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Abstract

The time dependent deformation of coal under a constant load can be described adequately by the sum of two power laws:

$$\dot{\epsilon} = At^{B} + Ct^{D}$$

where $\dot{\epsilon}$ is the strain rate

t is the elapsed time since the material has been under the constant load

A, B, C and D are constants.

The attempt to find the stress dependence of the creep rate of a model coal pillar was frustrated by the variability of the material. The Young's Modulus, E, of coal can vary widely within a relatively small area, which indicates that samples from the same sampling site can have much different deformation properties.

Cruden (1983) suggested that the stress dependence of creep rate can be determined by an increment test on a single rock specimen. Such a test eliminates variation caused by variation of physical properties between specimens. Further research, using this type of test might allow the determination of the physical parameters controlling the creep of coal.

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1. Introduction

1.1 Introductory Remarks

The study of time-dependent effects, usually spoken of under the general title of 'creep', is of the greatest importance in rock mechanics and geophysics. The phenomenon of time-dependent behaviour of rocks is a source of many problems in designing structures in rock. In underground work, the movements which occur after excavation are of creep type and the requirement is to find laws by which future behaviour may be predicted.

Since the original work by Andrade (1910), who studied the behaviour of metal wires subjected to constant tensile stress above the elastic limits, there has been developments of the time-dependent theory covering both a wide range of materials (such as metals, rubber, ice, soils and rocks) and applications (such as civil, mining and mechanical engineering, etc.). There are many useful reviews of creep of rocks by Robertson (1964) and Murrell and Misra (1961) and others. Time-dependent behaviour in several rocks has been studied both in the laboratory and in-situ. The decelerating strain rate period of creep has been well studied and several creep laws were developed, but there were no report on the accelerating strain rate period known to the author.

There are several creep equations for rocks published in for example Obert and Duvall (1967), Cruden (1971), Jaeger (1972). The power law proposed by Cruden (1970) is used in this thesis for two reasons: firstly, there are existing programs to reduce and fit the experimental data into the power law; and secondly, to present the hypothesis that accelerating strain rate period also follow the power law. Coal was chosen as the testing material because it is a rock-like material.

1.2 The Objective of the Study

The objectives of this study are:

a. To determine the functional form of the creep of a model coal pillar.

b. To confirm the functional form of creep by a large number of short experiments.

c. To use these experiments to check whether there is a critical creep strain for model coal pillars.

1.3 Structure of Thesis

Because the basic creep theory can be found in many rock mechanics books, therefore it is not presented in great detail here. Also, no detailed review on developments in creep theories is included as it had been done in previous research work by da Fontoura (1980).

Chapter two consists of a description of the testing program. It gives a detailed account of the sampling site and procedures. The method used in sample characterization and the testing equipments are also described.

Chapter three reports the method used in data analysis and problems that had been encountered. Results from the Star-Key Coal Mine test, which was conducted by Jeremic (Personal Communication), are also presented.

In Chapter four, results from the testing program are presented. A comparison of test results to those reported by da Fontoura is also included.

Finally in Chapter five, discussion of test results and conclusions are presented.

2. Preparations for Laboratory Tests

2.1 Sampling Site and Procedures

The coal samples used in the present study were obtained from the coal seams exploited at the Highvale Mine, which is situated on the south shore of Wabamun Lake. The Wabamun Lake district is west of Edmonton, Alberta in Tps. 50-54, Rs. 3-7, W. 5th Mer., and is centered about Wabamun Lake.

The geology as well as the topography and drainage of the area in the proximity of the sampling site have been described by Pearson (1959) and Noonan (1972). The coal unit is referred to as the Pembina Coal-bearing zone by Pearson (1959), and is sub-divided into several seams in the vicinity of Wabamun Lake. The coal-bearing unit can be divided into two main seams with a few thinner seams below. The two main seams are generally about three metres thick and are separated by an interval, from a few centimetres to ten metres of shale and sandstone. The thick seams have been termed the Upper Main and Lower Main seams (Pearson, 1959).

The coal seams at Highvale Mine are exploited by a conventional strip-mining operation. The till cover is removed by a dragline leaving the coal seam exposed and light explosive charges are set in boreholes to loosen the coal, thereby facilitating the mining operation.

Observations of the blast holes exposed along the face of the bench were made by Noonan (1972), who indicated that the visually detectable shatter-zone extended in a fan-like arrangement only about 45 cm from the point where the charge was detonated. Hence, only few, if any, additional fractures would be created at the top of the seam as a result of blasting.

Sampling was carried out on top of the exposed Lower Main seam. A water-operated laboratory drilling machine, manufactured by the Milwaukee Electric Tool Corp., with a core barrel of about 7.5 cm in external diameter was used in the coring operations. Reaction against the weight of the field vehicle was provided for the drilling machine in order to avoid unwanted vibration of the core barrel that could damage the core. Cylindrical cores of about 7 cm in diameter were drilled in the site.

Problems were encountered during the coring operations. The fracturing in zones inside the coal seams prevented the successful coring of samples because of breakage of the core. Also, partings inside the coal seams caused cores to separate into lengths which were less than the minimum requirement of length to diameter ratio of 2 to 1. Only one out of three sampling trips was successful where the coal seam is more intact and relatively free of partings. Two days were spent for the successful sampling trip and a total of twenty-seven samples were obtained.

2.2 Sample Preparation

After the samples were drilled at the site, the cores were removed manually by pushing them from the core barrel and carefully wrapped with Saran Wrap and aluminum foil to prevent moisture loss. Samples were then put into boxes and field work clothes were put between layers of samples to minimize the possibility of breakage during transportation to the laboratory.

After transporting the test samples to the laboratory, they were stored in a moist room at 5°C and 100% relative humidity to await trimming. The samples were cut into desired lengths using a Northland concrete saw manufactured by Oxford Machine and Welding Co. Ltd. of Edmonton, Alberta. The saw has a blade diameter of 60 cm and water was used as cutting fluid. The criterion used in selecting the length of the sample was to keep the length to diameter ratio at around 2 to 1. Special wooden holders were manufactured to hold the samples in the cutting machine. The wooden holders were made from two pieces of wood of size 200 mm W x 150 mm H x 63.5 mm T. A segment of circle, with the same diameter as the samples, was cut from the face of each piece of wood in order to accomodate the sample. Finally, the wooden holders were covered with a layer of roofing tar, a water-proof material, to prevent the swelling of the wood. Coal samples were first wrapped with a rubber membrane before being put in between the wooden holders. The rubber membrane, the same type used for any triaxial tests, acted as a shock-absorbing medium to minimize unwanted vibrations while samples were being cut with the saw to provide some confinement of sample.

After fine-tuning the adjustable alignment of the concrete saw and the sample holders, samples could be cut with acceptable parallelism of the end surfaces. The parallelism was measured by a dial gauge which was connected to a smooth level platform. By turning the sample on the smooth level platform with the dial gauge arm touching the sample's top end, the maximum difference of parallelism could be determined. All the samples used in testing had their ends parallel to each other within the tolerance limit of 0.25°, i.e., to within approximately 5 mm/m (Pit Slope Manual, Supplement 3-5, 1977).

2.3 Sample Characterization

There were two different sources of coal samples used in this study. The first source was samples obtained from the sampling site, which were drilled perpendicular to the bedding planes, as illustrated in Figure 2.1. The second source was samples not used by da Fontoura (1980), which were drilled from a block sample with their long axis parallel to the bedding planes and at an angle of 30° to the major cleat, as shown in Figure 2.2. A detailed structural survey, conducted by Noonan (1972) concluded that the major cleat in the coal seam is oriented approximately N45°E. Thus the configuration of the samples from the second source

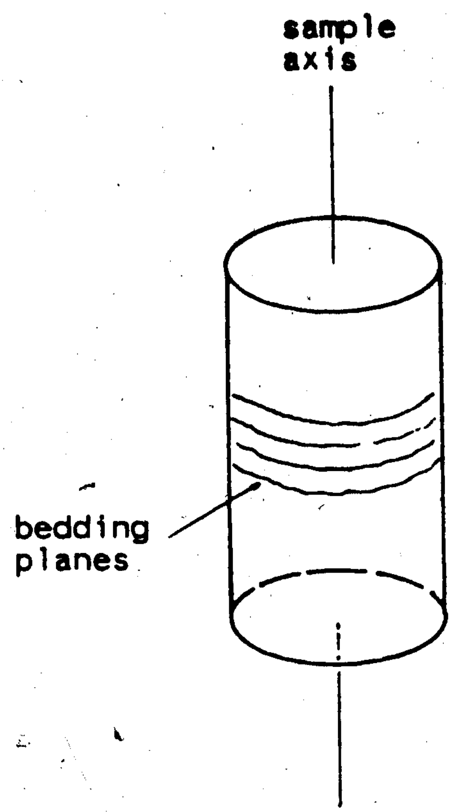


Figure 2.1 Coal structure of samples from the sampling site

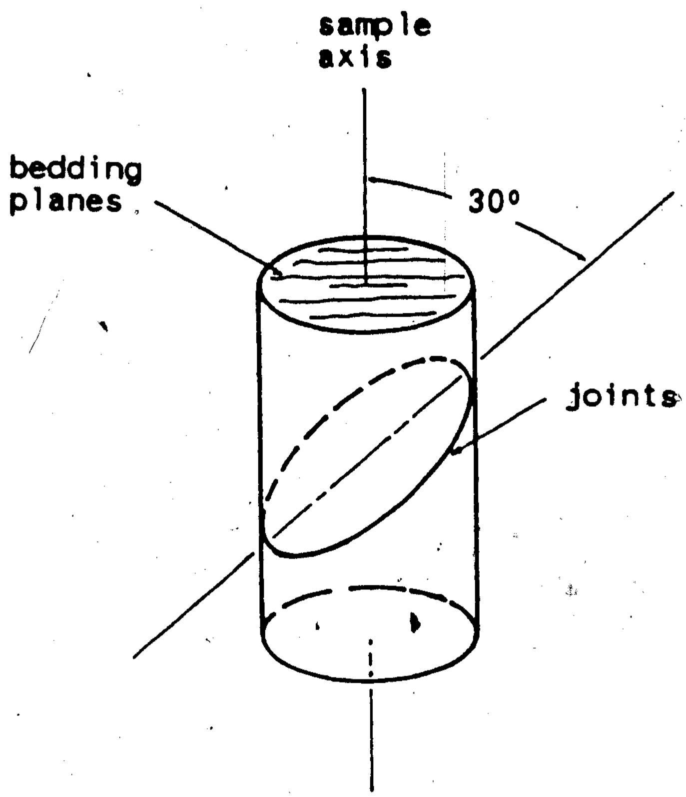


Figure 2.2 Coal structure of da Fontoura's samples

would correspond to a sample with its core axis horizontal and oriented either at N15°E or N75°E in the field.

