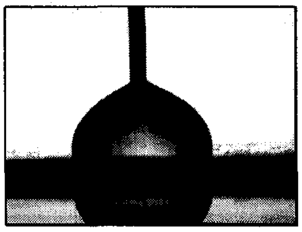
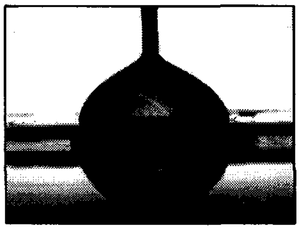
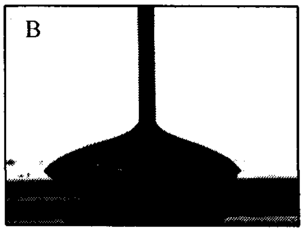
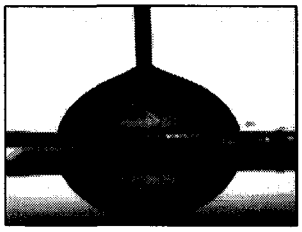
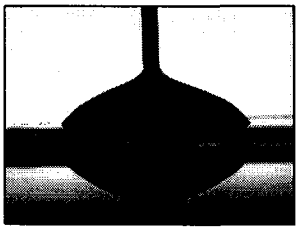
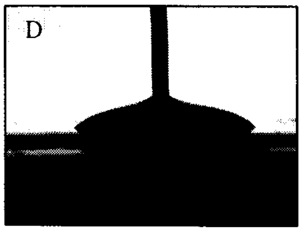
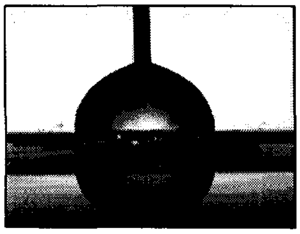
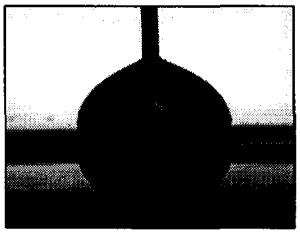
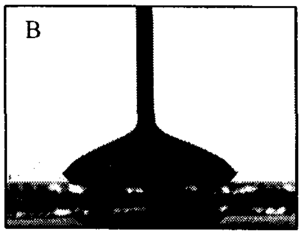
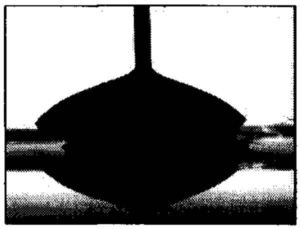
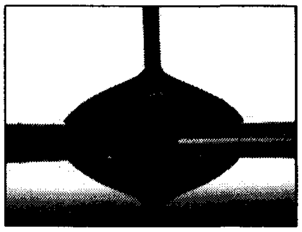
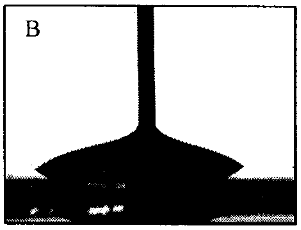
	Probing Liquid		
Adhesive	Water	Formamide	Apolar
Acryloid F10			
Beva 371			
Clariant T1601			
Dur-O-Set E150			
Lascaux 360/498 HV			
Vinamul 3252			

Table 3.4 Effect of probing liquids on adhesive films.

	Effect of Probing Liquid			
Adhesive	water	formamide	1-bromonaphthalene	diiodomethane
Acryloid F10	no apparent effect	no apparent effect	no apparent effect	rings visible on film surface after testing
Beva 371	no apparent effect	no apparent effect	film partially dissolved	no apparent effect
Clariant T1601	film whitens under drops	no apparent effect	no apparent effect	no apparent effect
Dur-O-Set E150	film whitens under drops	no apparent effect	drops spread asymmetrically	film whitens slightly around drops
Lascaux 360/498 HV	no apparent effect	no apparent effect	no apparent effect	film whitens slightly around drops
Vinamul 3252	film whitens under drops	no apparent effect	no apparent effect	film whitens slightly around drops

Fabrics

Contact angles for silk habutae and nylon taffeta were calculated from the slopes of absorption graphs of the probing liquids, hexadecane, 1-bromonaphthalene, formamide, and water (Figure 3.6). The average slopes and average contact angles for each liquid/fabric combination are given in Table 3.5. The slopes exhibited variation like that observed for the adhesive films but to a greater degree, with an average coefficient of variation of 20%.

Surface free energy components and work of adhesion

The surface free energy components of the adhesives and fabrics are given in Table 3.6. The total surface free energy for almost all adhesives and both fabrics was between 30 and 40 mJ m^{-2}, as expected for these polymers. Beva 371 exhibited a higher surface tension of 47 mJ m^{-2}. All solids had higher basic components than acidic components, although only Vinamul 3252 could be characterized as monopolar basic ($\gamma_S^+ \approx 0$). Of the adhesives, Beva 371 had the highest polar component (8.6 mJ m^{-2}) and Vinamul 3252 the lowest (0.2 mJ m^{-2}). Beva 371 also exhibited the highest disperse (38.6 mJ m^{-2}) and acidic (3.0 mJ m^{-2}) components. Lascaux 360/498 HV exhibited a relatively high acidic component (1.2 mJ m^{-2}) but had the lowest disperse component (27.5 mJ m^{-2}). Compared to the other adhesives, Vinamul 3252 exhibited a very high

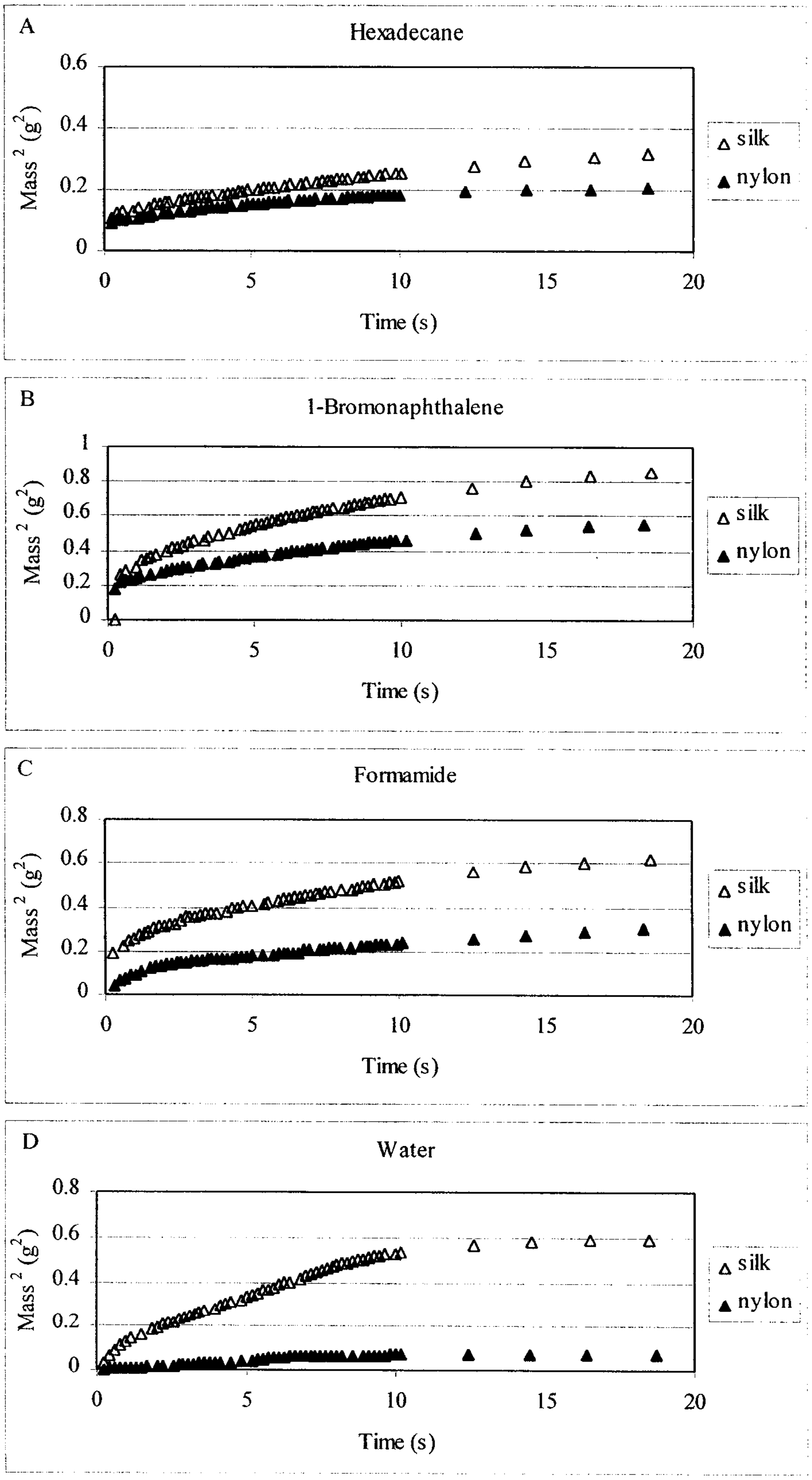


Figure 3.6 Representative sorption graphs (mass^2 versus time) of hexadecane (A), 1-bromonaphthalene (B), formamide (C), and water (D) on silk and nylon.

Table 3.5 Slope of absorption graphs and advancing contact angle for silk habutae and nylon taffeta.

Probing Liquid/ Fabric	Slope of Absorption Graph ($g^2\ s^{-1}$)	Calculated Advancing Contact Angle (degrees)
hexadecane		
silk habutae	0.0129 ± 0.0033	(0) [a]
nylon taffeta	0.0084 ± 0.0012	(0) [a]
1-bromonaphthalene		
silk habutae	0.036 ± 0.007	43 ± 13
nylon taffeta	0.025 ± 0.005	40 ± 12
formamide		
silk habutae	0.025 ± 0.005	62 ± 7
nylon taffeta	0.014 ± 0.003	66 ± 6
water		
silk habutae	0.047 ± 0.007	76 ± 2
nylon taffeta	0.00037 ± 0.00008	90 ± 0

[a] contact angle for hexadecane is assumed to be zero

Table 3.6 Contact angles (degrees) and surface free energy components (mJ m^{-2}) of adhesive films and fabrics.

Material	Advancing Contact Angle (degrees)			Surface Free Energy Components (mJ m^{-2})				
				Disperse	Polar	Acid	Base	Total
	W	FO	apolar	γ_S^{LW}	γ_S^{AB}	γ_S^{+}	γ_S^{-}	γ_S
Adhesive								
Acryloid F10	92	80	42	33.7	4.9	0.9	6.5	38.7
Beva 371	96	85	42	38.6	8.6	3.0	6.0	47.2
Clariant T1601	96	84	53	28.5	3.4	0.6	5.2	31.9
Dur-O-Set E150	77	59	51	33.7	3.0	0.26	8.7	36.7
Lascaux 360/498	93	87	55	27.5	6.7	1.2	9.5	34.2
Vinamul 3252	55	57	45	32.3	0.2	0.00	36.8	32.6
Fabric								
silk habutae	76	62	43	33.3	1.6	0.06	11.4	34.9
nylon taffeta	90	66	40	34.6	0.9	0.08	2.2	35.5

W = water, FO = formamide, apolar = 1-bromonaphthalene or diiodomethane basic component (36.8 mJ m^{-2}). Silk, known as a polar, hygroscopic fibre, has a larger acid-base component (1.6 mJ m^{-2}) than nylon (0.9 mJ m^{-2}), a less polar fibre.

The results of calculations for work of adhesion between fabrics and adhesives, W_{FA}, are given in Table 3.7. Values ranged from 66 to 85 mJ m^{-2}. Based on the W_{FA} results, Beva 371 bonds were strongest for both fabrics, by a margin of 7 to 10 mJ m^{-2}. The W_{FA} values for the other five adhesives, in contrast, varied by only 7 mJ m^{-2} for each fabric. Of the five adhesives, Clariant T1601 gave the weakest bonds, followed by Vinamul 3252 and Lascaux 360/498 HV, Dur-O-Set E150, and Acryloid F10. The adhesive/fabric work of adhesion is higher for silk than nylon for all but two adhesives, Dur-O-Set E150, which exhibited no difference, and Vinamul 3252, which exhibited slightly higher W_{FA} to nylon.

Comparison of work of adhesion and peel strength

Work of adhesion and peel strength values were ranked from highest (1) to lowest (6) by type of artifact fabric (Table 3.7). Peel strength results were averaged over application technique to produce these rankings. Results not significantly different were given the same rank. Except for Acryloid F10, the work of adhesion and peel strength ranks for each adhesive were relatively consistent, although not identical, within and across fibre types. This consistency can be seen graphically in Figure 3.7. A plot of peel strength versus work of adhesion (Figure 3.8) reveals an exponential relationship between the two measures of bond strength when Acryloid F10 results are excluded. Peel strength increases at a greater rate than work of adhesion.

Table 3.7 Work of adhesion (W_{FA}, mJ m^{-2}) of the adhesives to silk habutae and nylon taffeta compared to peel strength (N m^{-1}) with ranks of the adhesives for both parameters.

	Artifact Fabric							
	Nylon				Silk			
Adhesive	W_{FA} (mJ m^{-2})	Rank	Peel Strength (N m^{-1})	Rank	W_{FA} (mJ m^{-2})	Rank	Peel Strength (N m^{-1})	Rank
Acryloid F10	73	2	1.21	6	75	2	2.26	6
Beva 371	80	1	43.27	1	85	1	55.36	1
Clariant T1601	66	6	7.79	5	68	6	19.76	4
Dur-O-Set E150	72	3	13.57	3	72	3	25.67	2
Lascaux 360/498 HV	67	5	14.33	3	69	5	18.80	4
Vinamul 3252	71	4	19.07	2	69	5	25.48	2

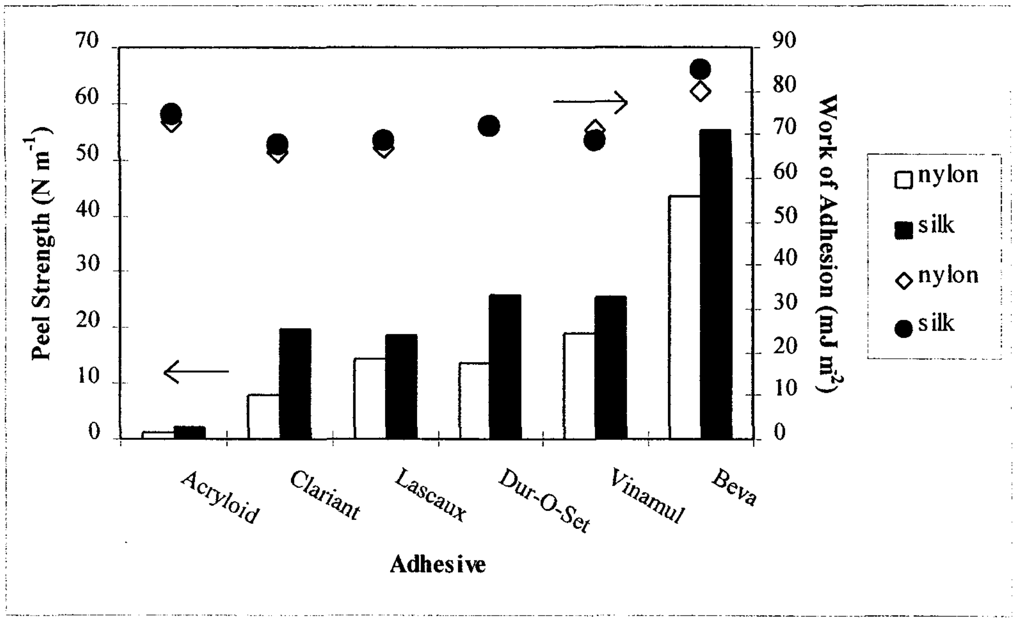


Figure 3.7 Work of adhesion and peel strength for adhesives to silk habutae and nylon taffeta.

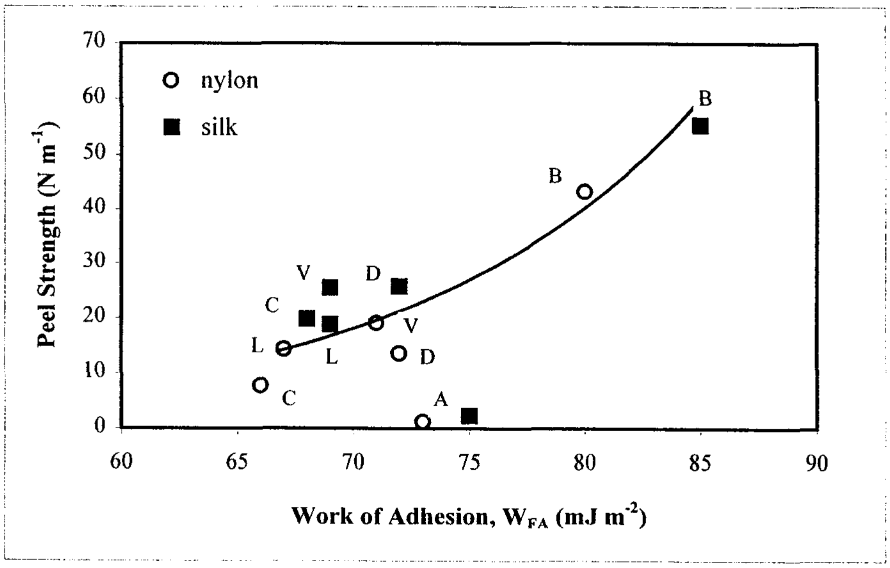


Figure 3.8 Relationship between work of adhesion, W_{FA}, and peel strength for adhesives to silk habutae and nylon taffeta. (Note: bond failure in peel tests was primarily adhesive for only Acryloid F10 (A), Clariant T1601 (C), and Dur-O-Set E150 (D). Failure was both adhesive and cohesive for Beva 371 (B), Lascaux 360/498 HV (L), and Vinamul 3252 (V).)

Discussion

Surface Characterization of the Materials

The surface free energy results indicate that the adhesives and fabrics are solids with strong basic and weak acidic character ($\gamma_S^+ \approx 0$). Both contact angle and surface free energy results for the adhesives and fabrics are fairly similar to values found in the literature (Table 3.8). One adhesive is essentially a monopolar Lewis base, Vinamul 3252 ($\gamma_S^+ = 0$). All of the adhesives exhibited strong Lewis base characteristics (γ_S^- values between 5.2 and 36.5 mJ m^{-2}). The basic character of the adhesives is expected given the molecular structure of acrylic and vinyl acetate copolymers. The ester groups in the acrylate and acetate side chains behave as Lewis bases (Good & van Oss, 1992). The weak acidic character is consistent with results obtained for many polymeric solids using the vOCG approach (Good & van Oss, 1992; van Oss, 1994). The relatively high acidic components for Beva 371 and Lascaux 360/498 HV and the high basic component for Vinamul 3252 must be due to additives in the adhesive formulations, since the adhesive polymers are fairly similar in structure (see Table 2.3). The high dispersive component in Beva 371, an ethylene/vinyl acetate copolymer, can be related to the predominance of polyethylene segments in the copolymer molecules and to the presence of paraffin, a hydrocarbon mixture, in the formulation.

The predominantly basic character of the fabrics is not predicted from their molecular structure. Both silk and nylon have both acidic and basic bonding sites within their molecular structure. Silk fibroin contains more acidic side groups (aspartic and glutamic acid) than basic side groups (lysine, arginine, and histidine) (Halvorson, 1991). Other groups, such as serine, contain hydroxyl groups that can function as Lewis acids. Amine and carboxylic acid groups and amide linkages provide the acid-base sites in nylon. The presence of both acidic and basic groups on the surface of nylon 6,6 has been demonstrated for fibres (Tate et al., 1996). Microfluorometry has further suggested that acidic groups are at least as prevalent as basic groups on air-drawn nylon 6,6 fibres while basic groups are more numerous than acidic groups on undrawn fibres (Tate et al., 1996). The vOCG approach, therefore, has been criticized for underestimating the acidic component of nylon 6,6 fibres (Tate et al., 1996; Kamath & Dansizer, 2000). Good and van Oss (1992) recognized that many solids tested using the vOCG approach have very low γ_S^+ values and suggested that this may result when Lewis acid groups, such as –OH and –NH, are oriented towards Lewis base groups in the bulk of the solid and are thus effectively neutralized. Alternatively, the acid character could be masked by surface hydration (Good & van Oss, 1992).

Table 3.8 Comparison of contact angle and surface free energy component data from this study (bold) and for similar materials from the literature (italized values are calculated from the literature data).

	Advancing Contact Angle (degrees)				Surface Free Energy Components					
					Disperse	Polar	Acid	Base	Total	Reference
Material	W	FO	BrN	DIM	γ_S^{LW}	γ_S^{AB}	γ_S^{+}	γ_S^{-}	γ_S	
Adhesives										
Acryloid F10	**92**	**80**	**42**		**33.7**	**4.9**	**0.9**	**6.5**	**38.7**	
PBMA									30.4	Wu, 1989
Lascaux 360/498 HV	**93**	**87**	**55**		**27.5**	**6.7**	**1.2**	**9.5**	**34.2**	
PMMA									41.1	Wu, 1989
PMMA					40.0-43.2	0	0	12 -22.4	40.0-43.2	van Oss, 1994
PMMA sheet					46.5		0.08	18.1		McCafferty and Wightman, 1999
PMMA sheet	77.91	54.58	33.23		40.52	*0*	0	6.83	*40.52*	Etzler et al., 2000
PBA									30.7-33.7	Wu, 1989
Beva 371	**96**	**85**		**42**	**38.6**	**8.6**	**3.0**	**6.029**	**47.2**	
Dur-O-Set E150	**77**	**59**		**51**	**33.7**	**3.0**	**0.3**	**8.70**	**36.7**	
Vinamul 3252	**55**	**57**	**45**		**32.3**	**0.2**	**0.0**	**36.79**	**32.6**	
EVA									30.6-35.5	Wu, 1989
Clariant T1601	**96**	**84**	**53**		**28.5**	**3.4**	**0.6**	**5.2**	**31.9**	
PVAc									36.5	Wu, 1989
PVAc cast film					42.6	*1.91*	0.041	22.3	*44.5*	McCafferty and Wightman, 1999
Fibres										
nylon taffeta	**90**	**66**	**40**		**34.6**	**0.9**	**0.08**	**2.2**	**35.5**	
nylon 66 film	70.0	52								Fort, 1964
nylon fibre	68.0									Grindstaff, 1969
nylon 66 fabric	57.4									Hsieh et al, 1992
nylon 66 solid	64.0	55	46	36	36.4	1.3	0.02	21.6	37.7	van Oss, 1994
nylon 66 fibres					38.6	0.4	0.002	21.3	39.0	Tate et al., 1996
nylon 66 fibres					33.9	*2.6*	0.16	10.7	*36.5*	Kamath and Dansizer, 2000
nylon 66 solid	70.0	50	41		39.1	4.1	0.4	10.7	43.2	Walinder and Gardner, 2002
silk habutae	**76**	**62**	**43**		**33.3**	**1.6**	**0.06**	**11.4**	**34.9**	
silk fibroin	60.0									Cheng et al., 2000
silk fibroin film					30.1	9.6	2.0	11.8	39.7	Tretinnikov and Tamada, 2001

W = water, FO = formamide, BrN = 1-bromonapthalene, DIM = diiodomethane

Interestingly, the acid/base ratio for nylon 6.6 in this study (~ 10^{-2}) is much higher than that of acid-base values reported by van Oss (1994) (10^{-3}) and Tate et al. (1996) (10^{-4}) (Table 3.8). The relatively high water contact angle value for nylon taffeta (90° versus 60-70°), which generated a relatively low γ_S^- value (2.2 versus 21 mJ m^{-2}), can account for this difference.

The relative strength of silk versus nylon bonds to Vinamul 3252 as indicated by work of adhesion, W_{FA}, versus peel strength provides additional evidence that the low-acid surface free energy characterization obtained by the vOCG approach for silk habutae and nylon taffeta is problematic. The W_{FA} for Vinamul/silk (69 mJ m^{-2}) is slightly lower than that for Vinamul/nylon (71 mJ m^{-2}). In contrast, Vinamul/silk laminates exhibited peel strengths (25 N m^{-1}) that were 1.3 times higher than the corresponding Vinamul/nylon laminates (19 N m^{-1}, Table 3.7). If acidic groups were accessible on the surface of these fibres as their molecular structure predicts, bonding with Vinamul 3252, which has a very high basic component (36.8 mJ m^{-2}), would be much more effective and might result in a higher W_{FA} rank, comparable to its high peel strength rank. The adhesives would, in general, perform more effectively if their predominant basic groups could bond to acidic groups on the fabrics.

Variability in the contact angle and fabric sorption results are expected given the nature of the specimens. The adhesives are not pure materials (see Table 3.1). The cast films were not perfectly smooth. The visible whitening of some adhesive films when exposed to water indicates a change in the film structure that may have affected the results. The assumption in accepting these contact angle values was that this swelling did not affect the spreading of the water drop over previously untouched adhesive. Fabric sorption variability is probably due to slight variations in specimen size and in rolling technique. Differences in the packing of the fabric layers while rolling affected the ease with which the probing liquid saturated the specimen layers.

Comparison of work of adhesion and peel strength

The two bond strength indicators, work of adhesion and peel strength, are positively related. The non-linear relationship between peel strength and work of adhesion (Figure 3.8) confirms what has been stated in the adhesives literature: an increase in adhesion results in a much larger increase in peel strength (Wake, 1982, p. 146). As bond strength increases (increased W_A), more energy tends to be dissipated through bending, stretching, and otherwise deforming the adhesive films and fabric components during peel tests (increased W_B and W_D). For example, the high peel strength of Beva 371 laminates was associated with fibrillation and stretching of the adhesive coating (see Chapter 2). These laminates also stretched so tightly that the fabrics sometimes puckered and occasionally pulled from the grips of the testing instrument. Another parallel between work of adhesion and peel strength results is that bonds to silk habutae are usually stronger than those to nylon taffeta. Given these similarities, adhesive ranking by peel strength does reflect an inherent ability of the adhesive to form bonds with textile fabrics independent of adhesive application technique and joint design.

Other results of this study suggest, however, that adhesive application technique or mechanical properties may affect peel strength in a manner independent of the degree of surface interaction. Relatively high work of adhesion does not guarantee high peel strength or increased work of bending and deformation. Although Acryloid F10 was characterized by the second highest W_{FA} values, its laminates exhibited the lowest peel strength. Laminates joined with Acryloid F10 peeled apart without fully extending and with little distortion of the adhesive film. This seemingly exceptional result can be explained by differences in specimen preparation technique. Acryloid F10 support fabric specimens were coated in a manner used by textile conservators, which resulted in the deposition of the lowest amount of adhesive by weight. Preparing the Acryloid F10 specimens in exactly the same manner as the Beva 371 specimens, which had the highest adhesive add-on, would likely have resulted in higher peel strength. Similarly, an adhesive formulated to extend easily when subjected to stress may give high peel strength despite relatively low work of adhesion values. Like Beva 371, Vinamul 3252 coatings exhibited fibrillation and stretching during peel tests. The discrepancy between Vinamul work of adhesion and peel strength ranks has been attributed to underestimation of the acidic components of the fabrics when using the vOCG approach. Alternatively, the energy dissipated by adhesive deformation may contribute to unexpectedly high peel strengths. Because laminates adhered with three adhesives, Beva 371, Lascaux 360/498 HV, and Vinamul 3252, exhibited cohesive failure during peel tests (see Chapter 2), the work of adhesion-peel strength correlation should be interpreted with caution. Peel strength tests cannot necessarily substitute for surface and interface characterization when assessing the relative ability of adhesive materials (versus adhesive treatment techniques) to form bonds with textile fabrics. On the other hand, interface characterization may not correctly predict the relative strength of bonds when subjected to peel stress.

Comparing the ranges of W_{FA} and peel strength values further reveals that differences in adhesive surface properties cannot fully account for peel strength variability. Work of adhesion values ranged from about 65 to 85 mJ m^{-2} (or 0.065 to 0.085 N m^{-1}). Peel strength values, on the other hand, varied from about 1 to 55 N m^{-1}. Some of the differences in peel strength have been attributed to differences in specimen preparation and adhesive add-on. Doubling the concentration of the same adhesive solution doubled the peel strength for several identical adhesive/fabric combinations (see Chapter 2). Clearly, textile conservators can manipulate the bond strength of fabric laminates to a greater degree by altering application technique than through choosing an adhesive based on its surface free energy characteristics.

Conclusions

Surface interactions between adhesives and silk and nylon fabrics have been characterized using the vOCG approach. The surface free energy components of six adhesives, Acryloid F10, Beva 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252, were determined from the contact angle values of one of two apolar probing liquids, 1-bromonaphthalene or diiodomethane, and two polar probing liquids, water and formamide. Similarly, the surface free energy components were calculated for two fabrics simulating artifact fabrics, silk habutae and nylon taffeta. Contact angles were derived from wetting rates for three probing liquids, 1-bromonaphthalene, water, and formamide, using the Washburn equation. Adhesives and fabrics were characterized as low energy solids (γ_S between 31 and 47 mJ m^{-2}) with relatively low acidic and high basic components. Values for work of adhesion, W_{FA}, calculated for each adhesive/fabric pair permitted ranking the adhesives from strongest (Beva 371) to weakest (Clariant T1601). Work of adhesion to silk habutae was usually higher than that to nylon taffeta. The W_{FA} ranking was similar to that produced by another indicator of bond strength, peel strength, with one major exception, Acryloid F10. Work of adhesion and peel strength results exhibited an exponential relationship, with increases in work of adhesion resulting in greater increases in peel strength. Adhesive/adherend interactions, therefore, contribute greatly to bond strength, independent of joint design. The exceptional results for Acryloid F10, due to the very low peel strengths of its textile laminates, which were joined with less adhesive than any other specimen type, indicate that variations in treatment technique (joint design) can obscure the ability of an adhesive material to form bonds relative to other adhesives.

The techniques used to determine contact angles in this study gave results that distinguished the ability of the adhesives to bond with silk and nylon fabrics, independent of joint design. Textile conservators could use these results to optimize bond strength by choosing adhesives, like Beva 371, that form stronger intermolecular bonds with silk and nylon fabrics than other adhesives, like Clariant T1601. Development of better surface characterization techniques for adhesive films and fabrics might produce results of even less variability than reported here, increasing conservators' ability to optimize bond strength even more. Of great value would be techniques for determining the surface free energy components of the adhesives at the temperatures used to heat-seal the coated support fabrics to the artifact fabrics. Such results would permit comparison of spreading coefficients and wetting tension, parameters that have been found particularly important in determining optimal surface interactions (Connor et al., 1997). A method for directly determining the contact angle of adhesive drops on the fibres would be particularly useful. Such a method would permit calculation of work of adhesion from the surface free energy of the adhesive and the contact angle alone using equation 3.3. Techniques have been developed for characterizing fibre-resin interactions in fibre composites (Chou & Miller, 1998; Lee & Chiao, 1996; Tissington, Pollard, & Ward, 1992). In order to characterize interactions equivalent to those in artifact fabric/adhesive laminates, the method should produce contact angles equivalent to those produced by the adhesives at heat-sealing temperatures, at which the adhesives are softened solids rather than liquids.

Close comparison of work of adhesion and peel strength results and ranks suggest, nevertheless, that examining the surface interaction of adhesives and fabrics used by textile conservators should not be a conservation science research priority at this time. Although some of the adhesives used by textile conservators may provide stronger molecular interactions than others, peel strength results indicate that altering application technique can modify the bond strength of a single adhesive to a greater degree than changing adhesives. Without better control over the effects of application technique on bond strength in textile laminates, the difference provided by adhesive type cannot be exploited effectively.

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CHAPTER 4

SURVEY OF HISTORIC TEXTILE ARTIFACTS GIVEN ADHERED SUPPORTS[4]

Introduction

The success of an adhesive support treatment for textiles depends to a large degree on the adequacy and stability of the adhesive bond. When the bond fails, the artifact is no longer supported in that area. Once an adhesive support has been decided on, the first question often asked is what adhesive to use. Although laboratory research has compared the relative strength of stable adhesives used in textile conservation (Pretzel, 1997a, 1997b; Karsten, 1998), the results give conservators little guidance regarding the strength needed for particular artifacts. Conservators speak of "adequate support" (Hartog & Tinker, 1998), but the conservation literature seldom discusses clearly the meaning of this concept. Conservators who have experience with adhesive treatments may develop knowledge of what sufficient bond strength feels like in mock up adhesion tests. Given that adhesive treatments are relatively rarely used, however, few conservators can depend on such knowledge. The only definition of sufficient strength is given by Pretzel (1997b) who cites a standard for minimum peel strength of 100 N m^{-1}, a standard met by only a few of the adhesives he tested for use in textile conservation. The bond strength level required of industrial textile laminates, for which this standard was probably derived, may not be necessary for the support of historic artifacts, however, since the artifacts are usually not required to bear significant stress after treatment. Like all artifacts, adhesive-treated textiles are likely to be handled carefully. Supplementary supports and mounts may restrict movement of the treated artifact and reduce, if not eliminate, the kinds and magnitude of stresses to which the textile will be exposed. Moreover, supplementary stitching of the artifact to the support fabric provides a form of mechanical attachment that contributes to overall bond strength and helps prevent delamination due to stress or environmental factors. A functional definition of adequate adhesive performance must account for these factors.

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[4] A version of part of this chapter was presented at the meeting of the Canadian Association for Conservation of Cultural Property in Victoria, BC on May 25, 2003. Karsten, I. F. & Kerr, N. (2003). *Assessing treatment effectiveness through a systematic survey of treated artifacts: Lessons from a pilot study of textile adhered to support fabrics.* Unpublished manuscript. Another version of this chapter will be presented at the North American Textile Conservation Conference in Albany, NY in November 2003 and has been accepted for publication in the preprints. Karsten, I. F. & Kerr, N. (in press). The effectiveness of adhesive support treatments for flags and banners: Condition of treated artifacts surveyed in Canada and the UK. In J. Vuori (Ed.), *Tales in the textile: The conservation of flags and other symbolic textiles.* Preprints of the fourth biennial North American Textile Conservation Conference.

If the nature of the artifact and all the materials and techniques used in its support and handling influence the success of an adhesive treatment, then adhesives and treatment techniques must ultimately be compared in that context. Ideally this would comprise some form of clinical trial, with proper sampling, standardized protocol, balanced numbers in treatment groups, and possibly blind methods, as for the trials used in medicine (Suenson-Taylor, Sully, & Orton, 1999). Planned clinical trials are to date virtually non-existent in the field of artifact conservation. Conservators have relied instead on anecdotal information (Suenson-Taylor et al., 1999). Surveys of previously treated artifacts, although lacking the control of clinical trials, can provide evidence of the long-term effects of conservation treatments on artifacts within a collection context. Since many textiles have been given adhered supports over the past four decades, a population of treated artifacts exists that could be studied to determine the relative efficacy of various adhesives and treatment techniques.

Survey Research of Conservation Treatments

In the field of conservation, surveys of treated artifacts, although rare, have been used to assess the efficacy of conservation treatments. Those surveys that have been published have taken a variety of approaches to the possibilities that this research technique offers. Stone (1996) covered a broad range of complex treatments, mostly of ethnographic artifacts, comparing the condition of the artifacts with that recorded in treatment dossiers. He found that most conservation treatments were still effective, although adhesive failures were noted, particularly when cellulose ethers were used. Sully and Suenson-Taylor (1996) focussed on the effects of a single treatment on archaeological leather in relation to the treatment date and the period of object manufacture. A few studies have compared treatment techniques for a single treatment problem: stabilizing paintings on glass and ceramics (Caldararo, 1997) or stabilizing archaeological iron (Selwyn & Logan, 1993) and bronzes (Johnson, Salzman, & Unruh, 1996). These studies show that survey research could greatly benefit conservators. More work is necessary, however, to develop and improve sampling and data collection techniques.

Surveys of textile artifacts treated with adhesives

Although textile conservators have been using adhesive support treatments since the 1960s, few studies have surveyed the state of these bonds after years of display or storage.

Conservators have reported on the condition of individual or small groups of treated artifacts and found that bonds are often holding ten to forty years after treatment (Cruickshank, Lee, & Potter, 1998; Gentle, 1998; Hartog & Tinker, 1998; Landi, 1992; Mailand, 1998). Delamination, blistering, distortion, and tackiness have also been noted (Blum, 1982; Cruickshank et al., 1998; Gentle, 1998; Hartog & Tinker, 1998; Landi, 1992). Certain artifact components, such as embroidery, soiling, finishes, or the residues of previous treatments, have been observed to interfere with the bond and cause delamination over time (Blum, 1982; Gentle, 1998; Hartog & Tinker, 1998). Boersma (1998) conducted a survey of flags and banners given adhesive support treatments during the 1960s and 1970s in the Netherlands. She used a tick chart to gather data on treatment, display and storage history, and to record the current condition of the artifacts, assessed through visual examination. Boersma noted that bonds were in general still holding, although blistering and bond failure were evident in some pieces. Many of the artifacts had been treated with excessive amounts of adhesive, which had often migrated away from the support fabric into the artifact. Because many of the artifacts Boersma studied were treated in ways that would not be used by textile conservators today, her observations have limited relevance to the assessment of currently used techniques.

The lack of survey research related to adhesive support treatments for textiles means that hypotheses that might explain failure of this treatment go untested. Textile conservators have attributed bond delamination to the weave structure of the artifact (Hartog & Tinker, 1998), to uneven adhesive coatings (Marko, 1978), to variable heat across the surface of the domestic irons used in heat-sealing (Boersma, 1998), to lack of control over warp tension during ironing (Marko, 1978), to the lack of supplementary stitching (Hartog & Tinker, 1998), to the use of a weak adhesive without mounting the treated artifact on a rigid mount to compensate for lack of bond strength (Keyserlingk, 1993), to movement of the treated artifact during hanging (Marko, 1978), and to adhesive migrating into the textile in response to temperature fluctuations (Boersma, 1998). They have accounted for differences in bond strength in terms of the number of points of contact (Hartog & Tinker, 1998), the type and mixture of adhesive resins and solvents used (Thomsen, 1984), and the ability of the adhesive to form intermolecular bonds (Bede, 1993). Although laboratory experiments might be used to test some of these ideas, surveys of artifacts given adhesive supports could also clarify whether these are general phenomena or whether they are limited to individual treatment techniques or artifacts.

In light of the lack of survey research relating to textile treatments used to systematically test hypotheses concerning treatment success and failure, the goal of this study is two-fold. First, the types of bond delamination on treated textile artifacts and the factors that might promote bond failure will be characterized. The frequency of bond delamination will be related to adhesive and support fabric materials, mechanical reinforcement of the bond with supplementary stitching, and the reduction of stress on the bond through the use of such techniques as rigid mounts. By considering treatments that provide both relatively weak and strong bonds, this study will determine whether high bond strength, as defined by Pretzel's (1997a; 1997b) criterion, is necessary to prevent bond delamination, and thus began to address the question of "adequate" bond strength. Examining treated artifacts that have aged within real museum environments provides an excellent opportunity to assess the effectiveness of adhesive support treatments for flags and banners and similar flat textiles. Secondly, the study will assess the challenges facing researchers who wish to use existing treated artifacts and the related records to study questions concerning treatment success or failure. The survey form was designed to capture the complexity of the textile artifacts and the conservation treatments used to stabilize them. The results of the survey will be summarized in general, both as background to the specific questions regarding bond delamination, and to illustrate broadly the difficulties encountered when studying treatment techniques without the benefit of relative control of variables that the laboratory offers.

Survey Methods

Sample

A selection of textile artifacts, mostly flag and banners, was surveyed. The sample was a convenience sample with an emphasis on flat textiles. Thirty-six artifacts treated at four institutions were examined (Table 4.1). All textile artifacts given adhered supports at the Canadian Conservation Institute (Ottawa) were examined at their museum of origin across Canada. Artifacts that had been treated by textile conservators at the National Maritime Museum (Greenwich, UK), People's History Museum (Manchester, UK), and the Victoria & Alberta Museum (London, UK) were also examined. Artifacts that were relatively accessible in the conservation studio or on display were selected. Institutions and artifacts were chosen with the intent of studying at least five objects treated with each of three adhesives, Acryloid F10, Beva 371, and Mowilith DMC2. In addition, artifacts treated within the last twenty years were preferred over earlier treatments, which were often treated with materials and techniques that are no longer used.

Table 4.1 Institutions at which artifacts included in this survey were treated and/or studied.

Institution		Number of Artifacts
Conservation Lab/Collection	Location	
Canadian Conservation Institute		(14)
Canadian Museum of Civilization	Hull, Quebec	4
Firefighters Museum of Nova Scotia	Yarmouth, Nova Scotia	2
Historical Museum of St. James-Assiniboia	Winnipeg, Manitoba	1
Laurier House National Historic Site	Ottawa, Ontario	1
New Brunswick Museum	St. John, New Brunswick	2
Newfoundland Museum	St. John's, Newfoundland	1
Trinity Parish Council	Cornwall, Ontario	2
Wellington County Museum and Archives	Fergus, Ontario	1
National Maritime Museum	Greenwich, London, UK	8
People's History Museum	Manchester, UK	7
Victoria & Albert Museum	London, UK	7

Survey Form

The survey form was designed in collaboration with a group of textile conservators who have experience with adhesive treatments (Table 4.2). The form was designed to permit collection of information on the artifact, its materials and condition before the adhesive treatment was performed, the adhesive treatment materials and techniques, other aspects of the treatment,

Table 4.2 Textile conservators collaborating on artifact survey.

Name	Institutional Affiliation	Location
Jan Vuori, Renee Dancause, Janet Wagner	Canadian Conservation Institute	Ottawa, ON, Canada
Zenzie Tinker, Lynda Hillyer, Frances Hartog, Flora Nuttgens	Victoria & Alberta Museum	London, UK
Nicola Yates	National Maritime Museum	Greenwich, UK
Vivian Lochhead, Susanne Kristiansen	People's History Museum	Manchester, UK
Deborah Bede	Stillwater Textile Studio	Bradford, NH, USA
Mary Kaldany	Textile Conservation Workshop	South Salem, NY, USA
Foekje Boersma	private practice	Haarlem, Netherlands
Shirley Ellis	University of Alberta	Edmonton, AB, Canada

the artifact's storage and display history, and the present condition of the artifact (Appendix E). A list of likely responses for each category was also compiled. The database software, Microsoft Access 2000, was used to construct the actual form such that data could be entered directly into a laptop while examining the artifacts on site. Likely responses were incorporated into the form as drop-down lists (combo boxes) to speed data entry and ensure consistency. Modified or completely new responses could also be recorded. Subforms were used so that supplementary information could be connected to each record without having to fill it in each time. The address of an institution or the composition of an adhesive, for example, could be linked to an artifact record by choosing the name of the institution or the name of the adhesive from a drop-down list. The names on that list were connected to another form, which contained the more detailed information. Subforms were also used to permit multiple entries in a single category for each artifact; for example, more than one adhesive or support fabric might have been used on a single artifact. Only information recorded in condition or treatment reports, in notes connected to the artifact or in published descriptions of treatments, or verified through examination of the artifact was recorded in the entries for object description, condition before treatment, and treatment techniques. A space for other comments was provided under each category (see Appendix E) so that responses based on memory, knowledge of studio practices, conjecture, or educated guesses could also be recorded. All data were collected and all artifacts examined by the author of this study. Conservators, curators, and museum technicians were consulted for clarification on the contents of reports and for information regarding the storage and display history of the artifacts.

Data Analysis

The results of the survey were analysed in order to produce a general description of the sample in relation to the current condition of the artifacts, with emphasis on the stability of the adhesive bond. The type of artifacts surveyed, the adhesive treatments used, and the presence of supplementary stitching and support were characterized. Attention was paid to what was not recorded about the adhesive treatment techniques in the treatment reports as well as to what was. The presence of delamination in the artifacts was characterized and related to the type of adhesive and support fabric, the presence of supplementary stitching, storage and display history, and the degree of flexing of the artifact since treatment. Data were abstracted from the tables in the Microsoft Access database by using select and crosstab queries. Because of the small sample size and the complex nature of the data, statistical analysis beyond description was not attempted.

Results

The Artifacts

Artifact Sample

The majority of textile artifacts studied were flags and banners (Table 4.3). This group of artifacts was quite diverse (Figure 4.1, Table 4.4). Their size varied greatly. The smallest artifact, a Union Jack flag, measured 11.0 x 7.5 cm, while the largest, the Coachmakers' trade union banner, measured 382.3 x 325.1 cm. Sixty per cent of the artifacts (22 textiles) were made principally from silk, with the remainder made of cotton (12 artifacts), both cotton and silk (1 artifact) and linen (1 artifact) (Table 4.5). Only 3 of 36 artifacts bore no decorative elements, one a small model flag, the others silk garment linings. The most common form of decoration on these artifacts was painted decoration (Table 4.5). Twenty-four artifacts were painted, including twenty-two of the twenty-five flags and banners. Other forms of decoration found on the textile component given adhered support included embroidery, resist dye patterning, printed patterns or words, and woven decorative bands. Decorative elements such as fringes, tassels, and pole sleeves or loops were also common, but were often not directly affected by the adhered support. The majority of the artifacts were complex structures consisting of several fabric components stitched together.

Table 4.3 Types of artifacts surveyed.