Both types of samples were prepared and cut into desired lengths as outlined in Section 2.2. Specimen weight and dimensions were recorded, and sample volume and density were then calculated. The samples were characterized by measuring the velocities of compressional, Vp, and shear, Vs, elastic waves through each sample. The Young's Modulus, E, of each sample could then be determined from the following equations (Jaeger, 1962):

$$Vp=[(\lambda+2G)/\rho]^{1/2} \quad (2.1)$$

$$Vs=(G/\rho)^{1/2} \quad (2.2)$$

$$E=G(3\lambda+2G)/(\lambda+G) \quad (2.3)$$

where λ and G are Lame's parameters and ρ is the density of the sample.

The velocities of compressional, Vp, and shear, Vs, elastic waves were determined by dividing the length of the sample by the time for the respective wave to travel through the sample. Each sample was clamped between a set of compressional sonic heads and shear sonic heads in order to measure the time for the compressional and shear elastic waves, respectively, to travel through the sample. Vaseline was used as a conducting agent between the heads and the sample in both cases. Sonic waves were sent from one head to the other through the length of the sample by a Terrametrics

Sonic Pulse Generator. The times were measured by a oscilloscope manufactured by Gould Advance Ltd., England.

Before the apparatus were used to determine the velocities of compressional and shear elastic waves through the coal samples, a calibration test was done by using aluminum cores. Aluminum cores of five, ten and twenty centimetres in length were used and the time of compressional and shear wave travel were determined in the same way as outlined above. Vaseline was also used as conducting agent between the heads and the core. Plots of distance travelled against time were made for compressional and shear waves, and the velocities were determined as the slope of the straight line of the respective plots. The Young's Modulus, E, of aluminum was determined by using Equations (2.1) to (2.3). The calculated Young's Modulus of aluminum is within 4% of the published value.

Despite the accuracy in determining the Young's Modulus of aluminum, errors could arise in many different ways. The time of travel of waves is slightly affected by the amount of vaseline used and also the clamping force. The time of travel is also subject to error in reading the time from the oscilloscope. Since coal is a heterogeneous material due to its composition and because of its discontinuous nature (Kaiser and Maloney, 1982), it is more difficult to determine the time of travel through coal than aluminum. Time error accounts for most of the errors that arise in sample characterization. From Equations (2.1) to (2.3), the

Young's Modulus, E, can be written in terms of Vp and Vs as

$$E = \frac{\rho Vs^2(3Vp^2-4Vs^2)}{Vp^2-Vs^2} \qquad (2.4)$$

It is obvious that the value of Vs can affect the value of the Young's Modulus, E, to a great extent. Also, the error in Young's Modulus is greater than the error in Vs as E is directly proportional to the square of Vs.

The results of sample characterization are summarized in Table 2.1. The last five samples in Table 2.1, T6A to T6J, are samples left over from da Fontoura (1980). Since these five samples were drilled in a different orientation from the others, and the differences were reflected in the results of sample characterization. Da Fontoura's samples were drilled parallel to the bedding planes and yielded higher values of compressional and shear wave velocities as the waves propagate parallel to the bedding and only have to cross the joints. Samples from the sampling site were drilled perpendicular to the bedding planes, they yielded lower values of compressional and shear wave velocities because the waves have to propagate across the bedding planes. Samples drilled parallel to the bedding planes tend to fail in shear failure along the joints or by buckling along individual bedding planes. For samples drilled perpendicular to bedding planes, cracks will be closed by

SAMPLE NUMBER	HEIGHT (mm)	DENSITY (gm/cm^3)	Vp (mm/sec)*10**6	Vs	E (MPa)
9-9#4	152.40	1.386	1.051	0.331	440
9-9#7	148.59	1.376	1.025	0.346	472
9-9#8	152.40	1.424	0.952	0.331	447
9-9#9	152.40	1.415	1.051	0.346	488
9-9#11	152.40	1.385	0.847	0.339	446
9-9#15	152.40	1.365	0.762	0.311	370
9-9#17	152.40	1.380	1.016	0.331	436
9-9#21	155.83	1.380	1.113	0.362	522
10-9#2	156.59	1.371	1.205	0.356	504
10-9#4	150.62	1.358	1.076	0.335	440
10-9#5	152.40	1.372	0.802	0.324	405
10-9#9	165.10	1.378	0.869	0.324	410
T6A	158.75	1.354	1.556	0.588	1330
T6C	157.63	1.347	1.659	0.788	2270
T6D	139.70	1.380	1.683	0.698	1880
T6F	149.23	1.351	1.696	0.829	2490
T6J	161.93	1.326	1.513	0.771	2090

Table 2.1 - Summary of Sample Characterization

compression and rupture by crushing.

2.4 Testing Equipment

A simple double-lever arm rig capable of applying a constant axial load, maximum capacity of 183 kN, was used for the series of creep tests reported here. The double-lever arm rig outlined in Figure 2.3, was originally designed and built for da Fontoura (1980). The rig consists of a reaction frame and two lever-arms (I-Section) which would transfer loads applied at their ends through a loading ram to the sample. The mechanical magnification for the double-lever arm system was 7.5. Before loading the sample, hydraulic jacks were used to support the weight at the ends of the lever-arms. The positions of the two hydraulic jacks is illustrated in Figure 2.1. Sudden loading was achieved by releasing the hydraulic jacks simultaneously.

The creep rig presented a problem when high axial load was required, large number of weights had to be put on the hangers. In order to achieve sudden loading, the hydraulic jacks supporting the weights had to be released simultaneously. If the hydraulic jacks were released one at a time, the weights on one of the hangers would cause instability of the creep rig. It would be desirable to widen or stabilize the base of the creep rig and thus to eliminate the instability problem.

A triaxial cell for 10 cm diameter samples was modified in order to accomodate 7 cm diameter samples by changing

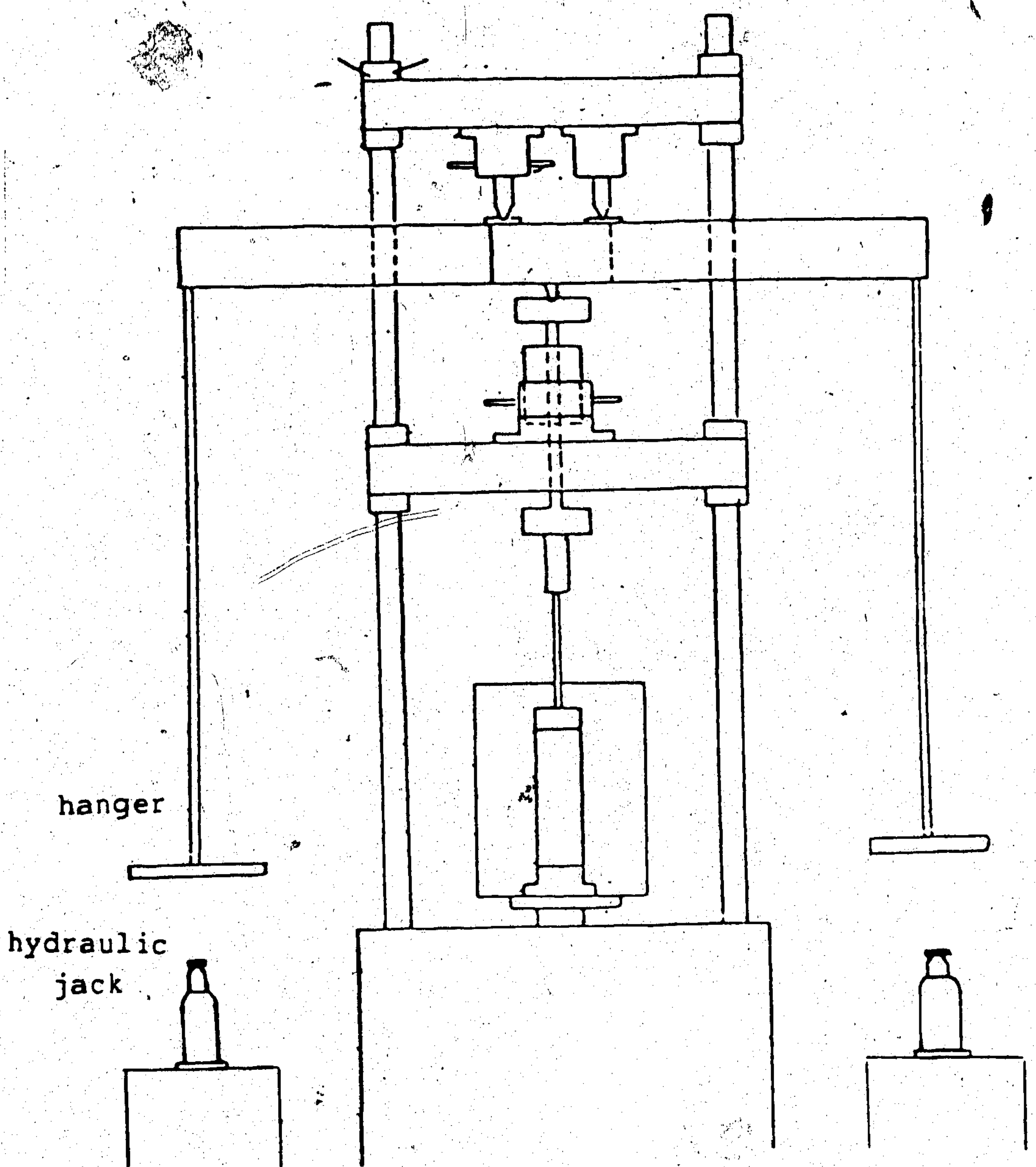


Figure 2.3 Sketch of creep rig

both the top cap and the bottom pedestal. Special Thompson linear bushings were used to guide the loading ram with minimal shaft friction. The triaxial cell used had drainage for the sample provided at both top cap and bottom pedestal.