Type of Artifact	Number
Flags and banners	
flag	8
banner	17
Flat Textiles	
embroidered picture	1
ribbon	1
Indian chintzes	5
Other textiles	
clothing lining	2
3-D costume	1
tunic	1

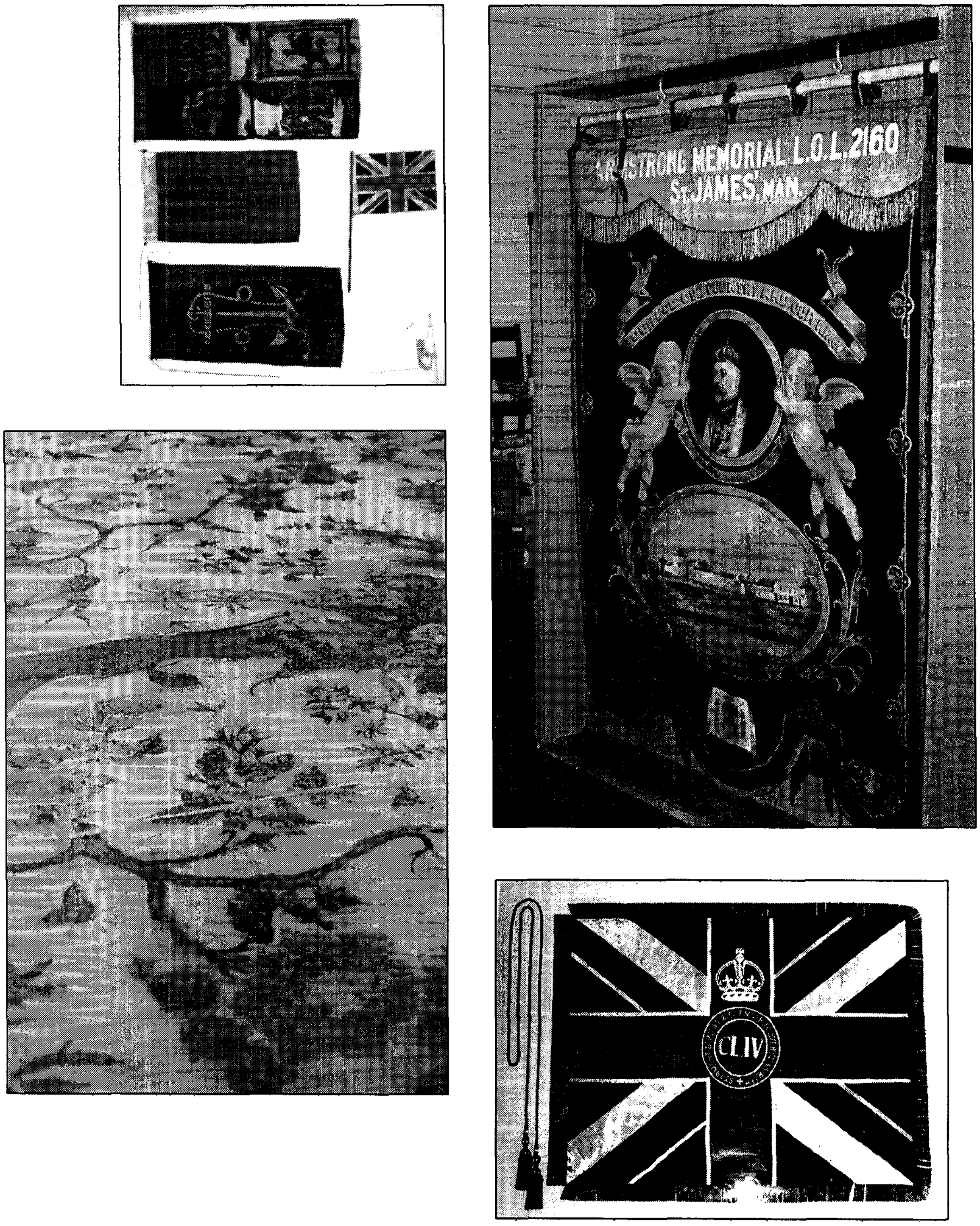

Figure 4.1 Artifacts included in the survey, clockwise from top left: model flags (courtesy of National Maritime Museum, Greenwich,UK), Loyal Orange Lodge Banner (courtesy of the Historical Museum of St. James-Assiniboia, Winnipeg, Manitoba), WWI Union Jack of the Stormont, Dundas & Glengarry Overseas Battalion (courtesy of Trinity Parish Council, Cornwall, Ontario), and detail of embroidered palampore (by kind permission of the Conservation Department of the Victoria & Albert Museum, London, UK).

Table 4.4 Descriptions of the artifacts given adhesive support treatments examined in this study.

Artifact	Date	Dimensions (cm)	Brief Description
Flags			
Union Jack		11.0 x 7.5	painted on plain-weave, cream silk with a linen hoist
Admirals of the Red Flag		21.5 x 12.5	plain piece of red ribbed silk stitched to a cream silk pole sleeve
Red Admiralty Flag		26.0 x 13.0	gold-coloured anchor painted on red ribbed silk
Royal Standard Flag		31.0 x 16.0	constructed from four rectangles of silk, two red, one blue and one yellow, stitched together and attached to a red silk pole sleeve; flag panels were painted with images of rampant lions and a harp
WWI Regimental Flag		108 x 85.5	blue silk embroidered on both sides with crowns, leaves, and battalion crest; edged with metallic fringe
WWI Union Jack		112.5 x 89.5	constructed from pieces of stitched silk of the appropriate colours and edged with a metallic fringe
Chinese pirate flag	c. 1849	288.5 x 221.0	painted with the image of a striking, corpulent male figure and mythical beast in front of stylized waves; ground consisted of six loom widths of plain-weave cotton stitched together with silk thread
Royal Dockyard Battalion	1848	63.5 x 55.6	blue plain-weave silk painted on both sides with insignia; edged with an off-white silk ribbon
Banners			
Eagle Foundry Banner	1853	299 x 193	detailed but somewhat naïve painted designs on pieced plain weave silk
Ropewalk Banner	early 19th c.	247 x 208	detailed but somewhat naïve painted designs on pieced plain weave cotton
Axe Company Banner		220 x 160	firefighter's banner consisting of two panels of pieced blue silk; painted images of scrolls, symbols, and floral garlands
Union Company Banner		260.5 x 236.5	firefighter's banner constructed from two panels of pieced silk taffeta; painted with coat of arms featuring a unicorn and a Native American Indian on blue side, with garland and scrolls on red side
Loyal Orange Lodge Banner	c. 1902		two-panel, silk taffetabanner with painted images of putti, King Edward VII, and Upper Fort Garry; silk and cotton valances on upper edge; sides and lower edge finished with metallic fringes
Temperance Banner	1848	85 x 126	two panels of ribbed silk; painted with the image of Queen Victoria on one side
set of three funeral banners	19th c.	140.5 x 205 134 x 250 281 x 234	painted images of angels on black cotton sateen
Sir John Colpoys banner	late 18th-early 19th c.		painted on plain weave cotton; namesake written along one edge beside large blue anchor; rescued from a rigid, folded state
T.U.C. sports banner	1934	63.5 x 104	painted on a single panel of red, ribbed silk, lined with cotton and edged with a silk/cotton fringe

Table 4.4 Descriptions of the artifacts given adhesive support treatments examined in this study (con't).

Artifact	Date	Dimensions (cm)	Brief Description
Banners			
Bradford Branch banner	pre 1924	198.1 x 238.7	red silk edged with a yellow silk fringe; painted images on both sides
Plumbers' banner	c. 1832	x	early trade union banner with a relatively simple image depicting the tools of the trade; painted on both sides of a plain-weave, glazed cotton, framed with red, glazed cotton and blue-gray pieced silk
Merthyr I.L.P. banner	c. 1920	143 x 172.5	a single-sided, lined banner; painted, stencilled designs on a cotton velvet central panel and red silk rep borders
Woodworkers' banner	early 20th c.	289.6 x 254.5	green silk rep edged with red silk rep borders; painted image of the patron saint of woodworkers flanked by female symbols of truth and justice on one side
Engineers' banner	pre 1920	325.1 x 339.1	painted images of working men on two sides of pieced, plain-weave blue silk panel surrounded by yellow, plain-weave silk borders
Coachmakers' banner	c. 1890	382.3 x 325.1	double-sided banner with two central panels of pieced, navy silk rep bordered with burgundy silk rep; one side expertly painted with coat of arm including elaborate scrolls, foliage, and rearing horses
Flat Textiles			
Delegate's ribbon	c. 1919	15.3 x 4.7	worn by delegates at a political convention; reputedly belonged to William Lyon Mackenzie King, a Canadian prime minister
embroidered silk painting	c. 1819	22 x 27.4	embroidered image of a small girl against a landscape; worked through silk satin to cotton backing
chintz qanat	18th c.	110.3 x 217.2	pieced, plain-weave cotton decorated with hand-painted/printed floral designs
chintz tent panel	late 18th c.	108 x 180	pieced, plain-weave cotton decorated with hand-painted/printed floral designs
Double Niche tent hanging	1630s	232 x 188	pieced, plain-weave cotton decorated with hand-painted/printed floral designs
chintz palampore	early 19th c.	360 x 300	pieced, plain-weave cotton decorated with resist-dye floral designs
palampore		352 x 256	pieced cotton twill palampore embroidered with floral designs
Other Textiles			
mantle lining			plain weave silk lining constructed from several pieces of fabric stitched together
uniform lining			silk twill lining constructed from several pieces of fabric stitched together
Coptic tunic			plain-weave linen Coptic tunic with supplementary weft wool bands
Merganser Canoe costume			painted cotton stretched over a wooden frame

Table 4.5 Fibre type and decoration of major components of artifacts given adhesive support.

Artifact Materials		Number of Artifacts			
Fibre	Decoration	Flags and Banners	Flat Textiles	Other Textiles	Total
cotton	painted	6		1	7
	embroidered		1		1
	painted/printed with dyes		3		3
	resist-dye		1		1
linen	supplementary weave bands			1	1
silk	none	1		2	3
	painted	15			15
	embroidered	2			2
	painted and embroidered		1		1
	printed		1		1
cotton/silk	painted	1			1
	Total Number of Artifacts:	25	7	4	36

The pre-treatment condition of the artifact fabrics varied but can be summarized. Many of the artifacts exhibited brittleness, splitting, and other forms of weakness, along with losses and tears. Some had creases, folds, wrinkles, and planar distortion of other types. Discoloration of the fabrics or decoration was less frequently noted. Almost all artifacts exhibited some kind of soiling or staining.

Artifact Preparation

Almost all the artifacts in this study were given some form of cleaning prior to adhesive support (Table 4.6). There was no record of cleaning for only 3 of 36 artifacts and these three lacked full treatment reports. Surface cleaning, usually using a brush and vacuum suction, was reported for 24 artifacts, 8 of which received only this kind of cleaning. It is highly likely that surface cleaning was done in most, if not all, cases but not recorded in the treatment report because it is such a standard component of cleaning textiles. Over half of the artifacts were wet cleaned using full immersion for at least some components. Wet cleaning was sometimes supplemented with solvent cleaning of fringes or localized cleaning to remove stains, adhesive residues, or soiling from painted decoration. In one exceptional case the artifact was wet cleaned

Table 4.6 Extent of cleaning artifacts given adhered supports.

Extent of Cleaning	Number of Artifacts Flags and Banners	Flat Textiles	Other Textiles	Total
surface cleaning only	4	3	1	8
surface cleaning and localized cleaning	1			1
surface cleaning and wet cleaning (full immersion)	11			11
surface cleaning and wet cleaning (full immersion of parts)	2			2
surface cleaning, wet cleaning (full immersion) and localized cleaning	1			1
surface cleaning, solvent cleaning and wet cleaning (full immersion of parts)	1			1
wet cleaning (full immersion)	1	2	1	4
wet cleaning (full immersion) and localized cleaning	1			1
wet cleaning (full immersion), solvent cleaning (parts) and localized cleaning	1			1
solvent cleaning	1			1
localized cleaning	1			1
wet cleaning by spraying and blotting		1		1
no record		1	2	3

after the adhesive support treatment was completed; the conservator usually does not do this. Two artifacts were primarily solvent cleaned using perchloroethylene. In three cases the only form of cleaning reported other than surface cleaning was localized cleaning or wet cleaning by spraying and blotting. Almost half of the artifacts were fully or partially disassembled before cleaning and adhesive treatment.

Adhesive Treatment Techniques

Adhesives

Eleven adhesives or adhesive combinations were used in the adhesive support treatments (Table 4.7). Almost a third of the artifacts were solely treated with either Acryloid F10 or Beva 371. Three artifacts were supported using Mowilith DMC2 and two with the combination of Mowilith DMC2 and DM5 mixed in a 1:1 ratio. In four cases both Beva 371 and the combination of Mowilith DMC2 and DM5 were used, the Beva on painted areas and the Mowilith mixture on

Table 4.7 Materials and techniques used to created adhesive-coated supports.

Adhesive support materials and techniques	Number of Artifacts			
	Flags and Banners	Flat Textiles	Other Textiles	Total
Adhesive				
Acryloid F10	9	1	1	11
Beva 371	9	1		10
Beva 371 / Mowilith DMC2 / DM5	4			4
Lascaux P550-40TB	1			1
Mowilith (type not specified)			1	1
Mowilith DMC2		3		3
Mowilith DMC2 / DM5	2			2
Vinamul 3252			1	1
Vinamul 6515 / 6525		1		1
Vinnapas EP1			1	1
unidentified		1		1
Support fabric				
cotton (plain weave)	1			1
nylon net		2		2
nylon net / silk crepeline	1			1
silk crepeline	12	2		14
silk crepeline / polyester crepeline (Stabiltex)	2			2
polyester crepeline (Stabiltex)	9	3	3	15
silk (twill weave)			1	1
Method of adhesive application				
brush	10	2		12
sponge		1		1
sprayer	8	1	1	10
no record	7	3	3	13
Release substrate/support used				
polyethylene film		1		1
polyethylene film or Teflon			1	1
polyester film (Mylar/Melinex)	2			2
silicone release paper	3			3
stretcher	4	1	1	6
Teflon-coated glass cloth	6			6
silicone-elastomer-coated glass fabric (Tygaflor)		1		1
V&A net table		1		1
no record	10	3	2	15

the unpainted silk. Lascaux P550-40TB, Vinamul 3252, a combination of Vinamul 6515 and 6525, and Vinnapas EP1 were used for one artifact each. The adhesive was not identified in only one case, a treatment completed in the mid 1960s.

The adhesive solutions used exhibited greater variety than this list of eleven adhesives suggests. Acryloid F10 and the similar Lascaux product, Lascaux P550-40TB, which were used by one studio, were applied consistently as a solution of 1 part adhesive to 8 parts toluene. In contrast, Beva 371 was used dissolved in petroleum spirits (6 artifacts), toluene (2), Stoddard's solvent (2), or white spirit (2) in ratios (volume adhesive to volume solvent) of 1:1 (1), 1:3 (9), or 1:10 (1). The dispersion adhesives (the Mowiliths, Vinamul 3252, and Vinnapas EP1) were diluted 10-20% by volume in water, with the type of water only sometimes specified as deionized or distilled. In a few cases, the use of water itself was not recorded but can be assumed given studio practice. Whether the Vinamul 6515/6525 mixture was diluted was not recorded, although the ratio of these adhesives, 2:8, was noted.

Support fabrics

Relatively few fabrics were used to support the artifacts (Table 4.7). The majority were supported using either silk crepeline (14 artifacts) or polyester crepeline (Stabiltex, 15 artifacts). Both polyester crepeline and silk crepeline were combined on two artifacts, polyester crepeline as the main support and silk crepeline as an overlay patch over a particularly weak section on the opposite side. Nylon net was used alone on two artifacts and as the main support on another. Silk crepeline served as support for the borders and as an overlay patch in the latter case. A plain-weave cotton and a twill weave silk were used in the other two cases.

Information on how the support fabric was prepared or used was sparse. Support fabric preparation was described for only 40% of the supports. Almost all of these indicated no cleaning, although some were dyed. Only some of the treatment reports indicated whether or how support fabrics were coloured. Eleven supports were conservation dyed, four were dyed by the manufacturer, two were not dyed, and four were hand-painted to match underlying painted decoration. A single piece of fabric was used to support the artifact in eleven cases. Multiple pieces were used to support eighteen artifacts and were either overlapped slightly during heat-sealing, worked into the seams of artifact components, or applied as patches. The number of support fabric pieces used was not recorded in seven cases. Twenty-two reports indicated that the grain of the support fabric was aligned to that of the artifact fabric. No mention was made of fabric alignment in the other cases.

Coating the support fabric

Descriptions of the technique used to coat the support fabric with adhesive were sporadic and cursory. Conservators used either a brush or sprayer for almost two thirds of the treatments (Table 4.7). The use of a sponge was mentioned once. The tool used in the other third was not recorded. Reported substrates included Teflon-coated glass fabric, silicone release paper, polyester film (Melinex), polyethylene film, and silicone-elastomer-coated glass fabric (Tygaflor). Supports included stretcher frames (looms) and the net table used in the past at the Victoria & Albert Museum (Landi, 1972). The release substrate or support used under the support fabric during coating was not mentioned in 40% of the treatment reports (Table 4.7). The number of coats of adhesive solution applied was noted in 13 of 36 reports. One to forty coats were applied with the higher numbers used for sprayed coatings. Nineteen reports indicated that only one side of the support was coated; the other seventeen made no mention of how many sides were coated although in most cases the number can be assumed to be one. The time that the adhesive coating was left to dry before heat-sealing was noted in five instances and given as 1 week, 5 weeks (twice each), or 18 days. The probable technique used could be ascertained in some cases by referring to standard studio practice.

Heat-sealing Techniques

The artifacts were heat-sealed to the coated support fabrics using mostly hand methods (Table 4.8). Spatula irons, flat irons or a combination of both were used in 22 treatments. Various other terms also described these irons: domestic iron, small iron, lining iron, tacking iron, hand iron, or, simply, iron. The lack of consistent terminology made it difficult to ascertain

Table 4.8 Techniques used to heat-seal the adhesive-coated support to the artifact.

	Number of Artifacts			
Heat-sealing method	Flags and Banners	Flat Textiles	Other Textiles	Total
spatula or tacking iron	8	1	1	10
flat (domestic) iron	3	1		4
spatula and flat iron	7		1	8
flat iron, vacuum hot table		1		1
spatula iron, vacuum hot table		1		1
spatula and flat iron, vacuum hot table		1		1
no record	7	2	2	11

whether spatula irons were used more frequently than flat irons, although the former was reported as the only tool used in the greatest number of reports. Hand irons were used in combination with a vacuum hot table in three cases. No description of the heat-sealing tool was given in one third of the reports. Only twelve reports indicated the release material used between the iron and the artifact. Those listed are silicone release paper (6 artifacts), Teflon-coated glass cloth (2), polyester film (Mylar, Melinex) (1), silicone parchment (1), and combinations of these materials (2).

Supplementary Stitching

Stitching supplemented the adhesive in attaching the adhered support fabric to the artifact in many cases. Supplementary stitching was used on 30 of 36 artifacts. This stitching took many forms (Table 4.9), which were recorded on the survey form as discrete tasks defined by location, fabric layers joined, stitch type, and thread used. More than one stitching task was recorded for most artifacts. Some stitching consolidated weak areas or ravelled fabric that might not be fully supported through adhesion. The primary purpose of much stitching was for reassembly of the artifact after cleaning and adhesive support or for attaching the treated artifact to a supplementary support fabric, lining, or display mount. Some of this stitching along artifact edges or through original seams may have also reinforced attachment of the adhered support if the stitching went through both the artifact and adhered support. To what extent this occurred could not be easily determined from the treatment reports. In one case, supplementary stitching not mentioned in the treatment report was observed on the artifact. The stitching, worked through the artifact to a supplementary silk fabric support, was completed subsequent to the initial adhesive support treatment. Other types of stitching, such as that used to finish hems, to reattach pole sleeves, or to attach the artifact to a mount through a secondary support fabric, may not have directly affected attachment of the artifact to the adhered support. No supplementary stitching was reported for only six artifacts, four small flags and two large Indian textiles treated more than 20 years ago.

Descriptions of stitching in treatment reports were perfunctory. Reports gave no details on the location of stitching in eleven cases. The thread and type of stitch used were not identified in 43% and 34% of stitching tasks described, respectively. The majority of threads reported were silk, followed by polyester, cotton, and linen (Table 4.10). Couching and running stitches were mentioned most frequently (25% each of all references to stitch type). Other stitches reported were back stitch, basting, blanket, blind hemming, bridge, herringbone, long, long and short, overcasting, saddle, slab, slip, tacking, tag, whip, and zig zag stitch (1 to 6% each).

Table 4.9 Location of supplementary stitching and frequency of use expressed as a percentage of all stitching tasks recorded for all artifacts.

Location of stitching	Percentage of Stitching Tasks
along edge(s) or perimeter of artifact	21
along or through artifact seams	16
over loose threads	6
over weak areas	8
over tears, holes or losses	9
through body of artifact	6
around decorative elements	2
over patch edges	6
for reattaching/reconstructing parts of artifact (e.g. pole sleeve, fringe)	12
mount, supplementary support, or display cover attachment	5
location not specified	9

Table 4.10 Types of thread used for supplementary stitching and frequency of their use expressed as a percentage of all stitching tasks recorded for all artifacts.

Type of Thread	Percentage of stitching tasks
hair silk	7
silk crepeline yarns	4
other silk threads	21
polyester Stabiltex yarns	4
other polyester threads	11
cotton threads	9
linen threads	1
no record	43

Other Treatment

The description of the treatment given above concentrates on those aspects that influence the attachment of the artifact to the adhered support. The full treatment of the artifacts was in most cases more extensive than this and merits a brief summary. Other procedures used to conserve the artifacts consisted mostly of humidification and paint consolidation, but also included such tasks as removal of overpaint or varnish, adhesive deposits and patches, and previous repairs. In most cases, these procedures were completed before the artifact was adhered to the support fabric. Over half of the artifacts were stitched to a secondary support fabric or lining. Patches or overlays were used on several textiles. Ten artifacts were attached to a rigid mount for display. Ten others were displayed by being suspended from a pole, dowel, or wooden support. A hook and loop tape mounting system (Velcro®) was used for four textiles and a three-dimensional support or mannequin for two others when on display. The remaining artifacts were either never displayed, did not require an additional mount, or were displayed at one time in a manner not recorded. Eight artifacts were given a glazed frame or permanent case.

Storage and Display History

The history of the artifacts after treatment varied considerably. The time since the treatment was completed ranged from just over 2 years to almost 40 years with most completed from 5 to 20 years before examination. Eleven artifacts remained in storage for the entire time since treatment (Table 4.11). Eight were on display for the whole time, six for over ten years. The other seventeen artifacts spent some time on display and some time in storage. Of the twenty-eight artifacts that were stored for some time, nine were stored flat, nineteen rolled. Six artifacts had been rotated on and off display three to eight times and stored rolled between display periods. The temperature and relative humidity where the artifacts were stored or displayed were not always controlled to museum standards. Ten artifacts were kept in fully controlled environments since treatment, eight in partially controlled environments, eight in fully controlled and uncontrolled environments at different times in their history, and six in uncontrolled environments. The environment for four artifacts was not ascertained. The lighting used was

Table 4.11 Location of artifacts since treatment according to the time elapsed since treatment.

Years since Treatment	Number of Artifacts by Location			
	storage	display	storage/display	total
less than 5		1	2	3
5 to 10	5	1	5	11
10 to 15	1	2	4	7
15 to 20	5	4	4	13
over 20			2	2
total:	11	8	17	

fluorescent in most cases, with incandescent, tungsten, halogen, and fibre optic lighting used otherwise. Ultraviolet radiation was filtered to acceptable levels for just over 60% of the light sources. In 10% of cases no filtration was used. The presence of filtration was not ascertained for the other cases.

Present Condition of the Treated Artifacts

Access to the artifact and the adhered support

The manner in which the artifacts were fully treated, displayed, or stored limited the degree to which both the artifact and the adhered support could be examined. Examination of the artifact in general was constrained by display behind glazing, rigid mounts, low light levels on display, elevated display, or large size. The adhered support could be particularly inaccessible (Table 4.12). The adhered support was fully visible on only 6 artifacts. In eight cases, the adhered support could not be examined at all. Access to the adhered support was partial for half of the remaining cases. The support fabric was visible through large or numerous losses in the artifact, through a crepeline overlay, or through limited access to the reverse of the artifact. When the adhered support could be examined only through small losses in the artifact, access was minimal. The level of access decidedly affected the degree to which the present condition of the artifact and adhered support could be determined.

Present condition of the artifact

Most artifacts appeared not to have deteriorated to any clearly visible degree since treatment. Twenty-six artifacts exhibited no apparent deterioration. Localized deterioration—powdering of decorative components, a tear caused by poor handling, splitting of a ribbon,

Table 4.12 Access to the adhered support during examination of the artifact.

Access to Adhered Support	Number of Artifacts		
	behind glazing	no glazing	Total
full		6	6
partial		12	12
minimal	5	5	10
none	3	5	8
total:	8	28	36

detachment of fragments—was observed on five artifacts. General deterioration was noted for five artifacts, four of which exhibited powdering of brittle silk fabrics that had been observed at the time of treatment. The fifth artifact, a cotton palampore treated in the mid 1960s, exhibited general brown discoloration and splitting at creases that appeared to have occurred after treatment since less discoloration was seen under patches applied as part of the treatment. Thirty-three artifacts showed no obvious post-treatment discoloration, although this interpretation was subjective and made without direct observation of the artifact immediately after treatment. Two cotton artifacts treated in the 1960s showed general yellowing or brown discoloration, as just described. The lack of condition reports for these artifacts made it difficult to ascertain what degree of discoloration occurred after treatment. The third case of discoloration consisted of localized blue-gray tarnish of a metallic fringe. Evidence of planar distortion was also noted. Judgement of what distortion existed prior to treatment and what occurred after was subjective since the artifacts had not been seen previously. Photographic documentation could only partially help and was usually not accessible while the artifact was being examined. Many of the undulations recorded were probably due the effects of painted decoration and stitched construction. Creasing was observed in a few cases, usually on textiles that were rolled for storage. Whether this occurred after treatment was not always clear. Three artifacts exhibited waviness and bubbling of the artifact fabric, which is related to delamination of the adhered support and will be discussed below. Supplementary stitching appeared to be sound in all cases but one: silk crepeline threads showed slight disruption at the armholes of a garment lining that had been displayed on a mannequin.

Present condition of the adhesive bond

The adhesive bond was relatively sound in most cases regardless of adhesive type. Less than half of the artifacts exhibited any form of apparent delamination. In most cases, the delamination was localized and minor (Table 4.13). Most instances of bond failure occurred at the edges of losses or at splits or tears in the artifact. These locations were particularly susceptible if the area was painted or damaged to form small sections of protruding fabric (Figure 4.2). In other cases, yarns in areas of degraded fabric or ravelled edges were poorly adhered (Figure 4.3). Local loss of adhesion was also noted in areas where the artifact fabric was fragmented, or highly distorted due to creases, puckering near seams, or poorly aligned tears. In one case, the edges of a patched support were delaminating where the patch was cut to fit around the shape of an area of painted decoration. Only three artifacts showed evidence of delamination

Table 4.13 Types of delamination observed in treated artifacts.

Type of Delamination	Number of Artifacts Flags and Banners	 Flat Textiles	 Other Textiles	 Total
poorly adhered ravelled yarns or fibres	3		2	5
lifting of edges of support patch	1			1
lifting at edges of losses or splits in artifact	6	2	1	9
delamination at distortions in artifact	2	1		3
separation of tiny artifact fragments	1		2	3
delamination under areas of sound fabric	2	1		3

between the support and areas of sound fabric. In one case, the adhesive-coated net had pulled away from the artifact and contracted or stretched slightly, leaving wavy undulations on the artifact and support fabric surfaces. This artifact, treated in the 1960s, was stored rolled with Melinex interleaving, was partially stuck to the interleaving, and could only be unrolled with difficulty along part of its length for examination. The other two artifacts exhibited localized bubbling of unpainted silk that appeared consistent with delamination, although this interpretation could not be confirmed (Figure 4.4). Both of these artifacts were adhered to polyester crepeline

Figure 4.2 Lifting at edge of tear and loss in painted area of banner.

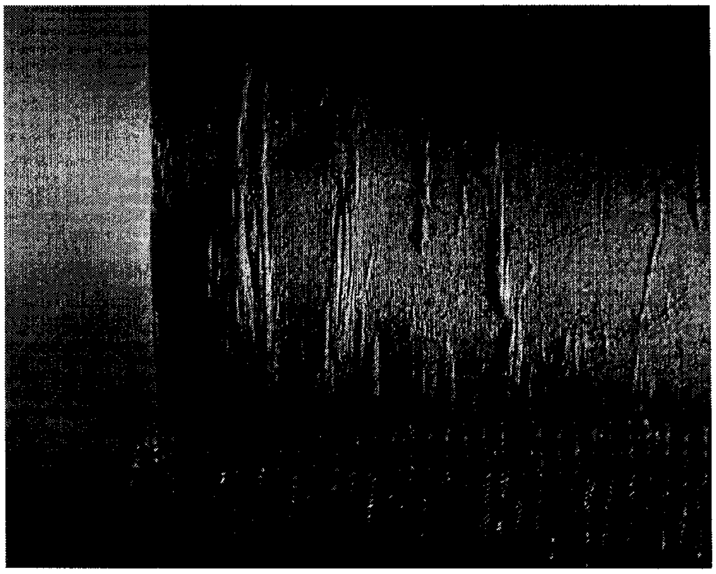

Figure 4.3 Poorly adhered yarns in area of flag where deterioration left floating yarns.

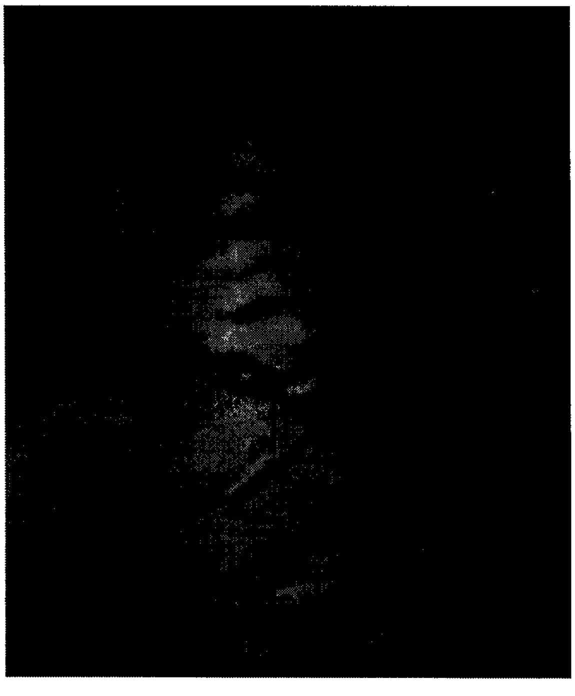

Figure 4.4 Localized bubbling of silk fabric of banner that is probably indicative of delamination.

using the weak adhesives, Acryloid F10 or Lascaux P550-40TB. Despite these forms of delamination, the adhered support continued to provide otherwise good support for the artifact in almost every case.

Bond failure was observed on artifacts treated with almost every type of adhesive (Table 4.14). Most of the artifacts exhibiting bond failure were supported using Acryloid F10 (6 artifacts), a treatment known to form very weak bonds. These were also relatively old treatments, treated 13 to 19 years ago (Table 4.15). Nevertheless, five artifacts adhered with this adhesive and treated equally long ago showed no apparent bond failure. The artifact adhered with Lascaux P550-40TB, an adhesive very similar to Acryloid F10, also exhibited delamination and was treated more recently (7.5 years ago). One artifact treated with Beva 371 ten years ago exhibited poorly adhered yarns. Other Beva 371 treatments, both older and more recent, showed no apparent delamination. Half of the artifacts treated with Beva 371 on painted areas and the Mowilith DMC2/DM5 mixture on silk exhibited minor delamination. Another artifact originally treated in this way exhibited sporadic delamination of the supported silk even before the treatment was completed and was retreated using only Beva 371. Bond failure was also observed on one of the two artifacts treated with only the Mowilith DMC2/DM5 mixture. Artifacts treated with Mowilith DMC2 alone showed no apparent delamination and tended to be older treatments. Minor bond failure was noted on artifacts treated with Vinamul 3252, Vinnapas EP1, and the

Table 4.14 Presence of delamination according to the adhesive used and type of artifact.

	Number of Artifacts exhibiting Delamination			
Adhesive	Flags and Banners	Flat Textiles	Other Textiles	Total
Acryloid F10	5		1	6 of 11
Beva 371	1			1 of 10
Beva 371 / Mowilith DMC2 / DM5	2			2 of 4
Lascaux P550-40TB	1			1 of 1
Mowilith (type not specified)				0 of 1
Mowilith DMC2				0 of 3
Mowilith DMC2 / DM5	1			1 of 2
Vinamul 3252			1	1 of 1
Vinamul 6515 / 6525		1		1 of 1
Vinnapas EP1			1	1 of 1
unidentified		1		1 of 1
Total:	10 of 25	2 of 7	3 of 4	15 of 36

Table 4.15 Number of artifacts exhibiting delamination and total number of artifacts treated for each adhesive categorized by the number of years since treatment.

	Years since Treatment				
Adhesive	less than 5	5 to 10	10 to 15	15 to 20	over 20
Acryloid F10			2 of 2	4 of 9	
Beva 371	0 of 2	0 of 4	1 of 1	0 of 3	
Beva 371 / Mowilith DMC2 / DM5	0 of 1	1 of 2	1 of 1		
Lascaux P550-40TB		1 of 1			
Mowilith (type not specified)			0 of 1		
Mowilith DMC2		0 of 1	0 of 2		
Mowilith DMC2 / DM5		1 of 2			
Vinamul 3252		1 of 1			
Vinamul 6515 / 6525					1 of 1
Vinnapas EP1				1 of 1	
unidentified					1 of 1

unidentified adhesive. The artifact that exhibited considerable delamination from its net support was adhered using the Vinamul 6515/6525 mixture and was one of the oldest treatments.

Bond delamination exhibited no clear relationship to either the type of support fabric or the presence of supplementary stitching. Bond failure was observed from all of the support fabrics used, silk crepeline, polyester crepeline, nylon net, and silk twill, with the exception of the plain woven cotton. The number of artifacts exhibiting delamination for each support fabric was approximately in proportion to the total number of artifacts treated with that type of fabric (Table 4.16). Similarly, bond delamination was observed on about one third of artifacts given supplementary stitching and one third of those without supplementary stitching (Table 4.17). Since very few treatments included no stitching at all, the performance of most of the adhesives with or without stitching could not be compared. The only treatment with Beva 371 that exhibited delamination was one that included stitching. Four of the ten Beva 371 treatments included no stitching and exhibited no delamination.

Some evidence suggested that the restriction of flexing after treatment may prevent bond delamination (Table 4.18). Treated artifacts were coded according to whether they were subjected to no, limited, or repeated flexing after adhesive support treatment. Artifacts on permanent rigid mounts or stored flat on rigid supports were considered not to have been flexed since treatment. Artifacts on flexible mounts but on exhibit since treatment, or stored rolled but

Table 4.16 Presence of delamination according to the support fabric used and type of artifact.

	Number of Artifacts exhibiting Delamination			
Support Fabric	Flags and Banners	Flat Textiles	Other Textiles	Total
cotton (plain weave)				0 of 1
nylon net		2		2 of 2
nylon net / silk crepeline				0 of 1
silk crepeline	5			5 of 14
silk crepeline / Stabiltex	1			1 of 2
Stabiltex	4		2	6 of 15
twill-woven silk			1	1 of 1

not examined since treatment were classified as receiving limited flexing. Artifacts which had been rolled and unrolled at least twice since treatment, or which had been handled for display for storage purposes in a manner that would have caused flexing were placed in the "repeated flexing" category. Although restriction of flexing did not prevent delamination (6 of 17 artifacts subjected to no flexing exhibited delamination), the highest frequency of delamination occurred

Table 4.17 Presence of delamination according to the absence or presence of supplementary stitching and the type of adhesive.

	Number of Artifacts exhibiting Delamination	
Adhesive	stitching present	no stitching
Acryloid F10	6 of 11	
Beva 371	1 of 6	0 of 4
Beva 371 / Mowilith DMC2 / DM5	2 of 4	
Lascaux P550-40TB	1 of 1	
Mowilith (type not specified)	0 of 1	
Mowilith DMC2	0 of 3	
Mowilith DMC2 / DM5	1 of 2	
Vinamul 3252	1 of 1	
Vinamul 6515 / 6525		1 of 1
Vinnapas EP1	1 of 1	
unidentified		1 of 1
Total:	13 of 30	2 of 6

Table 4.18 Presence of delamination according to adhesive type and whether the artifact was exposed to no, limited or repeated flexing since treatment.

	Number of Artifacts exhibiting Delamination		
Adhesive	no flexing	limited flexing	repeated flexing
Acryloid F10	5 of 6	1 of 5	
Beva 371	1 of 8	0 of 1	0 of 1
Beva 371 / Mowilith DMC2 / DM5	0 of 1		2 of 3
Lascaux P550-40TB		1 of 1	
Mowilith (type not specified)			0 of 1
Mowilith DMC2	0 of 2	0 of 1	
Mowilith DMC2 / DM5			1 of 2
Vinamul 3252			1 of 1
Vinamul 6515 / 6525			1 of 1
Vinnapas EP1			1 of 1
unidentified			1 of 1
Total:	6 of 17	2 of 8	7 of 11

among artifacts that were exposed to repeated flexing (7 of 11 artifacts). As for supplementary stitching, few adhesives were represented by artifacts in all categories. Nevertheless, most of the Acryloid-treated artifacts and the one Beva-treated artifact that exhibited delamination were not flexed.

Discussion

Factors affecting bond delamination

Adhesives

The results of the survey suggest that the adhesives conservators are using to support textiles can all be used successfully. In most of the treatments, the adhesives formed stable bonds that exhibited either no or only minor signs of bond failure. The weakest treatments, those using Acryloid F10, were continuing to give effective support to artifacts fifteen to twenty years later, even though some artifacts had been on continuous display in less than ideal environments. This confirms that Pretzel's (1997a; 1997b) suggested standard of 100 N m^{-1} as the minimum peel strength required for a successful bond is misleading when applied to textile conservation treatments. Acryloid F10, as it is usually used by textile conservators, provides very weak bonds. It was given a poor rating according to Pretzel's system (< 50 N m^{-1}), suggesting that it should be used with caution. That embroidered flags and large banners have been successfully treated with this adhesive while other conservators chose stronger adhesives, Beva 371 and Mowilith DMC2, for comparable textiles suggests that the concept of "adequate" strength requires further experimental study.

The relatively high prevalence of localized delamination in artifacts treated using Acryloid F10 may or may not indicate that this adhesive requires more care to ensure treatment success than the strong adhesive, Beva 371. Although six of the fifteen artifacts exhibiting delamination were treated with Acryloid F10 while only one of these artifacts was fully treated with Beva 371, the artifacts treated with these adhesives differ in other ways that may have contributed to the likelihood of delamination. The Acryloid F10 artifacts were earlier treatments, all over thirteen years old. Four of eleven artifacts had been on continuous display since treatment in environments with no humidity control. Four were displayed and stored in controlled museum environments at least most of the time. Delamination was observed on three artifacts in each of these groups. Three other Acryloid-treated artifacts had been stored rolled in a controlled environment, had never been examined since treatment, and exhibited no signs of delamination. In contrast, Beva 371 was represented by several more recent treatments: more than half were less than ten years old. Two of the three Beva 371 treatments in the 15 to 20 year category were small textiles displayed or stored flat since treatment. The third was mounted on a rigid support and remained in a controlled storage environment since treatment. The other Beva 371 treatment over ten years old had been on display twice in a controlled environment and stored in a fairly stable environment, but it showed some evidence of delamination. Moreover, most of the instances of delamination were minor. Some of the types of delamination recorded, such as poorly adhered yarns or lifting of protruding sections of painted silk at tears or losses, may never have been well adhered. The present examination could not conclusively distinguish lack of adhesion at the time of treatment from delamination since treatment except in a few cases. Given the weakness of bonds formed by the Acryloid F10 treatments relative to Beva 371, the low frequency of delamination is surprising and speaks to the skill with which the Acryloid F10 treatments were executed.

Although the survey may not be able to attribute delamination definitively to the adhesive used, it does offer an indication that the choice is important. In one case when a mixture of Mowilith DMC2 and DM5 was used, adhesion of the silk components of a large painted banner failed after it was rolled during treatment, although the same adhesives and treatment techniques had been used successfully on other, similar artifacts. The reason for failure can only be surmised and may be related to the ribbed structure of the silk weave combined with the flexing caused by rolling. When Beva 371 was substituted, the bond did not fail. This case illustrates that one adhesive may perform better for a particular artifact than another adhesive. Because adhesive type, treatment technique, and the nature of post-treatment handling varied considerably for the artifacts surveyed, the present study cannot offer any specific suggestions regarding which adhesive might be required for particular treatment objectives.

Support fabrics

The results of this survey provide no evidence to suggest that the type of support fabric influences the frequency of bond delamination. Delamination was observed on almost all supports. Artifacts supported on silk or polyester crepeline using the same adhesive were equally likely to exhibit delamination. The localized failure of the bond in banners adhered to polyester crepeline using the weak bonds of Acryloid F10 or Lascaux P550-40TB treatments, is troubling. Both banners were likely exposed to intermittent high relative humidity levels. Differences in response to humidity of the silk artifact and polyester crepeline, combined with the weakness of the bond, may have contributed to the delamination. This hypothesis remains to be tested.

The partial delamination of the palampore treated with Vinamul 6515/6525 may be attributed to contraction of the net support which was coated under tension on the net table in use at the time at the Victoria & Albert Museum. Similar wrinkling of an adhesive-treated silk robe has been attributed to such contraction of nylon net (Gentle, 1998). Only some of the undulations on this artifact, however, consisted of the cotton artifact ballooning over the nylon net. In other places, the reverse occurred, as if the net had stretched or the artifact contracted. Some of this artifact's delamination can be attributed to stress from unrolling since the coated net had adhered to the Melinex interleaving. A study focussed on the current condition of a larger number of artifacts treated with net coated under tension would be needed to understand this type of delamination better. Meanwhile, polyester film (Mylar, Melinex) should clearly not be used to interleave adhesive-treated textiles when the coated support has not been fully isolated.

Supplementary stitching

The lack of relationship between supplementary stitching and bond delamination is not necessarily evidence of no effect. Most artifacts exhibiting bond delamination (13 of 15) had also been given supplementary stitching. This result illustrates clearly that stitching at certain places on the treated artifact will not prevent all delamination, particularly localized, minor forms. Most instances of bond failure occurred at locations where no stitching was present. What cannot be ascertained is the degree of delamination that would have occurred had no stitching been done at all. Few artifacts with no stitching were examined and those were not necessarily comparable to other artifacts. The four Beva 371 treatments that included no stitching were done on small, flat model flags, which were exposed to little handling since treatment. That the bonds of these treated artifacts exhibited no delamination is evidence that stitching is not always necessary. The two large palampores, which were adhered but not stitched, exhibited delamination. They were also treated in the 1960s using materials and techniques that were no longer available or had been modified by the time the more recent treatments were executed. No artifacts treated with Acryloid F10 lacked supplementary stitching. Given the weak bonds provided by the Acryloid F10 treatments, such artifacts would be excellent test cases for the importance of stitching in preventing bond failure. The frequent lack of detail in the treatment records on stitch location, the lack of information as to whether stitching tasks mechanically reinforced the adhesive bond, and the difficulty locating stitching on the artifact combined to make the survey, as designed, a poor research approach for analysing the relationship between stitching and bond stability.

Stress control

As for supplementary stitching, determining whether methods of stress control reduced the frequency of bond delamination was difficult. Almost 65% of artifacts that were flexed several times since treatment exhibited delamination in comparison to 35% of artifacts that were not flexed. This is not proof that flexing causes delamination, however. No artifacts treated with Acryloid F10 were exposed to repeated flexing; therefore, the degree to which rigid supports or other means of reducing manipulation prevented failure of the weak bonds provided by these treatments cannot be ascertained conclusively from this study. Since delamination occurred on artifacts that were not flexed, the delamination on the flexed artifacts was not necessarily due to flexing. Some instances of minor delamination may have been due to poor bonding at the time of treatment due to ravelled fabric or planar distortion of the artifact. Nevertheless, the higher frequency of delamination in artifacts exposed to repeated flexing suggests that the relationship between stress control and bond stability is worth studying more closely.

Surveying previously treated artifacts

Although this exploratory survey showed that most of the adhesive treatments were successful, it also revealed substantial difficulties in using this research approach for studying the effects of particular adhesives, support fabrics, and treatment techniques. Assembling even a convenience sample was complicated and expensive. Adhesive treatments are not frequently used, even by the few conservators who have the most experience with this treatment. Moreover, compiling a list of artifacts treated with adhesives is time consuming since treatment reports are rarely filed by treatment type. This study benefitted from the concurrent development of workshops by textile conservators interested in this treatment. Conservators had, thus, already identified treated artifacts for that purpose. Artifacts treated by non-collecting conservation laboratories, such as the Canadian Conservation Institute, were geographically scattered. Artifacts within collections were sometimes relatively inaccessible. Large textiles were often stored rolled. Retrieving them from storage for examination was not a simple procedure. Textiles on display were often behind glazing, which could be removed only in some cases. Building a sample that properly reflected the entire population of adhesive-supported textiles or that contained equal numbers of comparable artifacts treated with the adhesives and/or support fabrics of interest would be substantially more difficult.

Properly examining the artifacts in the sample was also challenging due in part to restricted physical access and in part to the limitations of the survey form. The adhered support was fully accessible for only 6 of 36 artifacts. Both sides could be easily examined for only 4 of these artifacts. For many of the other artifacts, better access would have required removal of mounts, secondary support fabrics, or linings, or disassembly of the artifact itself, none of which could be considered ethical. Assessment of the current condition of the artifact, and in particular of the adhesive bond, therefore, involved a considerable amount of extrapolation from the limited visible evidence. A thorough list of likely outcomes helped to focus attention systematically when examining the artifacts and helped ensure that relevant data were not missed. Some of those lists, however, were produced during the survey and thus were not exploited as fully as they might have been had they been drawn up in advance. A more objective assessment of the extent of bond failure would have been possible, for example, if the relative frequency and severity of each type of delamination described in Table 4.12 had been determined for each artifact. This inevitable weakness highlights the importance of collaborating with conservators familiar with the treatment when developing the survey form and of pretesting the form on a few representative examples of the treatment before beginning the survey proper. Even collaboration and pretesting, however, which were both used in this survey, will not ensure that the survey form will be designed to collect the most useful data if the factors affecting the stability of the treatment are poorly understood prior to the survey.