A unit for monitoring axial load, displacement, and confining pressure complemented the laboratory set-up. This unit is a Hewlett Packard 3054 data logger which consists of a HP3497A data aquisition unit and a HP85 computer. The HP85 computer, which can be programed to take readings at a preset time-interval, has a built-in tape recording device and is capable of storing all the information in the tape. A more efficient HP82901M Flexible Disc Drive Unit was later introduced to replace the tape recording device. The HP85 computer is compatible with the Michigan Terminal System (MTS) at the University of Alberta, and data can be transferred directly from the tape or disc through the HP85 computer to the MTS for analysis.

The axial displacements of the samples were measured with two Linearly Variable Differential Transformers (LVDTs) manufactured by Hewlett Packard. Initially two 24DCDT-050 LVDTs with a displacement range of ±1.27 mm were used. However, it was found that the displacement of the sample was greater than the displacement range of the LVDTs. The two DCDT-050 LVDTs were then replaced by a pair of 24DCDT-100 LVDTS with a displacement range of ±2.54 mm. The axial load was measured with a Transducer Load Cell, manufactured by Transducer Inc., California, U.S.A., with a capacity of 45 kN (10,000 pounds). The confining pressure was measured with a transducer, manufactured by Celesco Trans Product Inc., California, USA, Model PLC with a capacity of 691 kPa (100 psi). A power supply unit capable of providing input voltage of 6 Volts was used to feed the load cell and the transducer. Another power supply unit was used to supply a 24 volts input voltage to the LVDTs.

The LVDTs, load cell and transducer were calibrated before being used and no change in the calibration factors was observed during the experimental program. The testing apparatus was kept in a temperature and humidity-controlled room, Room B21A in the Civil Engineering Building, capable in keeping the temperature variations within 2°C and the humidity within 5%.

Even though the testing room was temperature and humidity controlled, there were slight variation in temperature and humidity between day and night. Equipment with high sensitivity such as the LVDTs, were affected the most and this caused the scattering of data. Generally, from the read out of the LVDTs, the deformation of a sample under stress would be larger during the day and smaller during the night. This problem could be solved with a more effective and sophisticated way of temperature and humidity control, however, at a larger expense.

2.5 Testing Procedures

There were three different types of tests carried out in this experimental program. The first type was tests with confining and back pressure, referred to as the C-tests. Prior to set-up, each sample was enclosed within a double rubber membrane as an extra precaution to avoid leakage in case one membrane was punctured during the test. Double O-rings and screw clamps were used to provide extra seals along the contacts between membrane and both top cap and pedestal. Both confining and back pressure were applied before the sample was loaded.

The second type of test was the uniaxial compression test. The tests were carried out in the modified triaxial cell with no rubber membrane and no cell fluid. This type of tests was referred to as the U-tests.

The third type of test was with no rubber membrane on the sample and using small confining pressure, referred to as the S-tests. Prior to set-up, each sample was saturated by submerging it in water for about 24 hours. This type of test was carried out because the samples were too strong for failure under short term creep, thus samples had to be weakened by saturation.

For all the tests reported herein, sudden loading was obtained by opening the valves on the two hydraulic jacks that were supporting the weights. The duration of the creep tests ranged from three days to more than two weeks. None of the samples failed under the constant axial load during creep tests.

In the testing program, some samples were used for several creep tests. After each test, the sample was carefully removed from the testing apparatus and wrapped in Saran Wrap and aluminum foil to prevent moisture loss. A minimum recovery period of 24 hours was allowed for samples to be used in successive tests. Thus, each test performed in the testing program could be treated as individual single stage creep test. A single sample was used for tests CT6A1 to CT6A9. After each test was terminated, the sample was unloaded but remained in the triaxial cell for 24 hours before another test was carried out with a higher load.

Table 2.2 is a table of tests that were carried out in this testing program, the load and duration of each test are also indicated. The first letter of the name of each test represents the type of test. It is followed by the sample number, as listed in Table 2.1. The number following the sample number represents the number of times the sample is loaded. For example: CT6A is a confined test with sample T6A and it is the first time loading. UT6F2 is a uniaxial compression test with sample T6F and it is the second time loading.

Table 2.2 Table of tests

Test	Axial Load (kN)	Duration (Hours)
CT6A1	7	90
CT6A2	10	121
CT6A3	10	144
CT6A4	12	120
CT6A5	15	150
CT6A6	15	141
CT6A7	15	98
CT6A8	18	67
CT6A9	21	96
C9-9#8	15	93
C9-9#9	20	71
U9-9#9	25	168
U9-9#11	24	70
U9-9#17	16	71
U9-9#21	24	94
U10-9#2	27	92
UT6F	7	70
UT6C	11	70
UT6D	10	72
UT6F2	9	187
UT6D2	10	71
UT6D3	11	163
S9-9#7	20	360
S9-9#9	17	144
S9-9#11	22	142
S9-9#15	15	166
S9-9#17	15	166
S9-9#21	20	142
S10-9#2	16	148

3. Creep Behaviour from Laboratory Tests

3.1 Analysis of Creep Data

There are two steps in the analysis of laboratory tests which are of equal importance. First, the presentation and conditioning of the experimental observations and second, the analysis of the processed data.

The displacement of the sample was measured at a number of times after the application of the load, it was then transformed into engineering axial strain, ϵ_i, by the following expression:

$$\epsilon_i = (L - L_i)/L \tag{3.1}$$

where L represents the initial length of the sample and L_i is the length of the sample at the time when the reading is taken.

The interpretation of creep data is done basically in terms of strain rate, $\dot{\epsilon}$, which is the change of total strain, ϵ, per unit of time. The definition of strain rate can be expressed mathematically as in equation (3.2),

$$\dot{\epsilon} = \Delta\epsilon/\Delta t \tag{3.2}$$

Since the total strain is known only at certain times, t_i, the estimation of the strain rate has to be done by numerical differentiation. The simplest approach would be to approximate the strain rate, $\dot{\epsilon}_i$, at time $T_i = (t_{i-1} + t_i)/2$ by $(\epsilon_i - \epsilon_{i-1})/(t_i - t_{i-1})$. This approach, however, presents some difficulties. Small fluctuations in the output voltage of the LVDTs and also temperature caused some observations of strain, ϵ_i, at time t_i to be smaller than the observations, ϵ_{i-1}, at time t_{i-1}, which corresponds to a negative strain rate.

Cruden (1969) proposed to smooth the original observations using recursion formulae. If ϵ_i is less than ϵ_{i-1}, a new observation $E_{i-1} = (\epsilon_i + \epsilon_{i-1})/2$ is defined associated with a time $T_{i-1} = (t_i + t_{i-1})/2$. The new observation, E_{i-1}, is given a weight, W_{i-1}, which is equal to the sum of w_i and w_{i-1}. For the original data, all observations have a weight, w_i, equal to unity. This process is followed until all the observations, E_i, are such that every strain is greater than the previous ones. From the new set of observations, (E_i, T_i), the strain rates are calculated using the simple approach mentioned earlier in this section.

The process of creep deformation can be divided into two main regions. Initially, it is characterized by a decreasing rate of strain, this is called the decelerating creep region. There follows a stage where the rate of creep strains increases with time and eventually leading to failure. This region is known as the accelerating creep region.

Cruden (1971a) suggested that the decelerating creep could be adequately described by a power law. The power law relationship between strain rate and time was represented by Equation (3.3), where $\dot{\epsilon}$ is the strain rate, A is a constant which is stress dependent and B is a strain-hardening parameter.

$$\dot{\epsilon} = At^{-B} \tag{3.3}$$

This equation is represented by a straight line with a negative slope in a double logarithm plot of strain rate versus time.

It is believed that the accelerating creep can be represented by a similar power law except with a positive power, i.e., the straight line representing the accelerating creep in a double logarithm plot of strain rate versus time will have a positive slope. Thus, the entire creep curve might be represented by two power laws as in equation (3.4):

$$\dot{\epsilon} = At^{B} + Ct^{D} \tag{3.4}$$

where the first term on the right hand side would describe the decelerating creep and the second term describes the accelerating creep.