Gathering data on treatments from treatment reports posed its own challenges. Although most artifacts had fairly comprehensive reports, which conservators shared generously, only the most basic information about the treatment materials and techniques was consistently recorded. The adhesive and support fabric were almost always identified, but not necessarily the way they were prepared for treatment. The conservator likely assumed that readers of the report would have knowledge of the details of a treatment, since they are basic to a studio's practice. Alternatively, the details were not thought to be important. For the purposes of research, however, details are important. For example, treatment records usually reported in some form the solvent used to dilute the adhesive and the ratio of adhesive to solvent; but the nature of the adhesive coating (continuous film, coating only the yarns, etc.), which cannot be simply inferred from the solution used, was almost never described. Since the amount of adhesive deposited per unit area of support fabric has been shown to significantly affect peel strength (see Chapter 2), this information could be very useful in interpreting the long-term success of a particular treatment. Similarly, the location of stitching was often not easily discerned from the treatment record and was not always easily visible on the treated artifact, yet its position may significantly affect the efficacy of the treatment. Stone (1996) noted similar problems with finding the location of conservation work from treatment reports for ethnological artifacts. The terminology used in reports varied from studio to studio and within each studio to some degree, making classification of certain procedures difficult. Moreover, descriptions of what were often complex treatments were sometimes difficult to follow, particularly when the artifact could not be examined with the report in hand. The reason for choosing an adhesive treatment—useful information when assessing a treatment in retrospect—was mentioned in less than half of the reports and then usually obliquely. For treatment reports to function well as data sources for survey research, the information they contain should ideally be comprehensive and clearly organized. Computer technology could be exploited to make this possible without making the task of writing reports onerous.

As designed, this survey was successful as a descriptive tool but less successful as an investigative research technique. The results of the survey offer a useful supplement to surveys on what conservators say they are doing (Hillyer, Tinker, & Singer, 1997; Yates, 1987) by describing in detail actual artifacts and the treatments they received and by assessing the general efficacy of the treatments. The survey was also able to identify possible problem areas, particularly likely locations of delamination. As a means of relating problems to particular materials and techniques, however, the survey was less successful. As described earlier, the possible connection between delamination and the use of Acryloid F10 becomes less clear when difference in the age of the treatment and the handling of the artifacts since treatment are considered. Although the number of artifacts examined that were treated with each of Acryloid F10 or Beva 371, or supported on each of silk crepeline or polyester crepeline was fairly high (10 to 14), the numbers drop quickly when the adhesive and support fabric are considered together (4 to 12), and even faster when another factor, such as years since treatment or extent of artifact cleaning, is accounted for (1 to 4). The fewer the number per treatment group, the more difficult it becomes to draw any kind of general conclusions from the data. Given the complex nature of most textile treatments, this problem can be expected from most survey research of previously treated artifacts, unless larger numbers of artifacts can be examined, or artifacts are selected to maximize numbers for particular combinations of treatment factors.

Conclusions

This study has examined the effectiveness of adhesive support treatments for textile artifacts by surveying a group of artifacts treated in this way. A sample of thirty-six artifacts that were given heat-sealed adhesive support treatments, mostly flags and banners, was studied. The artifacts had been supported using one of eleven adhesives or adhesive combinations, the most frequently used being Acryloid F10, Beva 371, or Mowilith DMC2/DM5. Artifacts were supported using seven different support fabrics, most often silk crepeline or polyester crepeline (Stabiltex). The supports were coated, usually using a brush or sprayer, and heat-sealed to the artifact with a spatula iron, flat iron, vacuum hot table, or a combination of these. The treatments were completed from two to almost forty years before examination. In the intervening time, the artifacts had been exposed to a variety of storage and display conditions. Although evidence of localized, mostly minor delamination was observed on fifteen of the artifacts, most of the treatments were continuing to provide sympathetic support to the artifacts, regardless of the bond strength of the adhesive used. The results did suggest that bond failure occurred more frequently when artifacts were treated with Acryloid F10, treatments known to produce weak bonds. Differences in the age, nature, and handling of the artifacts treated with the various adhesives, however, makes it inadvisable to attribute the frequency of failure to the adhesive alone. The frequency of bond failure could not be related to support fabric type or the absence of supplementary stitching but appeared to increase when artifacts were exposed to repeated flexing after treatment. Treatments that provided both relatively weak and strong bonds were observed to provide long-term, adequate support to textile artifacts. Pretzel's (1997a; 1997b) suggested criterion of 100 N m^{-1} as the minimum peel strength required for good adhesion—a standard not met by the relatively weak adhesion provided by Acryloid F10 treatments—can, therefore, be safely ignored for textile conservation purposes. Given the complexity of these treatments, however, the presence or absence of bond delamination could not be definitively explained through the results of this survey. Until the causes of bond delamination are better understood, the full treatment, including supplementary stitching, mounting technique, and type of handling or environment after treatment, should be accounted for when selecting an adhesive or when interpreting the efficacy of a previous adhesive support treatment.

The results of this survey suggest that in order to choose an adhesive for a particular textile effectively, adhesive strength should be considered relative to the stresses that the adhered artifact will encounter after treatment and the ways in which other aspects of the treatment restrict those stresses. If it were sufficient to assess the adequacy of an adhesive's strength for an adhesive support treatment from the results of peel tests, Acryloid F10, a very weak adhesive in the way it is used, should not have been found to effectively support artifacts with minimal delamination almost as frequently as Beva 371, a strong adhesive. Future research regarding adhesive support treatments should concentrate on this stress/bond relationship and determine the limits of adhesive effectiveness in terms of stresses encountered in handling and flexing, such as those from rolled storage. The role supplementary stitching plays in preventing delamination needs to be further explored with an emphasis on the effects of stitch placement. Observation of these artifacts suggests that points where delamination is likely to occur, such as the edges of splits, tears, or losses, loose or floating yarns, fragmented areas, and protruding sections of the artifact or support fabric patches, may benefit from supplementary stitching.

This survey produced a useful depiction of the types of artifacts given adhesive treatments, particularly flags and banners, and a description of the adhesive techniques used. It has shown that adhesive support treatments using adhesives of varying strength on different support fabrics offer an effective treatment strategy for textiles like fragile flags and banners. The complex mix of factors related to artifact type, treatment materials and techniques, and subsequent history, however, makes identifying the causes of adhesive bond delamination difficult to ascertain without further controlled experimental research.

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CHAPTER 5

CONCLUSIONS

Summary of the Studies

The purpose of this research was to determine the effects and the relative importance of selected adhesive treatment materials (adhesives, artifact fabrics, and support fabrics), selected aspects of joint design (dispersion concentration, spray versus brush adhesive application), mechanical reinforcement (supplementary stitching), and stress control (restriction of flexing) on the formation of an adequate adhesive bond in textile artifact/adhesive/support fabric laminates. Three studies were designed to accomplish this purpose. These studies examined the bond from three perspectives: as a material structure subjected to stress (peel testing), as interacting surfaces (contact angle and surface characterization), and as one aspect of a complex treated artifact (treated artifact survey).

In the first study, the bond was examined through peel testing. Fabric laminates consisting of silk habutae or nylon taffeta artifacts, one of six adhesives, (Acryloid F10, Beva 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, or Vinamul 3252) and a support fabric (nylon net, polyester crepeline, or silk crepeline) were peeled at a rate of 50 mm min^{-1} in a controlled environment of 20 ± 2°C and 65 ± 5% RH. In addition to determining the peel strength of the laminates, the transfer of adhesive to the artifact fabric during peeling was observed visually and through scanning electron microscopy.

The purpose of the second study was to determine the surface free energy components of adhesive films and artifact fabrics in order to estimate the work of adhesion between the adhesive and fibre solid surfaces. The contact angles of three probing liquids against the solids were determined using drop shape analysis (adhesive films) and wetting rates or the Washburn technique (fabrics). Surface free energy components and work of adhesion were calculated using the van Oss-Chaudhury-Good (vOCG) approach. Work of adhesion results were compared to peel strength results.

The third study consisted of an exploratory survey of textile artifacts that had been given adhesive support treatments mostly within the past twenty years. A survey form, developed in collaboration with textile conservators, enabled collection of comprehensive data describing the artifact, its treatment, and subsequent history. The survey focussed on flat textiles and on adhesives equivalent to those tested in the laboratory studies. The treatment reports and current condition of thirty-six artifacts, mostly flags and banners, treated in four conservation studios were studied in detail.

Conclusions

This dissertation began by suggesting that the provision of adequate bond strength in adhesive treatments for textiles could not be understood without considering the effects of materials (adherends and adhesives) and joint design as well as the non-adhesive factors, mechanical reinforcement and stress control. The conclusions of the three studies comprising this research are summarized here by revisiting the hypotheses presented in the introduction and grouping them according to these broad factors. Following this is a final assessment of the system of comparing adhesive bond strength designed by Pretzel (1997a; 1997b), the system which inspired this inquiry in the first place.

Treatment Materials

Adhesives

Adhesive formulation has a significant affect on the peel strength of fabric laminates. Beva 371 bonds were the strongest; Acryloid F10 bonds were the weakest. The bonds of the dispersion adhesives were of intermediate strength, with Vinamul 3252 and Dur-O-Set E150 providing generally stronger bonds than Lascaux 360/498 HV and Clariant T1601. To a certain extent these results reflect not just adhesive formulation, but also application technique (joint design), since the adhesives were not applied in exactly the same manner. The dispersion adhesives were applied identically, however, and exhibited significant differences in peel strength. In part these differences are due to differences in the mechanical properties of the adhesives. Those adhesives that responded to peel stress by stretching and fibrillating tended to produce stronger bonds. In part, adhesive formulations dried to form adhesive coatings differently. The type of coating produced could affect the design of the bond independent of the techniques used by the conservator. Thus Lascaux 360/498 HV coatings were poorly anchored to the support fabric yarns in comparison to Clariant T1601, Dur-O-Set E150, and Vinamul 3252 coatings, although all four adhesives were diluted and applied to the support fabrics in the same manner.

The surface free energies of adhesive films cast from Acryloid F10, Beva 371, Clariant T1601, Dur-O-Set E150, Lascaux 360/498 HV, and Vinamul 3252 are distinct. All adhesives were low energy solids (γ_S of 32 to 47 mJ m^{-2}) with relatively low acidic and high basic components, when assessed using the vOCG approach. Each solid exhibited individual interactions with the probing liquids, and was thus characterized by distinctive surface free energy components. The differences in surface free energy components contributed to distinct work of adhesion results with silk and nylon fabrics. Since work of adhesion characterizes bond strength independent of joint design, the differences in work of adhesion indicate differences in molecular bonding ability among the adhesives.

There is a significant correlation between the results for work of adhesion and peel strength when the results for Acryloid F10 are excluded. This correlation indicates that the differences in peel strength reflect in part inherent difference in the ability of the adhesives to bond to the textile fabrics studied. The exceptional results for Acryloid F10—relatively high work of adhesion, very low peel strength—suggest that adhesive application technique can obscure differences in molecular bonding ability. The technique used for Acryloid F10 deposited a lower mass of adhesive on the coated support fabrics than the techniques used for the other adhesives. Similarly, the technique used for Beva 371 deposited a higher mass of adhesive on the coated support fabrics than the techniques used for the other adhesives, although the Beva 371 work of adhesion results do not contradict the peel strength results. A more accurate comparison of work of adhesion and peel strength would require standardized production of the laminate specimens for peel testing to ensure adhesive coatings of equal surface area.

The frequency of bond delamination in adhesive-treated textile artifacts is dependent on the type of adhesive used. The bonds between artifacts and support fabrics exhibited a higher frequency of delamination when the adhesive used was Acryloid F10 than when it was Mowilith DMC2/DM5 or Beva 371. In other words, bond delamination in treated textile artifacts occurs more frequently for adhesive support treatments that provide relatively weak bonds than for those that provide relatively strong bonds. Other factors besides adhesive type may have influenced this result, however. The nature of the artifact and treatment, as well as the time and handling of the artifact since treatment also varied. Given the low peel strength of the Acryloid F10 treatments relative to the other adhesives, as demonstrated by the peel tests, the minor amount of delamination on artifacts treated with this adhesive is surprising.

Artifact fabrics

Silk habutae laminates exhibit higher peel strength than the corresponding nylon taffeta laminates. The peel strength of silk laminates was consistently higher than that of nylon taffeta laminates, although the degree depended on the adhesive and application technique. The difference did not appear to depend on the mechanical properties of the fabrics but may have related to the shape of the fibres and the construction of the yarns. The difference is likely due to the higher polarity of silk relative to nylon.

The acid-base component of the surface free energy of silk habutae is greater than that of nylon taffeta. As determined using contact angles of probing liquids on the fabrics, the surface free energies of silk habutae and nylon taffeta are almost identical (33.3 versus 34.6 mJ m^{-2}) but the acid-base component for silk habutae was higher than that for nylon taffeta (1.6 versus 0.9 mJ m^{-2}). This result confirms the general characterization of silk as more polar than nylon.

The work of adhesion between the adhesives and silk fabrics is usually greater than that between the adhesives and nylon fabrics. Both measures of bond strength, work of adhesion and peel strength, indicate that adhesive bonds to silk are stronger than those to nylon. This result was expected, given the differences in the fibres' polarity. Two adhesives, Dur-O-Set E150 and Vinamul 3252, did not follow this pattern for work of adhesion: the results for nylon were equal to or slightly higher than those for silk. This discrepancy may be due to the tendency for the vOCG approach to underestimate the acidic component of the surface free energy of solids.

Support Fabrics

Silk or polyester crepeline supports provide for higher peel strength than nylon net. Most of the application techniques used to make the laminates produced adhesive coatings that covered only the surface of the yarns of the support fabrics. Since nylon net has fewer yarns per unit width than silk or polyester crepeline, the lower peel strength of nylon net laminates can be explained by the lower bonding surface available. When fabrics were covered with a continuous film of adhesive, Beva 371, the peel strengths of laminates supported by all three fabrics were not significantly different. Because more adhesives and artifact fabrics were tested, previously observed significant differences in the peel strength produced by polyester and silk crepeline (Karsten, 1998) were not replicated.

The frequency of bond delamination in adhesive-treated textile artifacts was not shown to be dependent on the type of support fabric. Bond delamination was observed on almost all support fabrics used on the artifacts surveyed in proportion to the frequency with which the fabrics were used. Silk and polyester crepeline were used almost equally and failed to the same degree. This result parallels the lack of distinction in peel strength for these two fabrics. Although the two artifacts supported on nylon net both exhibited delamination, this number is too small to warrant generalization.

Joint Design

Doubling the concentration of a dispersion adhesive solution doubles the peel strength of comparable laminates. Increasing the adhesive concentration from 1:10 to 1:5 (volume adhesive: volume distilled water) increased the amount of adhesive on the support fabrics both by mass and surface area. Increased surface area of adhesive over the width of the specimens contributed to higher peel strength.

The method of coating adhesive resins onto support fabrics—spray versus brush—affects the nature of the adhesive coating and may sometimes significantly affect peel strength. The different application techniques were studied on two adhesives, one showing a significant effect (Acryloid F10), the other not (Beva 371). The significant difference observed for Acryloid F10 was related to how the adhesive coated the yarns. When brushed, the adhesive formed a flat film on the surface of the fabric yarns, a film relatively available for bonding to the artifact fabric. When sprayed, the dilute adhesive conformed to the shape of the fabric yarns and was thus less available for bonding. Because Beva 371 was applied as a more concentrated solution, the sprayed adhesive was deposited as fine particles that protruded from the fabric surface, making it as available for bonding as the brushed film.

Associated treatment techniques

This study could not demonstrate conclusively that bond delamination in treated textile artifacts occurs less frequently when the bond is mechanically reinforced using supplementary stitching. Because so few artifacts examined were not given supplementary stitching, and because those artifacts were not comparable to the artifacts that were stitched, this survey did not provide a good test of this hypothesis. Furthermore, stitching that reinforced the bond could not easily be distinguished from stitching that did not. Most of the artifacts exhibiting delamination were reinforced with stitching, but not at the locations where delamination occurred. Four small artifacts treated with Beva 371 demonstrated that stitching was not required to prevent delamination in all cases.

Bond delamination in treated textile artifacts may occur less frequently when the flexing of treated artifacts is prevented. The frequency of bond delamination on artifacts that were exposed to repeated flexing after treatment was higher than that on artifacts that were not flexed. This suggests that stress control, through the provision of rigid mounts or the restriction of handling, can increase the likelihood that an adhesive will provide a bond of adequate strength. Delamination was observed, however, on artifacts that were not flexed. Moreover, a few artifacts that were repeatedly flexed exhibited no apparent delamination. Bond failure cannot, therefore, be attributed simplistically to handling and manipulation.

Assessment of Pretzel's system for comparing adhesive bond strength

Pretzel's scoring system is not always valid if the materials or techniques that will be used in adhesive support treatments are changed. The peel strength results of this study indicate that even when identical adhesives and support fabrics are used, differences in application technique can change the score that an adhesive would receive according to Pretzel's (1997a; 1997b) system. Moreover, ranking the adhesives according to the peel strength results of this study did not match ranks based on Pretzel's study. The differences can be attributed to differences in the surface area of adhesive covering the support fabrics. Pretzel also incorporated scores based on adhesive transfer into his scores for bond strength. This study showed that the tendency for an adhesive to transfer to the artifact fabric during peeling is affected by the type of artifact and support fabrics used. Pretzel's matrix is not a valid guide for the choice of an adhesive of adequate bond strength for an artifact treatment, therefore, if materials and techniques other than those used to produce the laminates for that study are used to treat the artifact.

Adhesive treatments that fail to meet Pretzel's criterion for adequate bond strength ($100\ N\ m^{-1}$) can provide adequate support for textile artifacts with minimal bond delamination. In both Pretzel's (1997a; 1997b) research and this study, treatments using Acryloid F10 formed bonds whose peel strength was ten to fifty times less than this criterion. Nevertheless, Acryloid F10 has been used to successfully support treated textiles, even large banners, with minimal or no evidence of bond failure after years of display or storage, even in less than ideal environments.

The adequate bond strength required for adhesive support of textile artifacts must clearly account for the stresses that the bond must endure and the ways in which other non-adhesive aspects of the treatment reinforce or protect the bond.

Assessment of the Materials Studied

The tripartite structure of this research permitted examination of the materials bonded in adhesive support treatments at three levels of observation: interfacial interactions, mechanical interactions, and in situ on treated artifacts. The result is a fuller picture of how these materials function than might have been produced had any one of these research strategies been pursued alone. Summarized below are some of the properties of the materials revealed through these studies in relation to adhesive support treatments.

Artifact Fabrics

Adhesive bonds to nylon taffeta are weaker than those to silk habutae when characterized by both peel tests and work of adhesion. Adequate support for nylon artifacts may therefore require "stronger" adhesives than for silk artifacts. This research uncovered some evidence that fabric and yarn structure may have an effect on peel strength, factors that need further study.

Support Fabrics

Nylon net

Because of the relatively large openings in its bobbinet structure, nylon net can carry less adhesive per unit area than silk or polyester crepeline unless a continuous film of adhesive is formed over the fabric. The result is consistently lower peel strength when the adhesive coats only the yarns. The greatest amount of transfer of adhesive to the artifact fabric during peeling was observed for this support fabric. Adhesive coatings tend to be poorly anchored to nylon net due to its monofilament yarns, few yarn twists, and large interstices.

Silk or polyester crepeline

Both silk crepeline and polyester crepeline (Stabiltex, Tetex) produced similar results for peel strength and reversibility. Polyester crepeline may be implicated in delamination when used in treatments that give very weak bonds on artifacts that are subsequently exposed to RH fluctuation.

Adhesives

Acryloid F10

Peel tests confirmed what was expected from conservator's descriptions (Keyserlingk, 1993): applied as a 1:8 v/v solution in toluene, this adhesive produces very weak bonds. Relatively high work of adhesion values demonstrate, however, that the *treatment* creates weak bonds, not the *adhesive*. Despite the weak bonds, this adhesive has been used successfully to support various artifacts including relatively large banners. Delamination noted on banners supported on polyester crepeline and housed in environments with poor RH control needs further investigation.

Beva 371

This adhesive exhibited high bond strength in peel tests and measures of work of adhesion. Several examples of successful, stable treatment were observed, including some with no supplementary stitching. With its strength, however, comes a great tendency to transfer to the artifact during peeling, especially when applied by spray using a fairly concentrated solution (1:1 v/v in toluene). Therefore, this adhesive may be the least reversible of all the adhesives tested, if peel techniques are used.

Clariant T1601

One of the weaker adhesives in terms of both peel strength and work of adhesion, Clariant T1601 can provide for adequate support, given the good condition of textiles adhered with its equivalent, Mowilith DMC2. A relatively stiff adhesive, Clariant T1601 specimens peeled without much adhesive transfer, suggesting good reversibility.

Dur-O-Set E150

This adhesive exhibited moderately high peel strength and work of adhesion relative to the other adhesives along with little transfer to the artifact during peeling, suggestive of good reversibility. Dur-O-Set E150 is not yet used for conservation treatments since it is still being tested for suitable durability (Down, 1999). Given that Dur-O-Set E150 is a neat dispersion adhesive, and thus likely to be unaffected by formulation changes (Down, 1995), it shows good promise as a possible textile conservation adhesive for the future.

Lascaux 360/498 HV

This adhesive mixture provided the tackiest, stretchiest adhesive coatings of all the adhesives studied. Lascaux 360/498 HV also anchored most poorly to the support fabrics. Its ability to dissipate energy through fibrillation during peeling was exceptional. This accounts for its ability to generate relatively high peel strengths (Pretzel, 1997a; 1997b), although its peel results in this study were moderately low. On the other hand, its flexibility, extensibility, and poor wetting of the support fabrics resulted in considerable transfer of adhesive to the artifact fabric during peeling. Its high tack could also be problematic since it might be susceptible to dust entrapment. Study of Lascaux 498 HV alone is warranted, since Lascaux 360 HV, with its low Tg, is probably responsible for the high degree of tack and extensibility.

Vinamul 3252

This adhesive provides bonds of moderately high peel strength, in part due to its ability to stretch and fibrillate in response to peel stress. It tends to transfer to the artifact during peeling, although less than Beva 371. Essentially a monopolar basic solid, its work of adhesion to silk habutae and nylon taffeta is relatively low but may have been underestimated when using the vOCG approach. Alternatively, the mechanical properties of the adhesive enhance peel strength despite relatively low work of adhesion.

Assessment of the research approaches

Three different approaches were used to examine the adhesive bond in this research. Peel tests are often used to assess the bond strength in fabric laminates in conservation science. The approach is useful since specimens can be prepared using materials and methods identical to those used in actual artifact treatments. The effects of materials and techniques, however, tend to be confounded in peel tests. Furthermore, measures of peel tests alone cannot predict bond adequacy without understanding the contributions that mechanical reinforcement and stress control make towards bond stability. In order to test more precisely the bonding ability of the selection of adhesives examined in this research, independent of joint design, surface science theory and techniques were used to characterize the surface free energy of the adhesives and the artifact fabrics and to determine their work of adhesion. The effects of associated, non-adhesive treatment techniques were studied through a survey of artifacts that had been given adhered supports. Neither of these last two approaches had been used before to study factors affecting bond strength in textile artifact/adhesive/support fabric laminates. This research presented an opportunity to test the usefulness of these approaches to textile conservation science.

Although determining surface free energy and work of adhesion provided a valuable perspective on the textile laminate bond, the results of this study suggest that this approach need not be a priority in studying adhesive support treatments for textiles. The small range of work of adhesion values (65 to 85 mN m^{-1}) contrasts to the much larger range of peel strength values (1 to 55 N m^{-1}). Peel strength is known to be greater than work of adhesion due to contributions to the peel force from the work of bending and deformation. Nevertheless, the scale of this difference is also due to the effects of varied adhesive application techniques, which need to be fully understood before the effects of surface interactions can be effectively exploited. Furthermore, the observation of cohesive failure within the adhesive layer during peel tests of some of the adhesives indicates that bond strength depends on more than interfacial forces. Moreover, the correlation between work of adhesion and peel strength suggests that peel tests do reflect differences in surface properties fairly well, as long as laminate specimens are prepared in a consistent manner.