3.2 Problems Encountered in Data Analysis

Experimental observations obtained from laboratory testing were collected and processed as outlined in Section 3.1. The time and strain rate were calculated accordingly. To fit the experimental data into the form of Equation (3.4), the BMDP Statistical Software was employed. The BMDP Statistical Software is prepared by the Department of Biomathematics, University of California, Los Angeles. It is available as one of the statistical package at the University of Alberta.

The BMDP computer programs (Dixon, 1981) are designed to aid data analysis by providing methods ranging from simple data display and description to advance statistical techniques. Data are usually analyzed by an iterative 'examine and modify' series of steps.

There are two BMDP computer programs for non-linear regression, namely the P3R and PAR programs. To use these programs, a main program using the BMDP Instruction Language had to be written. The main program gives the location of the input data, the initial estimates of the parameters A, B, C and D and most importantly, the specific function required. Table 3.1 gives a listing of a sample program using the BMDP Instruction Language.

Program P3R gives least squares estimates of the parameters of a non-linear function. Six functions (and their derivatives) are built-in. Other functions can be fitted to the data by specifying both the function and its

Table 3.1 Listing of a sample program using the BMDP instruction language

```
/PROBLEM      TITLE IS 'STAR-KEY COAL MINE NO.=5'.
              ERRLEV IS STRICT.
/INPUT        VARIABLES ARE 2.
              FORMAT IS FREE.
              MTSFILE IS BMDPINPUT.
/VARIABLE     NAMES ARE LNT, STRATE.
/REGRESS      DEPENDENT IS STRATE.
              PARAMETERS ARE 4.
/PARAMETER    INITIAL ARE 10.0, -0.1, 0.5, 1.0.
              MINIMUM ARE 0.0, -1.0, 0.0001, 0.5.
/SAVE         MTSFILE IS BMDPOUTPUT.
              CODE IS 'STARKEY5'.
              NEW.
/END
```

derivatives by BMDP Control Language statements or by FORTRAN statements. The parameters are estimated by a Gauss-Newton algorithm. Upper and lower limits can be placed on the parameters, and exact linear constraints for the parameters are available.

Similarly to program P3R, program PAR also estimates the parameters of a non-linear function by least squares. The program is appropriate for a wide variety of functions for which derivatives are difficult to specify or costly to compute. The regression function must be specified by FORTRAN statements; the derivatives are not specified. Upper and lower limits may be specified on the individual parameters or for arbitrary linear combinations of the parameters.

In order to use either program P3R or program PAR, Equation (3.4) had to be transformed. By utilizing the mathematical equivalence of Equation (3.5),

$$t^{B} = \exp\,(B \ln t) \tag{3.5}$$

Equation (3.4) can be re-written as

$$\dot{\epsilon} = A \exp\,(B \ln t) + C \exp\,(D \ln t) \tag{3.6}$$

where $\dot{\epsilon}$ is the strain rate

A, B, C and D are constants

Equation (3.6) becomes the fitted form of the power law and is one of the six built-in functions in program P3R.

Data of a creep test for the Star-Key Coal Mine (Jeremic, personal communication) were analyzed using programs P3R and PAR of the BMDP Statistical Software. The experimental observations were reduced with elapsed times, the time difference between the start of the experiment and the time that the observation was taken, and strain rates calculated as outlined in Section 3.1. Estimates of parameters A, B, C and D were obtained by separating the decelerating and accelerating creep portions, which was achieved by fitting a best fit straight line to the beginning and ending portions of the data individually. These estimates were used as initial estimates of parameters in progress P3R and PAR. Input data were strain rates and the natural logarithm of time.

Initially, the programs were run with no upper or lower restraints on the parameters. A convergence problem caused an error of overflow of exponents in the least squares calculation routine. Different measures were taken to solve the problem, including using double precision in the BMDP programs and setting lower limits to the four parameters. The programs were finally run successfully, but the results were less than satisfactory. Parameter C tends to approach zero, which makes the second term of Equation (3.6) vanish.

Programs P3R and PAR are typical of existing software programs available for non-linear regression. It is concluded that the programs P3R and PAR are not suitable for analyzing creep data because these programs only work with data with small scatters (M.L. Marshal, Computing Services, personal communication). Even with smoothing techniques for the creep data, the scatter is apparently still too much for the BMDP programs. Thus, another method of data analysis had to be found.

3.3 Method of Data Analysis

Since the programs P3R and PAR of the BMDP Statistical Software are not suitable for fitting the experimental creep data to the power law as in Equation (3.4), another method which involves least squares regression and integration of strain rates is used.

The experimental observations were used to calculate the elapsed time and strain rates. After smoothing the data, they were fitted into a decelerating creep power law by the least squares method. Then the decelerating creep power law was integrated to obtain estimates of the decelerating creep strains. The accelerating creep strains were calculated by subtracting the decelerating creep strains from the observed strains. From the accelerating creep strains, accelerating strain rates were calculated and fitted to an accelerating creep power law by the same least squares method used throughout the analysis. As we will see from the parameters fitted to typical experiments, at low value of t the contribution of the accelerating creep curve to creep is negligible. At high value of t, the contribution of the decelerating creep curve to creep is also negligible.

A series of computer programs were developed to carry out the analysis as outlined above. There are a total of six computer programs, which are put together in a package, named CPACK, to facilitate data analysis. Programs in CPACK are interactive programs, which require user response to terminal prompts.

The first program in package CPACK is the main program which outlines the steps of the analysis by calling the five subroutines in the package. The flow diagram of CPACK is shown in Figure 3.1. The five subroutines are CRED, BFIT, INTEG, CFIT and CPLOT.

The main program first called the Subroutine CRED to reduce the experimental data, compute engineering strains and smooth the data to avoid negative strains. The flow diagram of Subroutine CRED is shown in Figure 3.2.

The Subroutine BFIT is then called to convert the strains into strain rates, and to fit a best fit straight line to either the decelerating or accelerating creep portion based on the least squares method. The least squares criteria used in this Subroutine are the Durbin-Watson statistic (Durbin and Watson, 1951) and the Test of Slope Significance (Cruden, 1971a). These two criteria are to be explained in more detail in Section 3.4. In the decelerating creep portion, the reduced data are fitted by a straight line with negative slope in a double logarithm plot of