The artifact survey also provided an important perspective on the adhesive bond in textile support treatments. The ultimate test of an adhesive support treatment is its ability to support an actual artifact with no or minor delamination over time in the museum environment. This survey was successful in describing the treated artifacts, the materials and techniques used to support them, and their history since treatment. The survey was also able to identify types of bond delamination that occur on treated artifacts. It showed very clearly that high peel strength is not a necessary prerequisite for a successful adhesive support treatment. As a means of relating bond failure to particular materials and techniques, however, the survey was less successful. The artifacts and their treatments were sometimes too varied to establish patterns of effect. At other times certain combinations of treatment materials and techniques were not represented, for example, Acryloid F10-treated artifacts without supplementary stitching. Trends might be identified but not tested with any degree of certainty. Artifact surveys can play an important role in conservation science research but they cannot replace laboratory testing as a means of unravelling the effects of factors on a treatment such as adhesive supports for textile artifacts.

Recommendations for Further Research

Textile conservators will benefit from further research related to adhesive support treatments for textiles if it helps them make decisions about treatment materials and techniques that will result in an adhesive bond that adequately supports the textile artifact. This research has demonstrated that the achievement of "adequate" bond strength in an adhesive support treatment probably depends not just on the strength of the adhesive bond but also on the methods used to control exposure to stress. Future research should, therefore, begin by defining the causes of bond delamination in treated textile artifacts, and, for those causes that are mechanical, determining, if possible, bond strength standards required to prevent delamination. If, for example, rolling a treated textile can cause bond failure, tests could be devised that measure the ability of a bonded laminate to withstand delamination during repeated rolling. The results of such tests could then be related to a simple measure of bond strength, such as peel strength, producing benchmarks that could be used to interpret the results of studies regarding the effects of materials and application techniques on bond strength.

Since few aspects of adhesive support treatments for textiles have been studied rigorously, the possible areas of research on materials and application techniques are numerous. This research suggests a few areas worth exploring more fully. Since varying adhesive solution concentration modifies the surface area of an adhesive coating, detailed assessment of how these changes affect the bond strength of solution adhesives like Acryloid F10 and Beva 371 in addition to dispersion adhesives would be helpful. Although fibre type has been shown to influence bond strength, some evidence of the effect of fabric structure on bond strength has also been presented. Since artifacts are not all made from fine, smooth silk and nylon fabrics, the examination of bonds to different fabric structures through peel testing is justified. Ultimately, the results of such studies will have to be combined with research on bond strength standards if it is to help textile conservators make treatment decisions. As this research has shown, the "adequacy" of the bond, which an adhesive support treatment must provide to be successful, is not the result of adhesive choice alone.

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APPENDIX A

FABRIC PREPARATION AND CHARACTERIZATION

All fabrics were washed, rinsed, and air dried according to the delicate pretreatment procedures outlined in test method ASTM D 5429-93 (American Society for Testing and Materials (ASTM), 1998). Silk habutae and nylon taffeta were soaked in hot tap water (60°C) for ten minutes, washed using gentle agitation in a 0.3% w/w solution of Orvus WA Paste, a sodium dodecyl sulphate surfactant, in water for ten minutes, and then rinsed at least eight times in progressively cooler water. The fabrics were then rinsed in water purified through reverse osmosis at least six times beginning with water at 40°C and ending with water at 20°C. Removal of detergent residue from the silk habutae was particularly difficult and may not have been entirely complete. Nylon net, polyester crepeline, and silk crepeline were soaked in purified water at 40°C for 10 minutes, immersed and gently agitated in a 0.3% w/w Orvus WA Paste solution at 40°C for ten minutes, and rinsed at least eight times in purified water. All fabrics were blocked out onto a clean laboratory bench top and air dried at room temperature.

The weave and yarns of each fabric were characterized using standard test methods. The mass of the fabrics was measured according to the procedure of CAN/CGSB-4.2 No. 5.1-M90 (Canadian General Standards Board (CGSB), 1990) using five die cut specimens. Fabric count per centimetre was determined following CAN/CGSB-4.2 No. 6-M89 (CGSB, 1989). Linear density was calculated using the procedures of CAN/CGSB-4.2 No. 39-M88 (CGSB, 1988) to measure yarns lengths after removal of yarn crimp and CAN/CGSB-4.2 No. 5.2-M87 (CGSB, 1987). Yarn diameters of the support fabrics were determined using an optical microscope fitted with a calibrated eyepiece micrometer. Randomly selected warp and weft yarns on five specimens of each fabric were measured. The reported values are the averages for at least 50 measurements. The yarn diameters of the artifact fabrics were calculated from the fabric count results (1 cm / yarns per cm). The twist and number of fibres in fabric yarns were observed with the aid of a Stereo Star Zoom stereomicroscope (AO Scientific Instruments). Measurements were gathered from conditioned specimens under standard test conditions of 20 ± 2°C and 65 ± 2% RH.

Tensile strength, extension at break, and modulus were determined following the test method CAN/CGSB-4.2 No. 9.1-M90 (CGSB, 1997) using 200 x 30 mm (warp x weft) specimens, ravelled to 25 mm in width. Support fabrics were ravelled to a set number of warp yarns equivalent to 25 mm; namely, 27 yarns for nylon net, 59 yarns for polyester crepeline, and

76 yarns for silk crepeline. Tests were conducted on an Instron Universal Testing Instrument Model 4202 equipped with the software, Instron Series IX Automated Materials Tester, version 8.13.00, 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. Tests were conducted on conditioned specimens under standard test conditions of 20 ± 2°C and 65 ± 2% RH. Extension at break is the elongation at break expressed as a percentage of the original gauge length. Initial modulus was calculated automatically as the slope of the initial part of the load/displacement graph. The values of seven specimens were averaged for each fabric.

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APPENDIX B
PEEL STRENGTH AND ADHESIVE ADD-ON DATA

Adhesive: Acryloid F10, brushed

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NANb-01	0.0050	1.5
NANb-02	0.0077	1.6
NANb-03	0.0065	1.3
NANb-04	0.0029	1.2
NANb-05	0.0051	1.6
NANb-06	0.0066	1.2
NANb-07	0.0067	1.7
NANb-08	0.0061	1.4
NANb-09	0.0080	1.2
NANb-10	0.0082	1.5
Mean:	0.0063	1.4
Std Dev:	0.0016	0.2

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NAPb-02	0.0082	1.2
NAPb-03	0.0084	1.8
NAPb-04	0.0071	1.6
NAPb-05	0.0085	1.5
NAPb-06	0.0080	1.2
NAPb-07	0.0071	1.5
NAPb-08	0.0086	1.7
NAPb-09	0.0112	1.7
NAPb-10	0.0116	1.7
NAPb-11	0.0058	1.5
Mean:	0.0085	1.5
Std Dev:	0.0018	0.2

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NASb-02	0.0103	1.7
NASb-03	0.0111	1.3
NASb-04	0.0065	0.9
NASb-05	0.0091	1.5
NASb-06	0.0102	1.0
NASb-07	0.0074	1.1
NASb-08	0.0083	1.4
NASb-09	0.0092	1.6
NASb-10	0.0132	2.0
NASb-11	0.0063	1.3
Mean:	0.0092	1.4
Std Dev:	0.0021	0.3

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SANb-01	0.0077	2.7
SANb-03	0.0074	3.1
SANb-04	0.0047	2.7
SANb-05	0.0062	3.0
SANb-06	0.0057	3.2
SANb-07	0.0046	2.9
SANb-08	0.0064	3.0
SANb-09	0.0069	3.5
SANb-10	0.0084	3.7
SANb-11	0.0049	2.7
Mean:	0.0063	3.0
Std Dev:	0.0013	0.3

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SAPb-01	0.0083	2.7
SAPb-02	0.0089	2.6
SAPb-03	0.0082	2.8
SAPb-04	0.0050	1.8
SAPb-05	0.0088	2.4
SAPb-06	0.0083	3.2
SAPb-08	0.0068	2.8
SAPb-09	0.0078	3.3
SAPb-10	0.0105	3.6
SAPb-11	0.0067	2.7
Mean:	0.0079	2.8
Std Dev:	0.0015	0.5

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SASb-01	0.0059	1.5
SASb-02	0.0072	2.1
SASb-03	0.0068	2.0
SASb-04	0.0066	1.6
SASb-05	0.0078	2.5
SASb-06	0.0105	2.4
SASb-07	0.0069	2.0
SASb-08	0.0099	2.5
SASb-09	0.0089	2.9
SASb-10	0.0117	2.9
Mean:	0.0082	2.2
Std Dev:	0.0019	0.5

Adhesive: Acryloid F10, sprayed

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NANs-01	0.0130	0.8
NANs-02	0.0112	1.5
NANs-03	0.0093	0.7
NANs-04	0.0107	1.2
NANs-05	0.0137	0.9
NANs-06	0.0124	0.8
NANs-07	0.0115	1.1
NANs-08	0.0095	0.9
NANs-10	0.0099	1.0
NANs-11	0.0096	1.0
Mean:	0.0111	1.0
Std Dev:	0.0016	0.2

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SANs-01	0.0113	2.0
SANs-02	0.0104	2.3
SANs-03	0.0107	2.1
SANs-04	0.0100	1.6
SANs-05	0.0134	2.4
SANs-06	0.0116	1.7
SANs-07	0.0126	1.7
SANs-08	0.0127	1.9
SANs-09	0.0125	2.3
SANs-10	0.0090	2.3
Mean:	0.0114	2.0
Std Dev:	0.0014	0.3

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NAPs-01	0.0188	1.1
NAPs-02	0.0169	0.7
NAPs-03	0.0174	0.8
NAPs-04	0.0166	1.1
NAPs-05	0.0167	0.9
NAPs-06	0.0179	1.0
NAPs-07	0.0238	1.5
NAPs-08	0.0171	0.9
NAPs-09	0.0165	1.0
NAPs-10	0.0087	0.7
Mean:	0.0170	1.0
Std Dev:	0.0036	0.2

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SAPs-01	0.0170	1.3
SAPs-02	0.0139	1.6
SAPs-03	0.0149	2.0
SAPs-04	0.0168	2.1
SAPs-05	0.0202	1.6
SAPs-06	0.0160	1.9
SAPs-07	0.0177	1.8
SAPs-08	0.0165	2.0
SAPs-09	0.0175	2.2
SAPs-10	0.0150	1.7
Mean:	0.0166	1.8
Std Dev:	0.0018	0.3

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NASs-01	0.0169	0.6
NASs-02	0.0169	1.6
NASs-04	0.0155	0.7
NASs-05	0.0223	0.7
NASs-07	0.0179	0.8
NASs-08	0.0133	1.0
NASs-09	0.0190	1.0
NASs-10	0.0129	1.0
NASs-11	0.0134	0.8
NASs-12	0.0161	1.0
Mean:	0.0164	0.9
Std Dev:	0.0029	0.3

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SASs-01	0.0156	1.2
SASs-02	0.0203	2.0
SASs-03	0.0174	1.5
SASs-04	0.0182	1.7
SASs-05	0.0267	1.7
SASs-06	0.0223	1.2
SASs-07	0.0169	1.9
SASs-08	0.0191	2.3
SASs-09	0.0194	1.6
SASs-10	0.0095	1.6
Mean:	0.0185	1.7
Std Dev:	0.0045	0.3

Adhesive: Beva 371, brushed

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NBNb-02	0.0425	43.7
NBNb-03	0.0504	24.7
NBNb-04	0.0506	32.7
NBNb-05	0.0745	31.0
NBNb-06	0.0383	39.8
NBNb-07	0.0525	46.7
NBNb-08	0.0390	32.1
NBNb-09	0.0534	30.4
NBNb-10	0.0478	35.6
NBNb-12	0.0603	31.4
Mean:	0.0509	34.8
Std Dev:	0.0107	6.7

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NBPb-01	0.0442	51.3
NBPb-02	0.0453	53.5
NBPb-03	0.0450	45.4
NBPb-04	0.0557	34.1
NBPb-05	0.0306	38.0
NBPb-06	0.0516	47.2
NBPb-07	0.0443	38.5
NBPb-08	0.0420	42.1
NBPb-09	0.0379	41.3
NBPb-10	0.0557	34.3
Mean:	0.0452	42.6
Std Dev:	0.0077	6.7

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NBSb-01	0.0684	64.9
NBSb-02	0.0697	66.0
NBSb-03	0.0559	45.9
NBSb-04	0.0652	29.0
NBSb-05	0.0655	36.8
NBSb-06	0.0466	57.0
NBSb-07	0.0428	34.4
NBSb-09	0.0489	48.9
NBSb-10	0.0659	48.5
NBSb-11	0.0755	35.1
Mean:	0.0604	46.7
Std Dev:	0.0111	13.0

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SBNb-01	0.0696	37.5
SBNb-02	0.0394	73.1
SBNb-03	0.0332	44.1
SBNb-04	0.0550	19.9
SBNb-05	0.0498	55.8
SBNb-06	0.0435	58.2
SBNb-07	0.0488	53.5
SBNb-08	0.0485	29.7
SBNb-09	0.0441	53.6
SBNb-10	0.0625	49.9
Mean:	0.0494	47.5
Std Dev:	0.0107	15.3

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SBPb-01	0.0586	65.6
SBPb-02	0.0339	40.5
SBPb-03	0.0301	48.4
SBPb-04	0.0455	53.4
SBPb-05	0.0670	59.8
SBPb-06	0.0442	54.4
SBPb-08	0.0500	53.7
SBPb-09	0.0639	55.3
SBPb-11	0.0841	40.8
SBPb-12	0.0544	35.1
Mean:	0.0532	50.7
Std Dev:	0.0161	9.5

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SBSb-02	0.0613	87.4
SBSb-03	0.0352	56.3
SBSb-04	0.0669	60.6
SBSb-05	0.0493	54.9
SBSb-06	0.0408	45.3
SBSb-07	0.0624	61.4
SBSb-08	0.0502	50.7
SBSb-09	0.0745	56.2
SBSb-10	0.0596	58.4
SBSb-11	0.0676	35.6
Mean:	0.0568	56.7
Std Dev:	0.0125	13.3

Adhesive: Beva 371, sprayed

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NBNs-01	0.0342	39.1
NBNs-03	0.0285	22.7
NBNs-04	0.0295	27.9
NBNs-05	0.0281	28.4
NBNs-06	0.0332	33.3
NBNs-07	0.0406	40.9
NBNs-08	0.0285	29.9
NBNs-09	0.0385	36.4
NBNs-10	0.0296	29.6
NBNs-11	0.0367	40.5
Mean:	0.0327	32.9
Std Dev:	0.0046	6.2

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NBPs-01	0.0520	60.8
NBPs-02	0.0468	55.2
NBPs-03	0.0489	62.8
NBPs-04	0.0475	52.7
NBPs-05	0.0515	54.7
NBPs-06	0.0403	50.7
NBPs-07	0.0456	55.8
NBPs-08	0.0330	42.2
NBPs-10	0.0459	43.8
NBPs-11	0.0472	53.7
Mean:	0.0459	53.2
Std Dev:	0.0056	6.5

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NBSs-01	0.0458	49.2
NBSs-02	0.0511	55.2
NBSs-03	0.0451	44.4
NBSs-04	0.0433	37.9
NBSs-05	0.0388	45.5
NBSs-06	0.0298	33.5
NBSs-07	0.0473	45.9
NBSs-08	0.0403	47.9
NBSs-09	0.0587	71.1
NBSs-10	0.0525	64.3
Mean:	0.0453	49.5
Std Dev:	0.0080	11.4

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SBNs-01	0.0308	32.7
SBNs-02	0.0352	44.4
SBNs-04	0.0252	40.6
SBNs-05	0.0450	61.6
SBNs-06	0.0241	32.3
SBNs-07	0.0369	51.8
SBNs-08	0.0304	37.4
SBNs-10	0.0314	41.8
SBNs-11	0.0353	44.2
SBNs-12	0.0249	33.4
Mean:	0.0319	42.0
Std Dev:	0.0065	9.3

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SBPs-01	0.0528	63.3
SBPs-02	0.0510	58.4
SBPs-03	0.0471	69.8
SBPs-04	0.0511	84.5
SBPs-06	0.0332	57.5
SBPs-07	0.0421	75.9
SBPs-08	0.0445	75.9
SBPs-09	0.0518	78.5
SBPs-10	0.0551	82.3
SBPs-11	0.0440	74.6
Mean:	0.0473	72.1
Std Dev:	0.0065	9.5

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SBSs-01	0.0512	54.8
SBSs-02	0.0452	58.2
SBSs-03	0.0569	72.8
SBSs-04	0.0551	77.4
SBSs-05	0.0359	55.2
SBSs-06	0.0387	46.8
SBSs-07	0.0320	43.4
SBSs-08	0.0452	74.9
SBSs-09	0.0470	67.5
SBSs-10	0.0603	80.8
Mean:	0.0468	63.2
Std Dev:	0.0093	13.2

Adhesive: Clariant T1601, 1:10 v/v

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NCNo-02	0.0097	4.3
NCNo-03	0.0081	3.8
NCNo-04	0.0073	3.1
NCNo-05	0.0089	3.8
NCNo-07	0.0074	3.8
NCNo-08	0.0080	2.8
NCNo-09	0.0094	4.1
NCNo-10	0.0096	4.1
NCNo-11	0.0088	4.3
NCNo-12	0.0090	5.5
Mean:	0.0086	3.9
Std Dev:	0.0009	0.7

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NCPo-01	0.0113	6.2
NCPo-02	0.0115	5.8
NCPo-03	0.0122	6.7
NCPo-04	0.0130	6.8
NCPo-05	0.0116	5.7
NCPo-06	0.0131	7.4
NCPo-07	0.0128	6.6
NCPo-09	0.0131	7.5
NCPo-10	0.0137	8.4
NCPo-11	0.0141	9.8
Mean:	0.0126	7.1
Std Dev:	0.0010	1.3

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NCSo-01	0.0226	6.8
NCSo-02	0.0111	3.7
NCSo-04	0.0112	4.4
NCSo-05	0.0129	3.5
NCSo-06	0.0150	7.2
NCSo-07	0.0104	5.1
NCSo-08	0.0170	7.9
NCSo-09	0.0148	6.4
NCSo-10	0.0173	8.8
NCSo-11	0.0143	7.2
Mean:	0.0147	6.1
Std Dev:	0.0037	1.8

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SCNo-01	0.0090	6.9
SCNo-02	0.0092	9.8
SCNo-03	0.0101	11.0
SCNo-04	0.0061	6.5
SCNo-05	0.0078	9.8
SCNo-06	0.0109	12.2
SCNo-07	0.0076	9.3
SCNo-08	0.0104	11.3
SCNo-09	0.0083	10.4
SCNo-10	0.0088	11.0
Mean:	0.0088	9.8
Std Dev:	0.0014	1.9

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SCPo-01	0.0147	17.8
SCPo-02	0.0104	12.2
SCPo-03	0.0139	17.8
SCPo-04	0.0095	15.8
SCPo-06	0.0114	15.1
SCPo-08	0.0133	18.1
SCPo-09	0.0116	18.7
SCPo-10	0.0141	21.2
SCPo-11	0.0145	23.7
SCPo-12	0.0139	22.0
Mean:	0.0127	18.2
Std Dev:	0.0019	3.4

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SCSo-01	0.0110	8.8
SCSo-02	0.0106	11.1
SCSo-03	0.0111	10.3
SCSo-04	0.0121	12.8
SCSo-05	0.0129	15.6
SCSo-07	0.0176	20.5
SCSo-08	0.0150	13.4
SCSo-09	0.0099	10.8
SCSo-10	0.0139	17.0
SCSo-11	0.0191	18.1
Mean:	0.0133	13.8
Std Dev:	0.0031	3.8

Adhesive: Clariant T1601, 1:5 v/v

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NCNt-01	0.0239	7.9
NCNt-02	0.0197	6.0
NCNt-03	0.0225	6.2
NCNt-04	0.0157	5.2
NCNt-05	0.0211	6.4
NCNt-06	0.0148	5.3
NCNt-07	0.0181	5.9
NCNt-08	0.0244	8.4
NCNt-09	0.0168	4.7
NCNt-10	0.0213	6.8
Mean:	0.0198	6.3
Std Dev:	0.0034	1.2

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NCPt-01	0.0276	12.6
NCPt-02	0.0228	9.2
NCPt-03	0.0244	9.3
NCPt-04	0.0179	11.3
NCPt-06	0.0245	15.6
NCPt-07	0.0272	13.0
NCPt-08	0.0296	15.7
NCPt-10	0.0218	13.7
NCPt-11	0.0282	14.6
NCPt-12	0.0268	13.7
Mean:	0.0251	12.9
Std Dev:	0.0035	2.3

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NCSt-01	0.0304	9.9
NCSt-02	0.0238	10.3
NCSt-03	0.0205	7.4
NCSt-05	0.0218	9.4
NCSt-06	0.0229	8.9
NCSt-07	0.0325	12.2
NCSt-08	0.0293	10.6
NCSt-09	0.0273	12.7
NCSt-10	0.0214	10.8
NCSt-11	0.0350	12.7
Mean:	0.0265	10.5
Std Dev:	0.0051	1.7

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SCNt-01	0.0378	20.0
SCNt-02	0.0189	17.4
SCNt-03	0.0227	17.0
SCNt-04	0.0245	17.6
SCNt-05	0.0162	19.2
SCNt-06	0.0176	17.7
SCNt-07	0.0230	25.1
SCNt-08	0.0154	16.9
SCNt-09	0.0185	17.3
SCNt-10	0.0185	18.7
Mean:	0.0213	18.7
Std Dev:	0.0065	2.5

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SCPt-01	0.0268	30.1
SCPt-03	0.0267	30.4
SCPt-04	0.0209	30.8
SCPt-06	0.0231	30.5
SCPt-07	0.0273	34.6
SCPt-08	0.0247	30.5
SCPt-09	0.0303	35.0
SCPt-10	0.0249	34.5
SCPt-11	0.0257	38.1
SCPt-12	0.0206	38.3
Mean:	0.0251	33.3
Std Dev:	0.0030	3.2

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SCSt-01	0.0253	24.8
SCSt-03	0.0247	23.5
SCSt-04	0.0224	21.0
SCSt-05	0.0252	25.7
SCSt-06	0.0266	20.9
SCSt-07	0.0247	23.3
SCSt-08	0.0290	27.5
SCSt-09	0.0267	25.4
SCSt-10	0.0280	28.6
SCSt-11	0.0286	26.3
Mean:	0.0261	24.7
Std Dev:	0.0021	2.5

Adhesive: Dur-O-Set E150, 1:10 v/v

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NDNo-01	0.0141	12.3
NDNo-03	0.0122	9.0
NDNo-04	0.0101	7.3
NDNo-05	0.0072	5.7
NDNo-06	0.0104	8.1
NDNo-08	0.0064	5.6
NDNo-09	0.0070	6.0
NDNo-10	0.0066	5.7
NDNo-11	0.0100	10.5
NDNo-12	0.0076	6.6
Mean:	0.0092	7.7
Std Dev:	0.0026	2.3