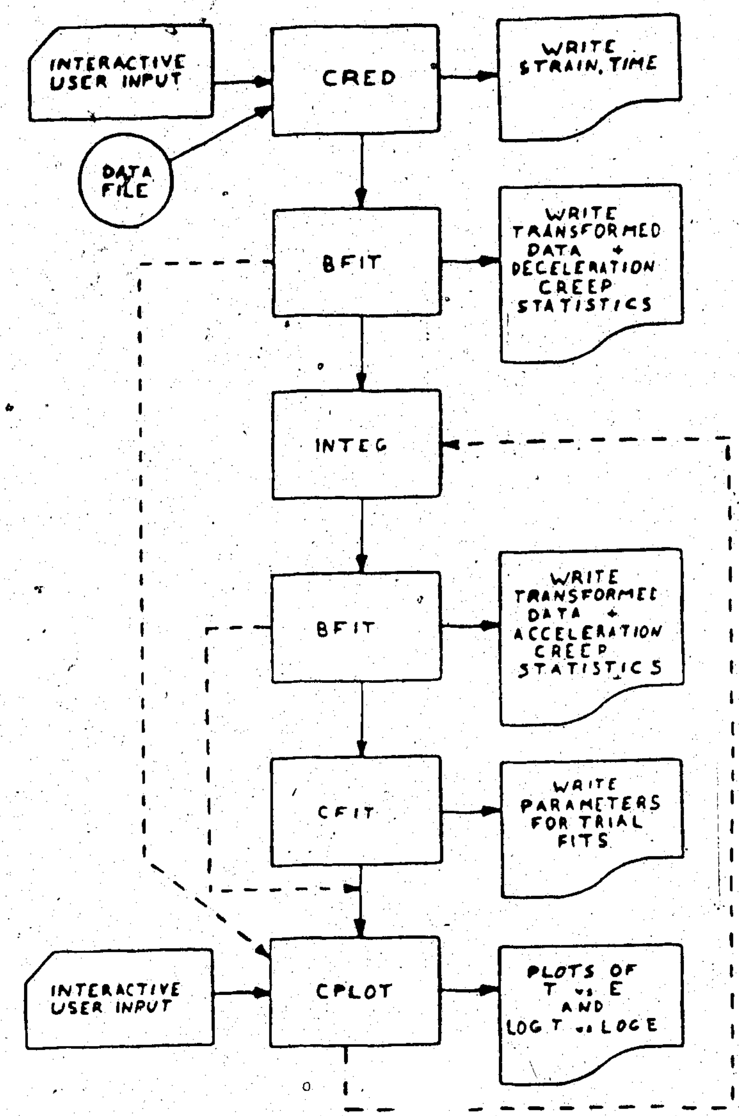


Figure 3.1 Flow diagram of program CPACK

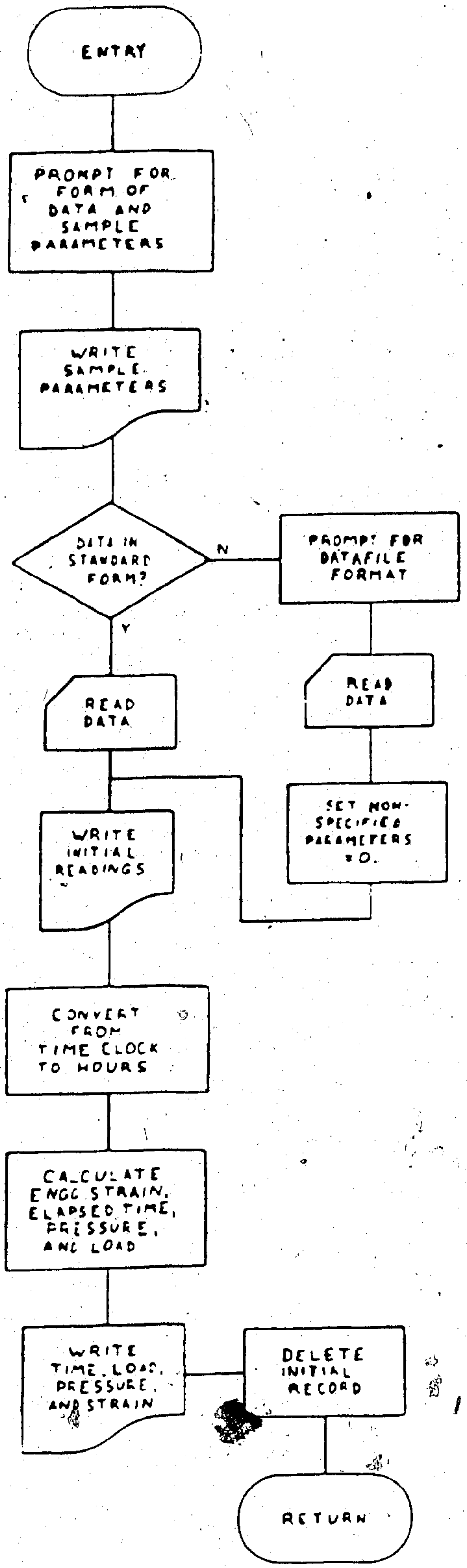


Figure 3.2 Flow diagram of Subroutine CRED

strain rate versus time. When the least squares criteria are not satisfied, the last data point is taken out and the rest of the data are fitted again. The process is repeated until the least squares criteria are satisfied. The flow diagram of Subroutine BFIT is presented in Figure 3.3. The first call to Subroutine BFIT is to fit a best fit straight line to the decelerating creep portion in a double logarithm plot of strain rate versus time.

The best fit decelerating strains are computed in the Subroutine INTEG by integrating the power law expression fitted for the decelerating strain rates in Subroutine BFIT. The decelerating creep strains are then subtracted from the observed creep strains to obtain the accelerating creep strains. The flow diagram of Subroutine INTEG is illustrated in Figure 3.4.

Subroutine BFIT is called again to convert the accelerating strains computed in Subroutine INTEG into strain rates and to fit a power law to the accelerating creep portion. For the accelerating creep portion, when the least squares criteria are not satified, the first data point is taken out and the rest of the data are fitted again. This process is repeated until the least squares criteria are satisfied.

The package allows the user to have the option of calling Subroutine CFIT, which calculates the strain rates for the overall fit, by combining the fits of the decelerating and accelerating components. It then calculates

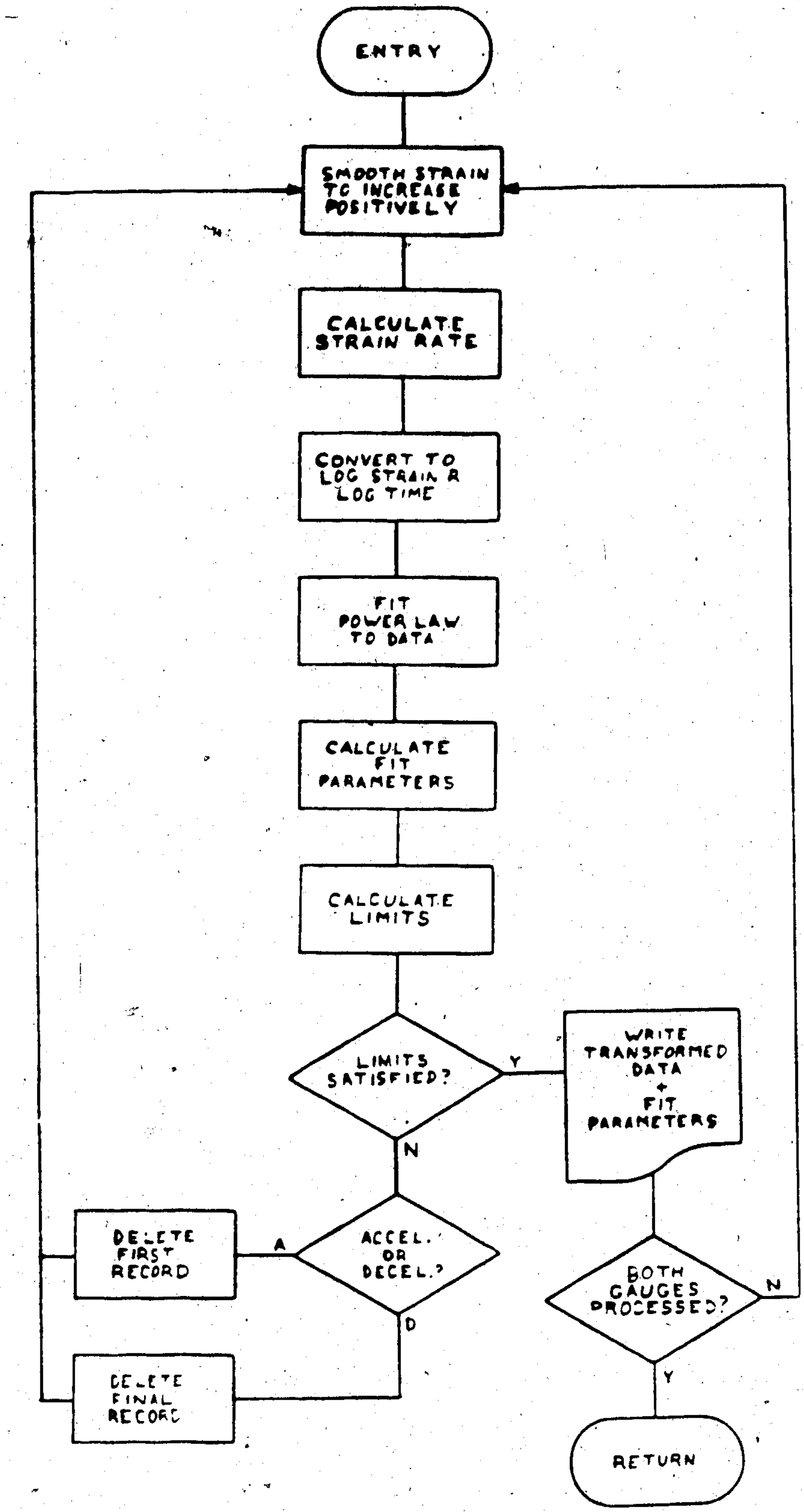


Figure 3.3 Flow diagram of Subroutine BFIT

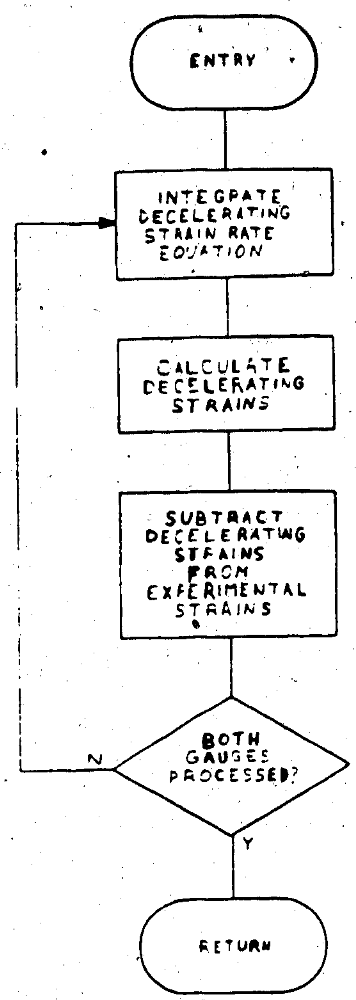


Figure 3.4 Flow diagram Of Subroutine INTEG

the ratio, R, of the squares of the scatter of the data points about their mean to the squares of the scatter about this overall fit, a measure of goodness of fit. Control is then transferred back to Subroutine BFIT to find the next smallest range of data which satisfies the least square criteria with a new power law. The resulting accelerating fit parameters are transferred to Subroutine CFIT, which evaluates the overall fit obtained with the new parameters. The process is repeated until the overlap between the accelerating and decelerating creep goes to zero, or until the accelerating creep strain rate comes to within one third of the decelerating strain rate at the beginning of the range of data used for the fit of accelerating creep. The parameters and statistics corresponding to each trial fit are tabulated, to allow the user to identify the best fit. The flow diagram of Subroutine CFIT is shown in Figure 3.5.

Finally, Subroutine CPLOT is called to produce two plots of the data: time versus strain rate and log (time) versus log (strain rate). The user has the option of calling Subroutine CPLOT to plot the data and the best fit straight line for only the decelerating creep portion or the overall fit in the double logarithm plot of strain rate versus time. The flow diagrams of Subroutine CPLOT are illustrated in Figure 3.6 and 3.7.