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NDPo-01	0.0191	16.7
NDPo-02	0.0146	11.9
NDPo-03	0.0166	14.3
NDPo-04	0.0131	12.1
NDPo-05	0.0124	11.4
NDPo-07	0.0152	15.7
NDPo-09	0.0137	12.3
NDPo-10	0.0149	12.5
NDPo-11	0.0146	17.8
NDPo-12	0.0124	17.0
Mean:	0.0147	14.2
Std Dev:	0.0020	2.4

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NDSo-01	0.0179	10.5
NDSo-02	0.0178	11.4
NDSo-03	0.0172	14.0
NDSo-04	0.0105	7.0
NDSo-05	0.0122	10.4
NDSo-06	0.0148	11.9
NDSo-07	0.0126	10.0
NDSo-08	0.0163	13.2
NDSo-10	0.0130	12.6
NDSo-11	0.0187	16.8
Mean:	0.0151	11.8
Std Dev:	0.0029	2.6

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SDNo-01	0.0189	21.7
SDNo-02	0.0095	12.1
SDNo-03	0.0150	28.0
SDNo-04	0.0093	8.6
SDNo-05	0.0070	13.3
SDNo-06	0.0089	11.6
SDNo-07	0.0096	16.3
SDNo-08	0.0115	17.6
SDNo-09	0.0083	16.7
SDNo-10	0.0106	17.6
Mean:	0.0109	16.4
Std Dev:	0.0036	5.6

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SDPo-01	0.0250	36.0
SDPo-02	0.0125	17.5
SDPo-03	0.0170	29.1
SDPo-04	0.0130	15.1
SDPo-05	0.0107	21.3
SDPo-07	0.0145	33.2
SDPo-08	0.0155	25.2
SDPo-09	0.0165	28.7
SDPo-10	0.0137	26.6
SDPo-11	0.0168	26.3
Mean:	0.0155	25.9
Std Dev:	0.0039	6.5

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SDSo-01	0.0192	17.2
SDSo-02	0.0155	16.8
SDSo-03	0.0185	24.6
SDSo-04	0.0163	13.8
SDSo-05	0.0129	17.3
SDSo-06	0.0130	14.7
SDSo-07	0.0183	27.2
SDSo-08	0.0163	20.3
SDSo-09	0.0163	20.2
SDSo-10	0.0144	21.1
Mean:	0.0161	19.3
Std Dev:	0.0022	4.3

Adhesive: Dur-O-Set E150, 1:5 v/v

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NDNt-01	0.0200	12.1
NDNt-02	0.0212	15.2
NDNt-03	0.0312	12.4
NDNt-05	0.0165	10.6
NDNt-07	0.0242	9.9
NDNt-08	0.0273	11.4
NDNt-09	0.0235	12.1
NDNt-10	0.0295	10.1
NDNt-11	0.0232	11.1
NDNt-12	0.0186	12.1
Mean:	0.0235	11.7
Std Dev:	0.0047	1.5

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NDPt-02	0.0244	17.2
NDPt-03	0.0182	16.4
NDPt-04	0.0253	21.3
NDPt-05	0.0262	18.5
NDPt-06	0.0263	17.7
NDPt-07	0.0212	23.0
NDPt-08	0.0304	24.6
NDPt-09	0.0293	19.9
NDPt-10	0.0255	14.6
NDPt-11	0.0278	16.3
Mean:	0.0255	18.9
Std Dev:	0.0036	3.2

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NDSt-01	0.0295	21.4
NDSt-02	0.0318	20.7
NDSt-03	0.0210	15.6
NDSt-04	0.0276	14.6
NDSt-05	0.0256	13.7
NDSt-06	0.0227	14.4
NDSt-07	0.0248	18.9
NDSt-08	0.0332	19.1
NDSt-09	0.0339	19.0
NDSt-11	0.0277	14.3
Mean:	0.0278	17.2
Std Dev:	0.0044	2.9

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SDNt-02	0.0305	31.9
SDNt-03	0.0185	26.1
SDNt-04	0.0202	20.8
SDNt-05	0.0286	27.2
SDNt-06	0.0203	19.0
SDNt-07	0.0225	25.1
SDNt-09	0.0304	28.6
SDNt-10	0.0291	25.8
SDNt-11	0.0241	23.8
SDNt-12	0.0231	26.2
Mean:	0.0247	25.4
Std Dev:	0.0046	3.7

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SDPt-01	0.0337	42.3
SDPt-02	0.0229	40.4
SDPt-03	0.0250	43.3
SDPt-04	0.0248	35.5
SDPt-05	0.0168	27.8
SDPt-06	0.0242	29.4
SDPt-08	0.0243	35.2
SDPt-09	0.0320	42.8
SDPt-10	0.0315	39.4
SDPt-11	0.0266	32.3
Mean:	0.0262	36.8
Std Dev:	0.0050	5.7

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SDSt-02	0.0302	35.4
SDSt-03	0.0302	27.5
SDSt-05	0.0279	29.4
SDSt-06	0.0272	20.7
SDSt-07	0.0242	37.3
SDSt-08	0.0320	33.4
SDSt-09	0.0320	28.7
SDSt-10	0.0348	30.0
SDSt-11	0.0274	26.1
SDSt-12	0.0307	33.2
Mean:	0.0297	30.2
Std Dev:	0.0030	4.9

Adhesive: Lascaux 360/498 HV, 1:10 v/v

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NLNo-02	0.0097	6.5
NLNo-03	0.0113	5.9
NLNo-04	0.0113	7.3
NLNo-05	0.0102	5.8
NLNo-06	0.0093	6.9
NLNo-07	0.0096	7.4
NLNo-08	0.0140	7.4
NLNo-09	0.0090	5.4
NLNo-10	0.0103	4.8
NLNo-12	0.0132	12.3
Mean:	0.0108	7.0
Std Dev:	0.0017	2.1

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NLPo-01	0.0149	8.8
NLPo-02	0.0132	4.1
NLPo-03	0.0125	6.5
NLPo-04	0.0120	6.2
NLPo-05	0.0117	2.5
NLPo-06	0.0133	6.7
NLPo-07	0.0114	5.9
NLPo-08	0.0158	7.9
NLPo-09	0.0103	6.3
NLPo-10	0.0131	5.1
Mean:	0.0128	6.0
Std Dev:	0.0016	1.8

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NLSo-01	0.0182	7.4
NLSo-02	0.0171	9.1
NLSo-03	0.0133	6.1
NLSo-04	0.0106	4.7
NLSo-05	0.0127	6.5
NLSo-06	0.0154	9.7
NLSo-07	0.0106	5.6
NLSo-08	0.0155	7.1
NLSo-09	0.0113	8.2
NLSo-10	0.0190	9.9
Mean:	0.0144	7.4
Std Dev:	0.0031	1.8

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SLNo-01	0.0165	12.2
SLNo-03	0.0118	14.9
SLNo-04	0.0097	8.4
SLNo-05	0.0098	10.8
SLNo-06	0.0101	9.1
SLNo-07	0.0087	10.4
SLNo-08	0.0100	9.4
SLNo-10	0.0112	12.3
SLNo-11	0.0118	13.0
SLNo-12	0.0124	15.4
Mean:	0.0112	11.6
Std Dev:	0.0022	2.4

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SLPo-01	0.0162	15.1
SLPo-02	0.0136	10.0
SLPo-03	0.0114	10.1
SLPo-04	0.0118	7.9
SLPo-05	0.0100	6.6
SLPo-06	0.0109	9.8
SLPo-07	0.0127	7.7
SLPo-08	0.0134	10.1
SLPo-09	0.0113	12.4
SLPo-10	0.0128	9.2
Mean:	0.0124	9.9
Std Dev:	0.0018	2.4

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SLSo-01	0.0209	8.5
SLSo-02	0.0174	10.9
SLSo-03	0.0157	9.7
SLSo-04	0.0130	7.6
SLSo-05	0.0133	6.2
SLSo-06	0.0089	5.8
SLSo-07	0.0125	9.0
SLSo-08	0.0142	7.6
SLSo-09	0.0116	8.8
SLSo-11	0.0129	6.7
Mean:	0.0140	8.1
Std Dev:	0.0033	1.6

Adhesive: Lascaux 360/498 HV, 1:5 v/v

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NLNt-01	0.0295	32.9
NLNt-02	0.0198	18.4
NLNt-03	0.0146	15.3
NLNt-04	0.0200	21.2
NLNt-05	0.0193	21.8
NLNt-06	0.0223	22.7
NLNt-07	0.0202	21.5
NLNt-08	0.0149	12.3
NLNt-09	0.0205	21.9
NLNt-10	0.0287	31.8
Mean:	0.0210	22.0
Std Dev:	0.0049	6.4

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NLPt-01	0.0319	38.1
NLPt-02	0.0230	21.1
NLPt-03	0.0256	23.8
NLPt-04	0.0211	21.3
NLPt-05	0.0199	21.2
NLPt-07	0.0231	25.8
NLPt-08	0.0239	26.5
NLPt-09	0.0261	23.3
NLPt-10	0.0217	21.5
NLPt-12	0.0306	27.4
Mean:	0.0247	25.0
Std Dev:	0.0040	5.2

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NLSt-01	0.0351	23.6
NLSt-02	0.0262	13.7
NLSt-03	0.0336	24.7
NLSt-04	0.0158	11.8
NLSt-05	0.0229	16.0
NLSt-06	0.0242	16.0
NLSt-07	0.0231	17.2
NLSt-08	0.0288	20.0
NLSt-09	0.0246	16.2
NLSt-10	0.0308	19.5
Mean:	0.0265	17.9
Std Dev:	0.0057	4.1

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SLNt-01	0.0410	36.4
SLNt-02	0.0186	22.7
SLNt-03	0.0361	37.6
SLNt-04	0.0275	31.2
SLNt-05	0.0165	19.3
SLNt-06	0.0211	25.7
SLNt-07	0.0239	28.3
SLNt-08	0.0265	31.3
SLNt-09	0.0240	27.2
SLNt-11	0.0359	34.4
Mean:	0.0271	29.4
Std Dev:	0.0081	5.9

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SLPt-01	0.0302	31.7
SLPt-02	0.0263	30.0
SLPt-03	0.0262	37.5
SLPt-04	0.0257	40.6
SLPt-05	0.0230	22.0
SLPt-06	0.0199	20.1
SLPt-07	0.0250	27.4
SLPt-08	0.0333	39.5
SLPt-09	0.0254	32.0
SLPt-11	0.0277	30.4
Mean:	0.0263	31.1
Std Dev:	0.0037	6.8

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SLSt-01	0.0306	21.5
SLSt-02	0.0219	18.7
SLSt-04	0.0235	19.2
SLSt-06	0.0267	18.1
SLSt-07	0.0267	23.5
SLSt-08	0.0268	26.1
SLSt-09	0.0286	22.4
SLSt-10	0.0308	21.6
SLSt-11	0.0348	28.8
SLSt-12	0.0313	27.2
Mean:	0.0282	22.7
Std Dev:	0.0039	3.7

Adhesive: Vinamul 3252, 1:10 v/v

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NVNo-02	0.0091	8.5
NVNo-03	0.0177	15.1
NVNo-04	0.0079	7.8
NVNo-05	0.0086	8.9
NVNo-06	0.0094	7.8
NVNo-08	0.0091	5.9
NVNo-09	0.0104	10.1
NVNo-10	0.0106	8.4
NVNo-11	0.0171	13.7
NVNo-12	0.0090	8.4
Mean:	0.0109	9.5
Std Dev:	0.0035	2.8

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NVPo-01	0.0181	17.3
NVPo-02	0.0112	9.5
NVPo-03	0.0152	14.2
NVPo-04	0.0115	13.2
NVPo-05	0.0108	13.8
NVPo-06	0.0139	15.0
NVPo-07	0.0138	12.9
NVPo-08	0.0135	14.6
NVPo-09	0.0125	19.1
NVPo-10	0.0140	12.2
Mean:	0.0135	14.2
Std Dev:	0.0022	2.7

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NVSo-01	0.0183	12.5
NVSo-02	0.0127	8.5
NVSo-03	0.0147	11.2
NVSo-04	0.0179	12.8
NVSo-05	0.0150	12.7
NVSo-06	0.0142	10.4
NVSo-07	0.0179	12.2
NVSo-09	0.0157	16.4
NVSo-10	0.0149	11.7
NVSo-11	0.0163	13.3
Mean:	0.0158	12.2
Std Dev:	0.0018	2.0

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SVNo-01	0.0149	15.5
SVNo-02	0.0097	11.4
SVNo-03	0.0104	13.9
SVNo-04	0.0062	7.8
SVNo-05	0.0089	13.3
SVNo-06	0.0083	11.7
SVNo-07	0.0098	12.2
SVNo-08	0.0107	14.8
SVNo-09	0.0097	18.2
SVNo-10	0.0099	16.5
Mean:	0.0099	13.5
Std Dev:	0.0022	3.0

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SVPo-01	0.0167	21.2
SVPo-02	0.0115	10.6
SVPo-03	0.0135	22.0
SVPo-04	0.0116	20.5
SVPo-05	0.0137	22.6
SVPo-06	0.0124	19.5
SVPo-07	0.0138	19.0
SVPo-08	0.0131	17.9
SVPo-09	0.0140	22.4
SVPo-10	0.0136	21.4
Mean:	0.0134	19.7
Std Dev:	0.0015	3.5

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SVSo-01	0.0198	13.0
SVSo-02	0.0121	13.2
SVSo-03	0.0173	18.2
SVSo-04	0.0146	16.4
SVSo-05	0.0155	22.0
SVSo-07	0.0174	20.9
SVSo-08	0.0164	16.7
SVSo-09	0.0152	14.4
SVSo-10	0.0155	19.2
SVSo-11	0.0201	19.8
Mean:	0.0164	17.4
Std Dev:	0.0024	3.2

Adhesive: Vinamul 3252, 1:5 v/v

Fabrics: nylon taffeta/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NVNt-01	0.0239	27.2
NVNt-02	0.0217	21.0
NVNt-03	0.0252	28.8
NVNt-04	0.0184	19.7
NVNt-05	0.0201	19.4
NVNt-06	0.0176	15.9
NVNt-07	0.0153	14.7
NVNt-08	0.0235	23.1
NVNt-09	0.0201	15.1
NVNt-10	0.0187	14.5
Mean:	0.0205	20.0
Std Dev:	0.0031	5.2

Fabrics: nylon taffeta/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NVPt-01	0.0309	30.1
NVPt-02	0.0226	25.3
NVPt-03	0.0267	32.9
NVPt-04	0.0243	30.8
NVPt-05	0.0236	26.1
NVPt-06	0.0215	28.5
NVPt-07	0.0236	30.4
NVPt-08	0.0255	32.2
NVPt-09	0.0233	30.6
NVPt-10	0.0221	22.0
Mean:	0.0244	28.9
Std Dev:	0.0028	3.4

Fabrics: nylon taffeta/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
NVSt-01	0.0268	28.1
NVSt-02	0.0218	23.3
NVSt-03	0.0351	32.7
NVSt-04	0.0272	29.1
NVSt-05	0.0246	27.5
NVSt-06	0.0271	30.8
NVSt-07	0.0278	26.9
NVSt-08	0.0356	38.8
NVSt-09	0.0247	29.5
NVSt-10	0.0282	31.5
Mean:	0.0279	29.8
Std Dev:	0.0044	4.1

Fabrics: silk habutae/nylon net

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SVNt-01	0.0206	22.4
SVNt-02	0.0248	31.9
SVNt-03	0.0309	42.9
SVNt-04	0.0167	21.0
SVNt-05	0.0194	26.0
SVNt-06	0.0166	20.3
SVNt-07	0.0208	31.3
SVNt-08	0.0199	26.2
SVNt-09	0.0157	23.5
SVNt-10	0.0202	25.2
Mean:	0.0206	27.1
Std Dev:	0.0045	6.8

Fabrics: silk habutae/polyester crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SVPt-01	0.0240	32.4
SVPt-02	0.0215	29.4
SVPt-03	0.0301	47.2
SVPt-04	0.0210	36.9
SVPt-05	0.0215	37.2
SVPt-07	0.0144	25.6
SVPt-08	0.0335	45.3
SVPt-09	0.0253	46.2
SVPt-10	0.0224	42.4
SVPt-11	0.0291	49.4
Mean:	0.0243	39.2
Std Dev:	0.0055	8.2

Fabrics: silk habutae/silk crepeline

Sample Code	Coat Mass (g)	Peel Strength (N/m)
SVSt-01	0.0339	32.1
SVSt-02	0.0251	34.7
SVSt-03	0.0331	45.1
SVSt-04	0.0272	35.1
SVSt-05	0.0266	39.5
SVSt-06	0.0199	26.9
SVSt-07	0.0228	37.1
SVSt-08	0.0277	40.2
SVSt-09	0.0235	35.7
SVSt-10	0.0244	33.8
Mean:	0.0264	36.0
Std Dev:	0.0044	4.9

APPENDIX C

ANOVA RESULTS FOR ANALYSIS OF PEEL STRENGTH RESULTS USING LOG-TRANSFORMED DATA

Table C.1 SAS Analysis

The SAS System 09:31 Tuesday, February 18, 2003

The GLM Procedure
Class Level Information

Class	Levels	Values
artifact	2	nylon silk
support	3	nylon polyester silk
adhesive type	12	Ab As Bb Bs Co Ct Do Dt Lo Lt Vo Vt

Number of observations: 720

Dependent Variable: logpeel

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	71	173.6370465	2.4455922	290.52	< .0001
Error	648	5.4548700	0.0084180		
Corrected Total	719	179.0919165			

R-Square	Coeff Var	Root MSE	logpeel Mean
0.969542	8.327109	0.09175	1.101819

Source		DF	Type I Sum of Squares	Mean Square	F Value	Pr > F
Main Effects	artifact	1	8.8777813	8.8777813	1054.62	< .0001
	support	2	2.0037719	1.0018860	119.02	< .0001
	adhesive type	11	158.1970682	14.3815517	1708.43	< .0001
2-Way Interactions	artifact*support	2	0.1369375	0.0684687	8.13	0.0003
	artifact* adhesive type	11	2.1117771	0.1919797	22.81	< .0001
	support* adhesive type	22	2.1843914	0.0992905	11.80	< .0001
3-Way Interaction	artifact*support*adhesive type	22	0.1253192	0.0056963	0.68	0.8646

Table C.2 Results of multiple comparisons using Tukey's adjustment. Groups in the same row under each interaction are not significantly different. Groups that overlap with the following row are shown in italics.

Two- Way Interaction									
Artifact/ Adhesive Type			Adhesive Type/ Support						Artifact/ Support
NAs			ASs	APs	*ANs*				NN
NAb			ANs	*ASb*					NS
SAs			ASb	APb	ANb				NP
SAb			CNo	*LPo*	*LSo*				SN
NCo	NLo		LPo	LSo	*LNo*	*CSo*			SS
NCt	*SLo*	*NDo*	LNo	CSo	CNt	DNo	VNo	*CPo*	SP
SLo	NDo	*NVo*	CPo	*VSo*					
NVo	*SCo*		VSo	*DSo*	*CSt*	*VPo*	*DNt*		
SCo	*NDt*		DSo	*CSt*	*VPo*	*DNt*	*DPo*		
NDt	*SVo*		CSt	VPo	DNt	*DPo*	*LSt*	*CPt*	
SVo	*SDo*		DPo	*LSt*	*CPt*	*DSt*	*VNt*		
SDo	*NLt*		LSt	*CPt*	*DSt*	*VNt*	*LNt*		
NLt	*SCt*		CPt	*DSt*	*VNt*	*LNt*	*DPt*		
SCt	*NVt*	*SLt*	DSt	VNt	LNt	*DPt*	*LPt*		
NVt	SLt	*SDt*	DPt	LPt	*VSt*	*VPt*			
SDt	*SVt*		VSt	VPt	*BNs*	*BNb*			
SVt	*NBb*		BNs	*BNb*	*BPb*				
NBb	*NBs*		BNb	*BPb*	*BSb*				
NBs	*SBb*		BPb	*BSb*	*Bss*				
SBb	SBs		BSb	Bss	BPs				

Artifact fabrics: nylon taffeta (N), silk habutae (S)

Adhesives: Acryloid F10 (A), Beva 371 (B), Clariant T1601 (C), Dur-O-Set E150 (D), Lascaux 360/498 HV (L), Vinamul 3252 (V)

Application techniques: brush (b), spray (s), 1:10 v/v (o), 1:5 v/v (t)

Support fabrics: nylon net (N), polyester crepeline (P), silk crepeline (S)

APPENDIX D

THE VAN OSS-CHAUDHURY-GOOD APPROACH TO DETERMINING THE APOLAR AND POLAR CONTRIBUTIONS TO SURFACE FREE ENERGIES

The van Oss-Chaudhury-Good approach permits estimation of the apolar and polar contributions to surface and interfacial free energies from the following equation (Good, 1993):

$$\gamma_L (1 + \cos\theta) = 2[(\gamma_S^{LW}\gamma_L^{LW})^{1/2} + (\gamma_S^{+}\gamma_L^{-})^{1/2} + (\gamma_S^{-}\gamma_L^{+})^{1/2}] \quad \text{(D.1)}$$

Contact angles are determined using three liquids of known surface free energy components. Liquid 1 is apolar but of sufficiently high surface tension to form a measurable contact angle on most solids (van Oss, 2002); for example, diiodomethane or 1-bromonaphthalene. When the liquid is apolar, i.e. $\gamma_L^- = \gamma_L^+ = 0$, and $\gamma_L = \gamma_L^{LW}$, equation D.1 becomes:

$$\gamma_S^{LW} = \gamma_L (1 + \cos\theta)^2/4 \quad \text{(D.2)}$$

This equation permits the calculation of the Lifshitz-van der Waals (γ_S^{LW}) component of the solid surface free energy from the contact angle of the apolar liquid.

Once the dispersion component of the solid surface free energy is known, the acid-base components are calculated by solving a system of two equations,

$$\gamma_{L2} (1 + \cos\theta_{L2}) = 2[(\gamma_S^{LW}\gamma_{L2}^{LW})^{1/2} + (\gamma_S^{+}\gamma_{L2}^{-})^{1/2} + (\gamma_S^{-}\gamma_{L2}^{+})^{1/2}] \quad \text{(D.3)}$$

$$\gamma_{L3} (1 + \cos\theta_{L3}) = 2[(\gamma_S^{LW}\gamma_{L3}^{LW})^{1/2} + (\gamma_S^{+}\gamma_{L3}^{-})^{1/2} + (\gamma_S^{-}\gamma_{L3}^{+})^{1/2}], \quad \text{(D.4)}$$

for two unknowns, γ_S^+ and γ_S^- as follows:

$$(\gamma_S^+)^{1/2} = (AF - BD) / (CF - DE) \text{ and} \quad \text{(D.5)}$$

$$(\gamma_S^-)^{1/2} = (BC - AE) / (CF - DE) \ ,$$

where

$$A = \gamma_{L2} (1 + \cos\theta_{L2}) - 2(\gamma_S^{LW}\gamma_{L2}^{LW})^{1/2},$$

$$B = \gamma_{L3} (1 + \cos\theta_{L3}) - 2(\gamma_S^{LW}\gamma_{L3}^{LW})^{1/2},$$

$$C = 2(\gamma_{L2}^-)^{1/2}, \qquad D = 2(\gamma_{L2}^+)^{1/2},$$

$$E = 2(\gamma_{L3}^-)^{1/2}, \text{ and } F = 2(\gamma_{L3}^+)^{1/2}.$$

References

Good, R. J. (1993). Contact angle, wetting, and adhesion: a critical review. In K. L. Mittal (Ed.), *Contact angle, wettability and adhesion* (pp. 3-36). Utrecht: VSP.

van Oss, C. J. (2002). Use of the combined Lifshitz-van der Waals and Lewis acid-base approaches in determining the apolar and polar contributions to surface and interfacial tensions and free energies. *Journal of Adhesion Science and Technology, 16* (6), 669-677.

APPENDIX E
SURVEY FORM

Artifact Description and Pre-Adhesive Treatment Condition

Research Number:

Artifact:
flag
banner
embroidery
painting
sampler
sail
memorial picture
ribbon
lace

Institutions [subform]

Institution:
Contact Person:

Address:
Street:
City:
Province:
Country:
Postal Code:
Phone Number:
Fax:
E-mail Address:

Role:
owner
conservation lab
owner and site of treatment

Condition Report for Artifact Written before Adhesive Treatment

Is a condition report available for the artifact?
yes, with detailed information
yes, but with minimal information
no

Institution at which condition report was prepared:

Date condition report data was reviewed and entered into this survey (DD/MM/YYYY)

Condition report reviewed and entered into survey by Irene Karsten

General Description of Artifact

Accession Number:

Dimensions: length (cm) x width (cm) x depth *(if applicable)* (cm)

Date of fabrication:
[date]
no record

Other comments:

Artifact Fabric Components

Component number: *(Derive number as follows: Research number -F01, -F02, etc.)*

Component:
- main substrate
- main substrate (front)
- main substrate (back)
- lining
- interlining
- pole sleeve

Fibre Type:
- acetate
- cotton
- linen
- nylon
- rayon
- polyester
- silk
- wool
- unidentified
- no record

Fabric weave or construction:
- plain weave
- satin
- rib
- twill
- basket
- dobby
- jacquard
- knit
- leno
- lace
- net
- nonwoven
- pile
- no record

Fabric finish:
- dyed
- weighted with metal salts
- bleached
- calendered
- starched
- unidentified
- no record

Component construction:
- single piece of fabric
- pieced with stitched seams
- no record

How is component joined to other fabric components?

Is fabric component attached to adhesive support?
- yes
- no
- no record

If so, briefly describe surface to which adhesive support is attached:

Other comments:

Decorative Components

Component number: *(Derive number as follows: Research number -D01, -D02, etc.)*

Type of Decoration:
applique
embroidered
gilded
painted
printed
stencilled
supplementary weave
varnished
fringe
sequins
tassels
trim
beading
not identified
none

Materials

Fibres:
acetate
cotton
linen
nylon
rayon
polyester
silk
wool
unidentified
not applicable
no record

Metals:
copper
gold
silver
iron
tin
gold-coloured
silver-coloured
gilded
silvered
unidentified
not applicable
no record

Paints/Dyes:
acrylic
casein
gesso
gouache
natural resin
oil
paint (type unknown)
pigment
shellac
tempera
varnish
watercolour
dye (type unknown)
acid dye
mordant dye
vat dye
not applicable
no record

Other:
fabric
glass
unidentified
not applicable
no record

Location

Position:
whole surface
central area
borders
localized areas
no record

Side:
one side
both sides
no record

Is decoration present on bonded side of treated artifact?
yes
no
no record

Description of surface to which adhesive support is attached:
(neatness of embroidery stitches on the reverse, presence of paint on the reverse, etc.)

Other comments:

Pre-Treatment Condition of Fabric Component/Decorative Component

Degradation

Type	**Extent**	**Severity**	**Comments**
brittleness	general	slight	
dessication	localized	moderate	
powdering		severe	
splitting			
stiffening			
warp/weft exposed			
none			

Discoloration

Type	**Extent**	**Severity**	**Comments**
dye fading	general	slight	
discoloration	localized	moderate	
dye bleeding		severe	
dye transfer			
yellowing			
tarnish			
none			

Distortion

Type	**Extent**	**Severity**	**Comments**
creases	general	slight	
folds	localized	moderate	
planar distortion		severe	
wrinkling			
none			

Mechanical Damage

Type	**Extent**	**Severity**	**Comments**
losses	general	slight	
tears	localized	moderate	
abrasion		severe	
broken yarns			
thinning			
insect damage			
cracking			
lifting			
unravelling			
none			

Soiling

Type	**Extent**	**Severity**	**Comments**
soiling	general	slight	
staining	localized	moderate	
greasy stains		severe	
mould/mildew			
surface dust			
none			

Adhesive Treatment of Artifact

Treatment Report

Is a treatment report available for the artifact?
yes, with detailed information
yes, but with minimal information
no

Institution at which treatment report was prepared:
Date treatment report data was reviewed and entered into this survey (DD/MM/YYYY)
Condition report reviewed and entered into survey by Irene Karsten
Date adhesive treatment completed: (MM/YYYY)
Was artifact previously treated with adhesives? yes / no / no record
Reason for choosing adhesive support treatment as reported in treatment report: no record

Artifact Preparation

Was artifact disassembled before treatment?
yes
no
partially
no record

Extent of cleaning of artifact fabrics and decoration:
surface cleaning
full immersion
surface cleaning and full immersion
localized cleaning
none
no record

Surface cleaning technique:
vacuum suction
Groom/Stick
brush
swab
chemical/soot sponge
chamois
no record
not applicable

Wet cleaning liquid:
deionized water
distilled water
reverse osmosis purified water
tap water
no record
not applicable

Detergent type:	anionic non-ionic none no record	**Brand:**	Orvus WA Paste no record not applicable	**Concentration:** *(give units)*	[value] no record not applicable

Other additives:
soil carrier (anti-redeposition agent)
sequestering agent
buffer
none
no record

Solvent cleaning:
IMS
perchloroethylene
Stoddard's solvent
trichloroethylene
white spirit
no record
not applicable

Drying technique:	**Restraint during drying:**
air dried, no fans	weighted along edges
air dried with fans	pinned
blotting paper	blocked
blotting with towels	dried on glass
suction table	weighting of painted areas
hand-held blow dryer	none
drying cloth	no record
no record	not applicable
not applicable	

Other comments:

Support Fabric

Support fabric or substrate: [linked to Support Fabric subform]

Support Fabrics/Substrates [subform]

Substrate name:
(as referred to in report)

silk crepeline
Stabiltex
Tetex
Japanese paper
nylon net
none
cotton (type unknown)
polyester (type unknown)
poly/cotton (type unknown)
pongee silk
silk crepeline ribbon
down-proof cotton cambric
Belgian gauze linen
Nun's veiling
silk (type unknown)
tussah
linen (type unknown)
no record
cotton muslin
cotton (plain weave)

Fibre:

acetate
cotton
linen
nylon
rayon
polyester
silk
wool
unidentified

Weave:

basket
knit
net
plain
non-woven
satin
twill

Fabric Type:

broadcloth
crepeline
damask
georgette
organdy
paper
pongee
tulle

Scouring/stripping technique:

hand washing
machine washing
none
no record
not applicable

Scouring liquid:

deionized water
distilled water
reverse osmosis purified water
tap water
no record
not applicable

Scouring temperature:

cold
lukewarm
warm
hot
very hot
no record
not applicable

Detergent type:

anionic
non-ionic
commercial
none
no record
not applicable

Brand:

Orvus WA Paste
no record
not applicable

Concentration:
(give units)

[value]
no record
not applicable

<u>Support Fabric</u> (con't)

Method of colouring support:
conservation dyed
custom dyed
hand-painted
screen printing
manufacturer dyed
none
no record

Extent of colouring:
entire support
partial
no record
not applicable

Dye type:
acid
azoic
basic
direct
disperse
metal-complex
mordant
reactive
fabric paint
acrylic
none
no record
not applicable

Brand:
Irgalan
Lanaset
Telena
no record
not applicable

Dyeing temperature:
cold
lukewarm
warm
hot
very hot
no record
not applicable

Drying technique:
air dried, no fans
air dried with fans
clothes dryer
no record
not applicable

Restraint during drying:
weighted along edges
pinned
dried on glass
none
no record
not applicable

Number of support fabric pieces used to construct adhesive-coated support:
one
two
a few
several
no record
not applicable

Describe method of joining support fabric pieces:
overlapped slightly during heat-sealing
stitched
no record
not applicable

Grain direction relative to artifact grain:
aligned
on bias
mixed
no record

Other comments:

Preparation of the Adhesive Solution

Adhesive: [linked to Adhesives subform]

Adhesives [subform]

Type:
- dispersion
- resin
- solution

Class:
- synthetic
- cellulosic
- proteinaceous

Brand:
- Acryloid F10
- Appretan MB extra
- Beva 371
- Beva 371 film
- Beva D8
- Clariant T1460
- Clariant T1601
- Elvace 1874
- Jade 403
- Lascaux 360 HV
- Lascaux 498 HV
- Lascaux P550-40TB
- Mowilith DM5
- Mowilith DMC2
- Paraloid F10
- PVA dispersion
- PVA resin
- unidentified
- Vinamul 3252
- Vinnapas EP1

Alternate Names:

Polymer:
- acrylic copolymer
- ethylene/vinyl acetate copolymer
- poly(vinyl acetate) homopolymer
- vinyl acetate/acrylic copolymer
- vinyl acetate/butyl maleate copolymer
- vinyl acetate/ethylene copolymer

Manufacturer:

Polymer ingredients:

Known additives:

References to adhesive composition:

Amount used to prepare solution:
- [value]
- no record

units:
- percent (volume)
- percent (weight)
- part (mass)
- part (volume)
- mL
- g
- tablespoons
- no record

Age of adhesive (time since purchase):
- one month
- six months
- one year
- more than one year
- no record

Solvent type:
- acetone
- distilled water
- ethanol
- IMS
- petroleum spirits
- Stoddard's solvent
- toluene
- VM&P naptha
- water
- white spirit
- xylenes
- none
- no record

Amount used to prepare solution:
- [value]
- no record

units:
- percent (volume)
- percent (weight)
- part (mass)
- part (volume)
- mL
- g
- tablespoons
- no record

Other comments:

Adhesive Coating Technique

Tool used to apply adhesive:
- aerosol sprayer
- brush
- bristle brush
- sponge brush
- polybrush
- roller
- sponge
- sprayer
- no record
- not applicable

Method of constraining support fabric:
- hook and loop tape
- pins
- pressure-sensitive tape
- stretcher frame
- weights on one end
- weights around perimeter
- V&A net table
- none
- no record
- not applicable

Release material used under support fabric:
- polyester film (Mylar, Melinex)
- polyester film, mil
- polyethylene film
- silicone-coated polyester film
- silicone release paper
- Teflon-coated glass cloth
- none
- no record
- not applicable

Number of coats:
- 1
- 2
- no record

Sides coated:
- one side
- both sides
- no record

Environment during adhesive drying:

Relative humidity (%):
- [value]
- no record

Temperature (degrees C):
- [value]
- no record

Drying time before heat-sealing:
- [value]
- no record

units:
- days
- months
- years
- not applicable

Description of coating:
- continuous film
- coated yarns with partially filled interstices
- coated yarns
- partially coated yarns
- flocked strands
- dust-like coating
- dot matrix
- no record

Adhesive add-on (g adhesive/square metre support):
- [value]
- no record

Other comments: [describe briefly any observations or conjectures regarding the above aspects of the artifact or treatment that might influence the success of the treatment; give reasons for all conjectures]

Heat-sealing Technique

Source of heat:
domestic iron
tacking iron
spatula
hot air gun
vacuum hot table
no record

temperature
units

Temperature: [value] **degrees** C
F

Method of determining temperature:
instrument dial/digital readout
thermocouple
temperature indicator strips
not measured
no record

Was temperature determined through layer of release material?
yes
no
no record
not applicable

Instrument setting if temperature was not recorded:
[value]
no record

Pressure:
[value]
no record
not applicable

units
mm Hg
in Hg
psi
no record
not applicable

Time heat and pressure applied (seconds):
[value]
no record

Release material:
(between artifact/support and heat source)
polyester film (Mylar, Melinex)
silicone release paper
Teflon-coated glass cloth
no record

Surface heat applied to:
artifact side
support fabric side
no record

Surface under artifact:
polyester film (Mylar, Melinex)
quilt pad
silicone rubber pad
silicone release paper
table felt
no record
not applicable

Was adhesive removed from exposed areas?
yes
no
no record
not applicable

Describe technique used to remove adhesive:

Other comments: [describe briefly any observations or conjectures regarding the above aspects of the artifact or treatment that might influence the success of the treatment; give reasons for all conjectures]

Additional Treatment, Mount, Storage, and Display of Artifact

Supplementary Support Fabrics

Support fabric component:
overlay/facing
overlay patch
secondary support fabric
display mount cover fabric
lining
patches
none
no record

Fabric type: [link to Support Fabrics/Substrates subform]

Method of colouring fabric:
undyed
conservation dyed
conservation painted
manufacturer dyed
no record

Method used to attach artifact to support fabric component:
stitching
adhesive
pressure mount
no record
(List all that are necessary to maintain direct or indirect attachment of the artifact to a support fabric component)

Other comments: [describe briefly any observations or conjectures regarding the above aspects of the artifact or treatment that might influence the success of the treatment; give reasons for all conjectures]

Supplementary Stitching

Was supplementary stitching done? *(if yes, tick box and complete the rest of this form)*
(Consider supplementary stitching in levels according to the fabric components that are joined by the stitching)

Supplementary stitching worked from:
foremost fabric component
facing/overlay
facing patch
artifact
primary adhered support

through to :
rearmost fabric component
artifact
primary adhered support
secondary support
display mount cover
lining
patch

Stitching thread: [Link to Threads subform]

Method of colouring thread:
undyed
conservation dyed
manufacturer dyed
no record

Stitch type:
couching
hemming
overcasting
running
no record

Approximate distance between lines of stitching
[give approximate value]
no record
not applicable

Stitch location:
along perimeter of artifact
along seams of artifact
through body of artifact
through losses or around edges of artifact fragments
localized weak areas
around decoration
along edges of foremost support fabric
no record

Other comments: [describe briefly any observations or conjectures regarding the above aspects of the artifact or treatment that might influence the success of the treatment; give reasons for all conjectures]

Supplementary Stitching (con't)

Threads [Subform]

Stitching thread:
(as referred to in report)

cotton unidentified
Cotton Zwicky Ursus
embroidery floss
hair silk
linen, type unknown
machine embroidery, cotton
no record
polyester buttonhole twist thread
polyester Stabiltex yarns
polyester Tetex yarns
polyester thread (Gutermann)
silk (unidentified)
silk crepeline yarns
Silk finish' mercerized cotton
Skala

Fibre:

acetate
cotton
linen
nylon
rayon
polyester
silk
wool

Brand:

DMC
Gutermann
Mettler
not applicable
unidentified

Other Treatments given to the Artifact

Describe treatments given to the artifact other than adhesive support, supplementary support and stitching, and mounting techniques.

Type of treatment:

fibre consolidation
paint consolidation
humidification
not applicable

Time of treatment relative to heat-sealing:

before heat-sealing
after heat-sealing
before and after heat-sealing
no record

Briefly describe materials and techniques used in treatment:

Other comments: *(include observations of why the treatment might affect the efficacy of the adhesive support treatment)*

Storage/Display Mount or Method

Display method:
mounted on rigid board
mounted on rigid board and framed
hung from wooden slat/support
no record
not applicable

Mounting board or support:
acid-free cardboard
aluminum honeycomb board
Coroplast
ethafoam
Fome-cor
Gatorboard
acid-free matboard
sealed plywood
strainer
original support [describe]
none
no record

Method used to attach cover fabric to mount board:
stitching
adhesive
staples
no record
not applicable

Frame type:
sealed wood
aluminum
none
no record
not applicable

Glazing material:
glass
UV-filtering glass
acrylic sheet (Plexiglas/Perspex)
UV-filtering acrylic sheet (Plexiglas)
none
no record
not applicable

Other comments: [describe briefly any observations or conjectures regarding the above aspects of the artifact or treatment that might influence the success of the treatment; give reasons for all conjectures]

Storage/Display History of Artifact

Location of artifact since treatment:
storage
static display/exhibition
travelling exhibition
no record

Months at location since treatment completed:
[value]
no record

Environment

Control of environment at location:
none
partial
full
not ascertained

Temperature range (degrees C):
[value/range]

Relative humidity range (%):
[value/range]

Lighting

Type of lighting:
daylight
fluorescent
incandescent
fibre optic
halogen
not ascertained

Level of lighting:
low
high
intermittent
not ascertained

UV radiation filtered?
yes
no
not ascertained

Method of storage and handling at location:

Other comments: [describe briefly any other factors that may be pertinent to the present condition of the artifact, including here any conjectures regarding storage and display that might account for the artifact's current condition along with the basis for such conjectures]

List all sources of information regarding storage, display and/or handling at this location:

Present Condition of Treated Artifact

Examination

Artifact examined date: (DD/MM/YYYY)

Months since treatment completed:
[recorded]
[estimated]
no record

Artifact examined by: Irene Karsten
Institution where examination took place: [linked to Institution form]
Location of artifact during examination:
storage
display

Artifact access during examination:
behind glazing
rigid mount, front surface accessible
rigid mount, front and some back surface accessible
flexible mount, front surface accessible
flexible mount, front and some back surface accessible
not mounted

Photography

Photographs taken during examination: *(check if yes)*
Date photographs taken: (DD/MM/YYYY)
Subject of photographs:
Description of details:

Other comments:

Type of photographs:
colour slides
colour photographs
B&W photographs
colour photomicrographs
B&W photomicrographs
digital images

Artifact and Support Fabrics

Support fabric component:
facing/overlay
facing patch
artifact
primary support fabric
secondary support fabric
display mount cover fabric
lining
patch

Extent of deterioration since treatment:
none
localized
general

Extent of planar distortion since treatment:
none
localized
general

Discoloration since treatment:
none
localized
general

Evidence of deterioration:
[give concise description]
Location of deterioration:
[give concise description]
Evidence of planar distortion:
[give concise description]
Location of planar distortion:
[give concise description]
Evidence of discoloration:
[give concise description]
Location of discoloration:
[give concise description]

Indicate which changes are due to adhesive: *(Give reasons for your interpretation)*
Other comments:

Condition of Supplementary Stitching

(Consider supplementary stitching in levels according to the fabric components that are joined by the stitching)

Supplementary stitching worked from:			**through to :**
foremost fabric component	facing/overlay facing patch artifact primary adhered support	**rearmost fabric component**	artifact primary adhered support secondary support display mount cover lining patch

Condition of stitching: sound localized deterioration general deterioration	**Evidence of deterioration:** [give concise description] **Location of deterioration:** [give concise description]

Other comments:

Condition of Adhesive and Adhesive Bond

Extent of bond failure	none localized general not ascertained	**Evidence of bond failure:** [give concise description] **Location of bond failure:** [give concise description]

Surface exhibiting adhesive residue after bond failure:

primarily on support fabric	no residue visible
primarily on artifact	not ascertained
on both support and artifact	

Reason for bond failure: [record any hypotheses (e.g. poor treatment technique) and evidence to support each]

Tack of exposed adhesive:	none slight high not ascertained	**Adhesive flexibility:**	brittle flexible stiff not ascertained
Dust on exposed adhesive:	none apparent slight	substantial not ascertained	

Extent of discoloration: none localized yellowing general yellowing not ascertained	**Evidence of discoloration:** [give concise description] **Location of discoloration:** [give concise description]

Other problems caused by adhesive: [give concise description]
Other comments:

Efficacy of adhesive support treatment: [state and give reasons for your opinion on whether the adhesive support treatment did or did not contribute to the preservation of the artifact]

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March 13, 2003

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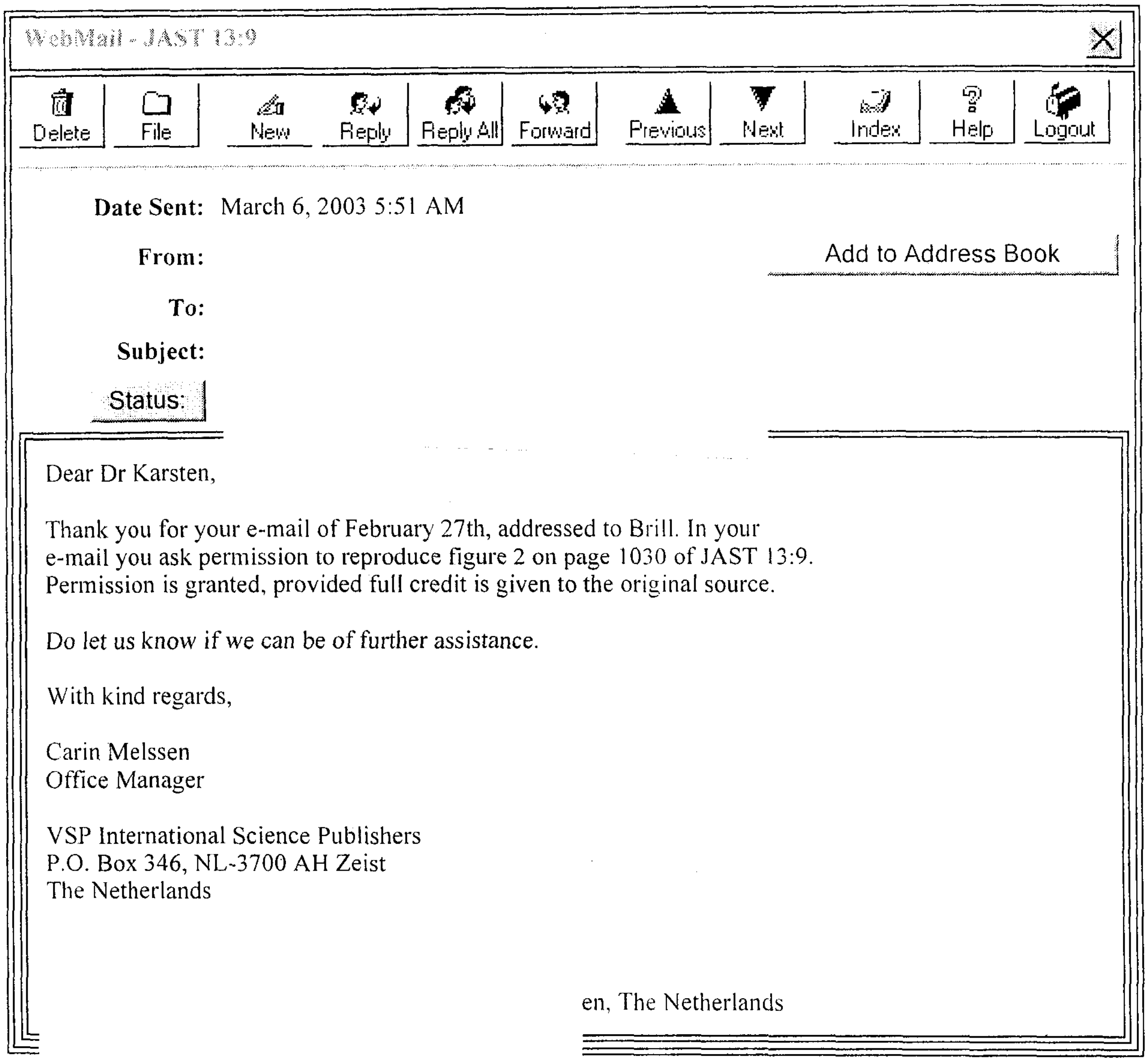

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