This method of data analysis works very well for data containing both decelerating and accelerating creep rate portions. For data that do not have any accelerating creep

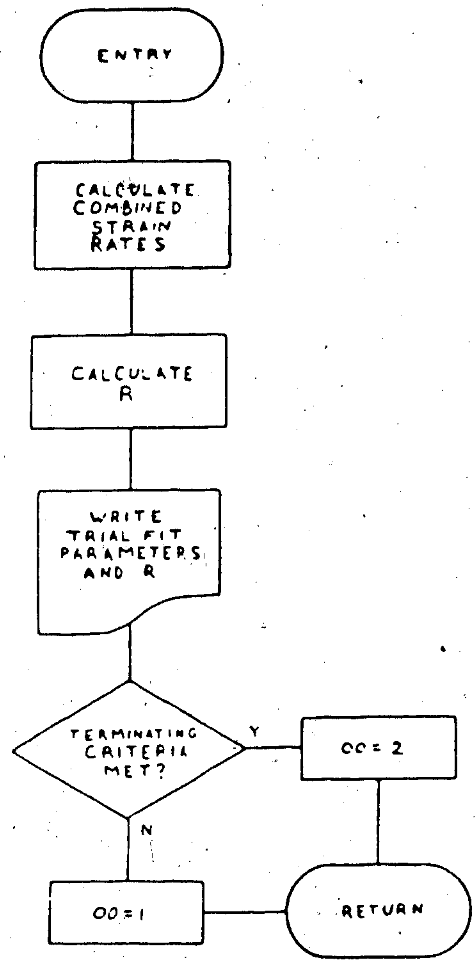


Figure 3.5 Flow diagram of Subroutine CFIT

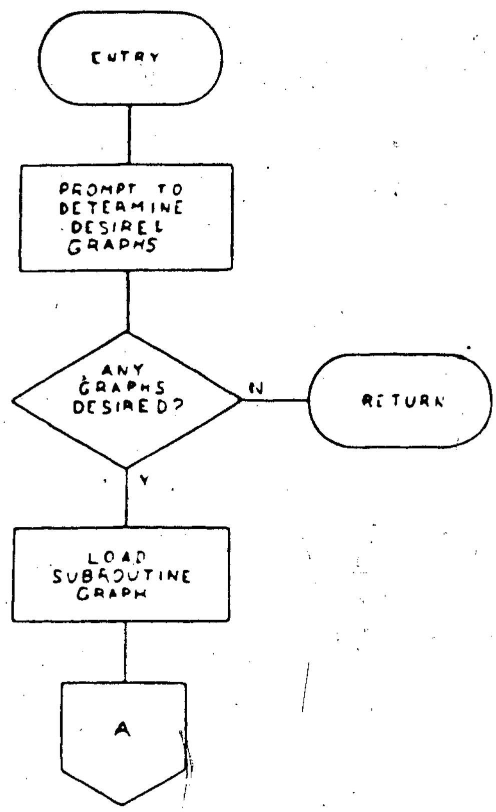


Figure 3.6 Flow diagram of Subroutine CPLOT

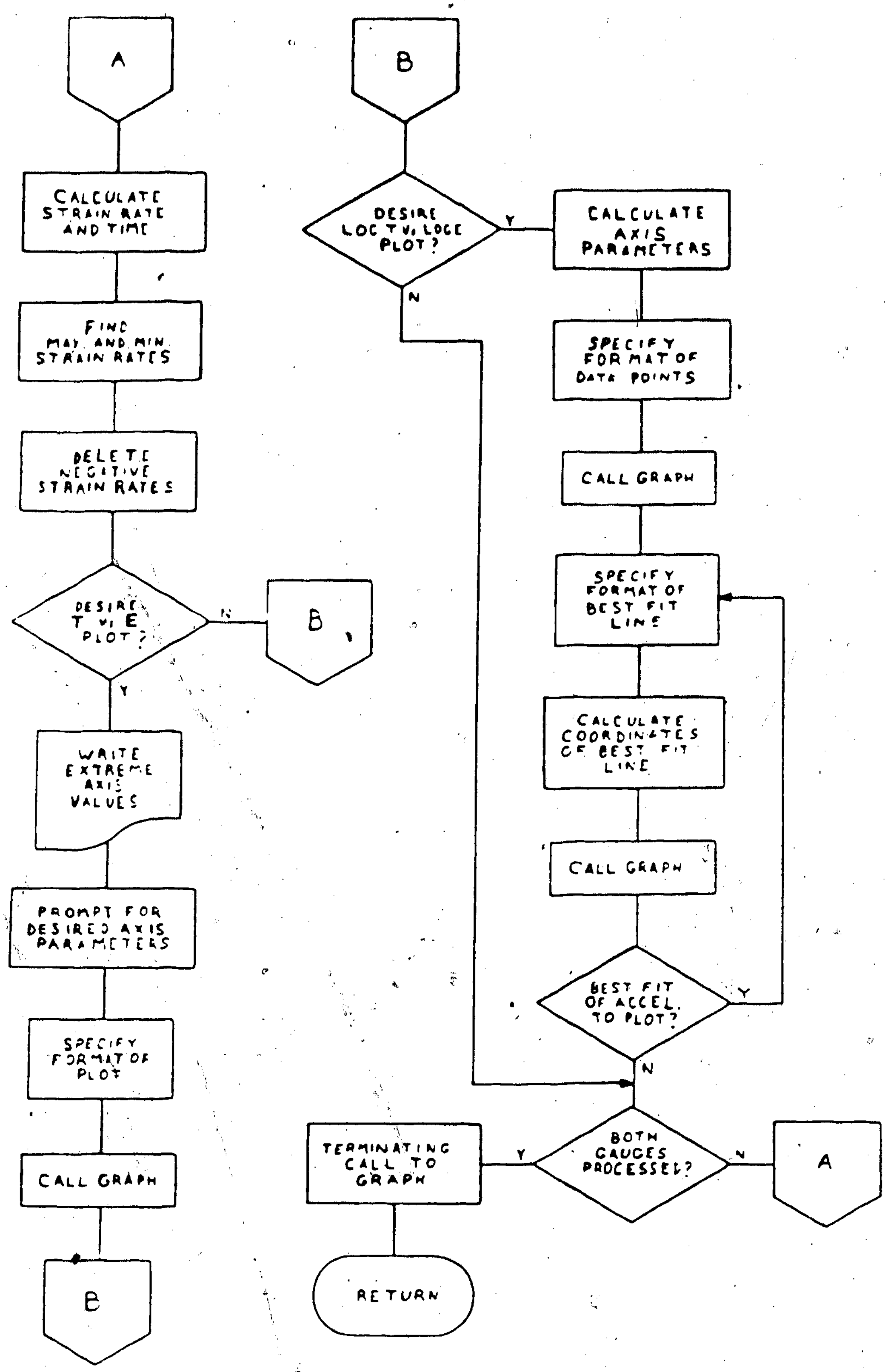


Figure 3.7 Flow diagram of Subroutine CPLOT (con't)

rate portion, an error message will likely be encountered at the second call of Subroutine BFIT. The cause of the error may be due to too few points left after the decelerating fit or the points left are too scattered to get a good accelerating fit that satisfies the least squares criteria.

The user's manual of the computer package CPACK together with the program listings are put together in Appendix A. In Section 3.4, the program is used to analyze a long (159 days) creep experiment.

3.4 The Creep of Star-Key Coal

The Star-Key Coal Mine is located at Lsd. 4, Sec. 36, Tp. 54, R. 25, W. 4th Mer., approximately 17.7 km north of Edmonton, Alberta on the west bank of the Sturgeon River valley. The coal is sub-bituminous (Jeremic and Cruden, 1979), the same classification as the coal from the Wabamun Lake District (Pearson, 1959).

Samples were brought in drums from the mine site to a laboratory in the Mineral Engineering Department at the University of Alberta to protect them from disintegrating during transportation. The test data were obtained from a particular creep test carried out by Jeremic (Personal Communication). The test was a uniaxial compression creep test on a right rectangular prism of 46.2 Wide x 47.8 Long x 48.5 Height, all measurements are in millimetres. The axial stress was reported as 19.4 MPa and the duration of the test was 159 days. The test was carried out to failure.

A simple creep machine was designed and constructed for the test, which was one of a series of tests. A hydraulic system with a bladder-type accumulator to maintain the necessary load constant was chosen. The loading frame consisted of two 305 mm x 305 mm x 38 mm steel plates spaced 305 mm apart by four 19 mm high tensile steel bolts giving a load capacity of 223 kN. The hydraulic ram is ENERPAC RC 256 25 ton cylinder with 152 mm stroke. An ENERPAC P-39 single speed hand pump drove the ram and pumped up the accumulator. The accumulator made by American Bosch is 328 cm^3 in volume and limits the system pressure to 52 MPa. A 34.5 MPa Marcsh pressure gauge of 0.25 percent accuracy, and a 0.00254 mm (0.0001 inch) dial indicator completed the required instrumentation. The creep test was carried out at room temperature and uncontrolled humidity and the sample was loaded perpendicular to the bedding planes. The laboratory set up is outlined in Figure 3.8.

The data from the creep test was analyzed as outlined in Section 3.3. A power law was fitted to the data and the data points and the best fit straight lines that were fitted to the decelerating and accelerating creep portions were plotted in the log (strain rate) versus log (time) plot. As seen in Figure 3.9, the data seem to scatter but they fit well to the power law. Figure 3.10, a plot of strain rate versus time, shows that the strain rate decreases from the beginning to a certain time and then increases towards failure. Figure 3.10 clearly illustrated the two stages of

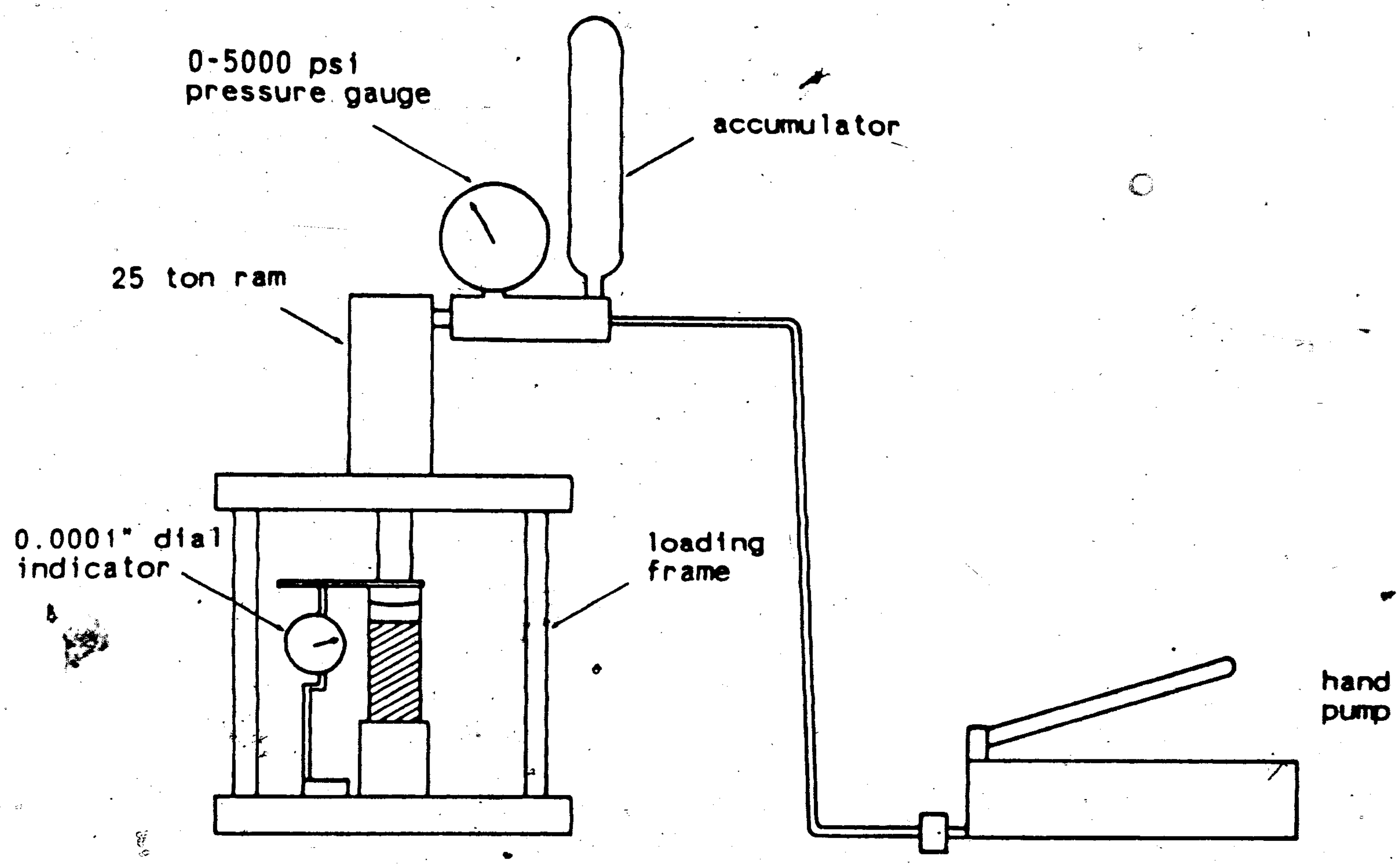
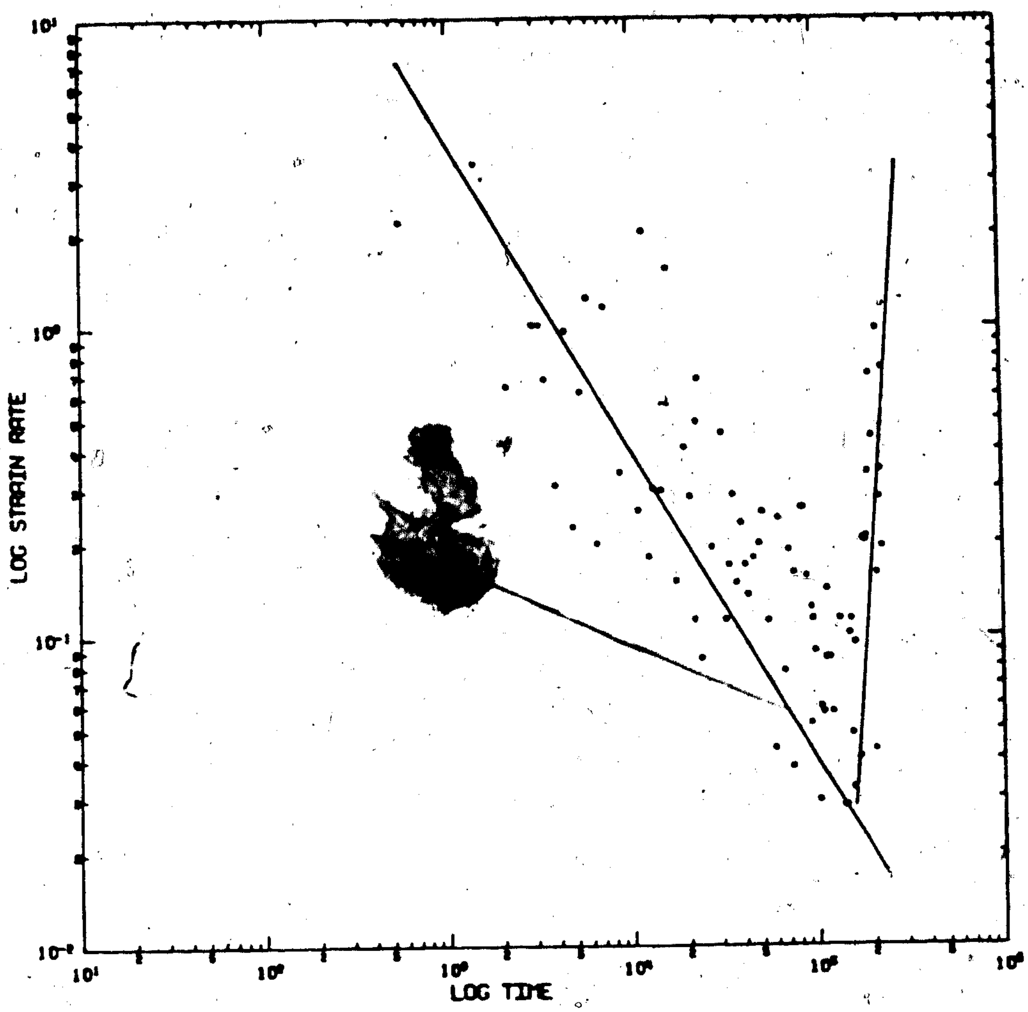


Figure 3.8 Outline of Jeremic's laboratory set up



Axial Stress = 19.4 MPa

Figure 3.9 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test Starkey5 creep, decelerating and accelerating.

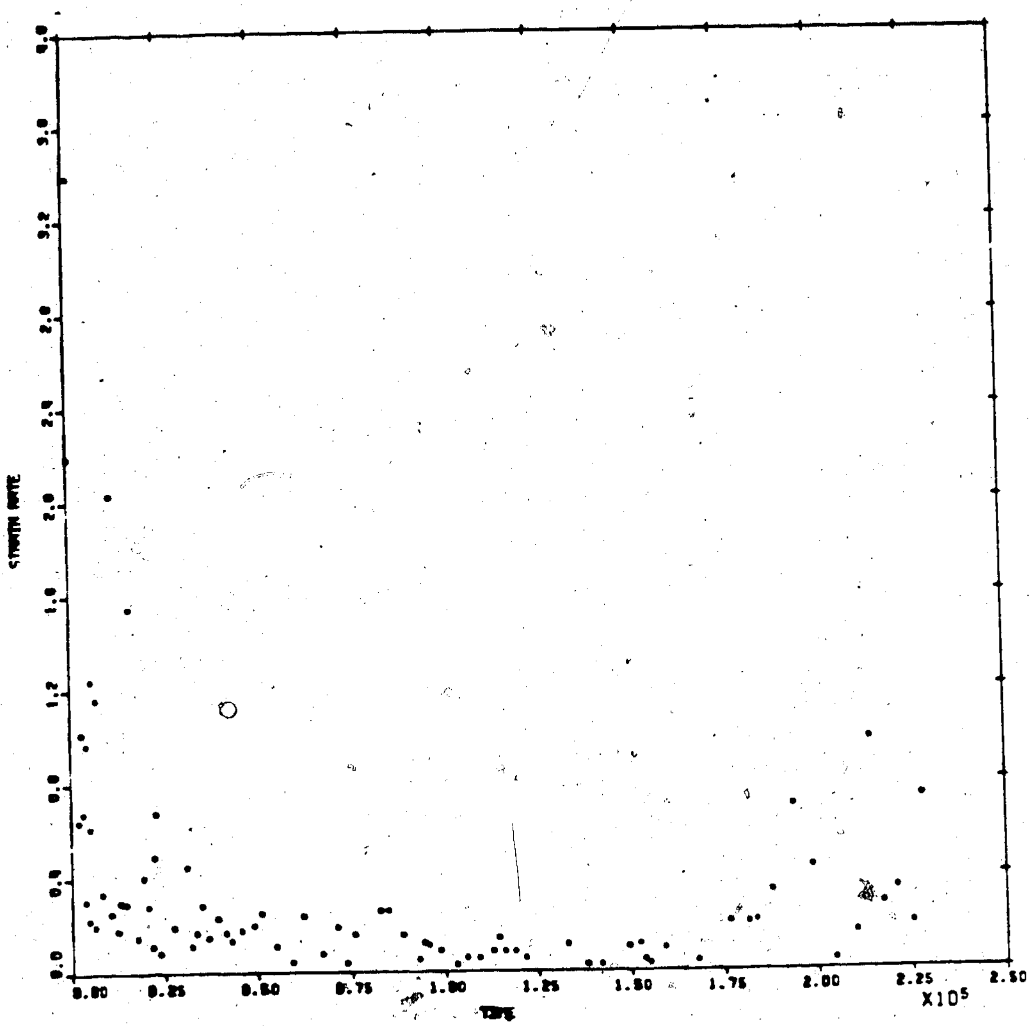
The straight line fit of the decelerating creep rate portion in Figure 3.9 has a slope of -1.00 and a one minute strain rate (strain rate at one minute) of 3971 micro-strains per minute. The accelerating creep rate portion has a slope of +8.09 and a strain rate value at one minute of 2.51×10^{-44} micro-strain per minute.

Table 3.2 presents the results of analyzing data from the Star-Key Coal Mine. DW stands for the Durbin-Watson statistic (Durbin and Watson, 1951) which is a test for serial correlation in the residuals of the fit. If the creep law is a reasonable fit to the data, then the residuals will be randomly distributed. If the values of the residuals show some dependence on the variables, x, y, then the proposed law is not a satisfactory fit to the data, because there still remains in the residuals a systematic variation which the creep law has not satisfied. Durbin and Watson (1951) tabulated two groups of critical values for DW against n, the number of observations, at three different confidence levels. The 5 per cent confidence level is used in this analysis. The two groups of critical values for DW are the upper, dU, and the lower, dL, bounds. If the observed DW is less than dL, it suggests that positive serial correlation of the residuals exists in the sample. If the upper value, dU, is not exceeded, positive correlation of the residuals might exist in the observations.

Table 3.2 Summary of the Star-Key data analysis

Fit	Data Range	log A Intercept	B Slope	DW	Slope Significance	log Inflexion Time (min)	R Total Fit
Decelerating	1-80	+3.7564	-1.0406	1.476	73.945		
	1-79	+3.8045	-1.0526	1.459	72.937		
	1-78	+3.9474	-1.0880	1.445	76.196		
	1-77	+4.0498	-1.1135	1.237	73.891		
	1-76	+3.7616	-1.0414	1.500	77.274		
	1-75	+3.5991	-1.0007	1.677	76.231		
	1-74	+3.5069	-0.9776	1.779	76.906		
	1-73	+3.5027	-0.9765	1.759	72.359		
	1-72	+3.3460	-0.9373	1.736	63.208		
	1-71	+3.2557	-0.9144	1.721	78.852		
Accelerating	60-90	-41.7652	+7.7399	1.617	90.227	5.190	48.796
	61-90	-44.8557	+8.3276	2.630	112.218	5.194	49.215
	62-90	-49.2026	+9.1534	1.609	197.507	5.200	49.609
	63-96	-44.0275	+8.1738	1.681	57.144	5.191	49.039
	64-96	-43.5989	+8.0928	1.690	52.815	5.190	48.973

DW = Durbin Watson statistics



Axial Stress = 19.4 MPa

Figure 3.10 Plot of strain rate (micro-strain/min) vs time (min) Test Starkey5

Another measure of goodness of fit is the Test of Slope Significance. Cruden (1971a) outlined the calculation of R1, the ratio of the estimated variance of a simple linear regression to the variance about the mean value of the dependent variable. The statistic, R1, can be referred to F-tables with one and (n-2) degrees of freedom with 1 per cent confidence level suggested by Cruden (1971a) because of the large amount of data.

The upper bound of the Durbin-Watson statistic is calculated in the Subroutine BFIT in package CPACK. The regression analysis will carry on until the observed DW exceeded the upper bound value and R1 exceeded 10.

In Table 3.2, several fits of the decelerating and accelerating regression lines are summarized. For the decelerating fit, the regression lines fitted to data range from 1 to 75 or less satisfied the two criteria outlined above. The rest of the decelerating fits had the observed DW too low to exceed the upper value, dU. The regression line fitted to data range from 1 to 75 was chosen as the decelerating fit. For the accelerating fits, all five regression lines summarized in Table 3.2 satisfied the two criteria. It appeared that the regression lines with data range of 61 to 96 and 62 to 96 were the optimum fits. However, the regression line with data range of 64 to 96 was chosen as the accelerating regression line plotted in Figure 3.9 because it was the smallest range of data used to calculate the goodness of overall fit, R, by combining the decelerating and accelerating fits in Subroutine CFIT. The inflexion time in Table 3.2 is the time when the decelerating regression line with data range of 1 to 75 intersects with the accelerating regression line. The inflexion time was calculated by equating the decelerating and accelerating power laws.

The scatter in the Star-Key Data can be explained by the change of ambient temperature and humidity. A very slight change in temperature and humidity can affect the deformation of a sample under stress. The temperature and humidity dependent deformation are being recorded together with the real creep deformation and this causes the scatter of the data. The analysis of the Star-Key Data is included in the User's Manual in Appendix A as an example.

Finally, base on the analysis of the experimental data, the form of the creep of the Star-Key Coal is as follow:

$$\dot{\epsilon} = 3971t^{-1.00} + (2.51\times10^{-44})t^{+8.09} \qquad (3.7)$$

where $\dot{\epsilon}$ is the strain rate in micro-strains per minute

t is the elapsed time in minutes

4. Presentation of Test Results

4.1 Typical Results

As mentioned in Section 2.3, there were two different sources of coal samples used in this study. The first source was samples obtained from the sampling site and the second source was samples not used by da Fontoura (1980). In Section 2.5, the three different types of tests carried out in this experimental program were described in detail. The first type was testing with both confining and back pressure, referred as the C-tests; the second type was the uniaxial compresison test, referred as the U-tests; and lastly, testing on saturated samples, referred as the S-tests.

Because of the similarity in test results, not all the results from all tests are presented here. Only a few tests from each group of tests are presented as typical results. The rest of the results are included in Appendix B.

Figure 4.1 to Figure 4.7 are double logarithm plots of strain rate versus time of the results of tests done on samples from the first source. Figure 4.1 and Figure 4.2 are results of the C-tests, Figure 4.3 to Figure 4.5 are results of S-tests and Figure 4.6 and Figure 4.7 are of the U-tests. Table 4.1 is a summary of the decelerating fit of all the tests carried out with samples from the first source.

Figure 4.8 to Figure 4.16 are double logarithm plots of strain rate versus time of the results of tests done on

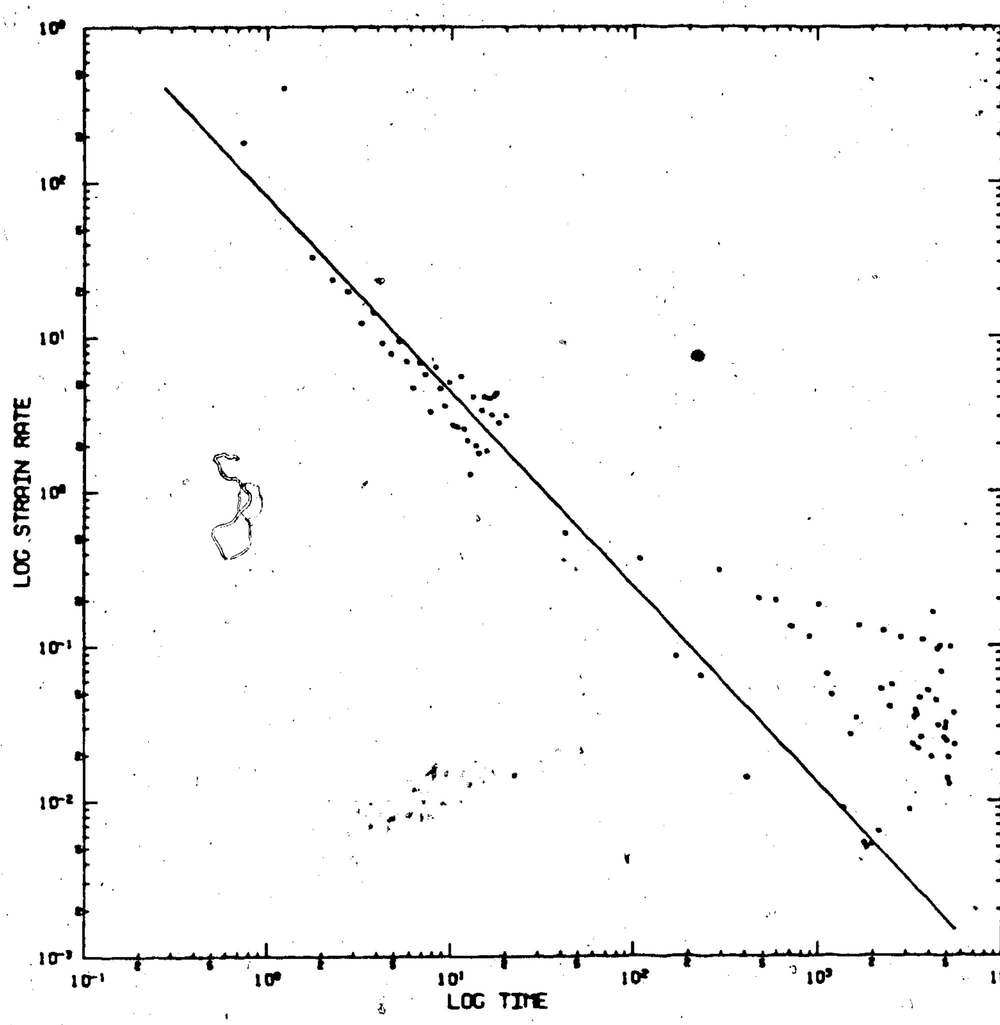
Table 4.1 Summary of decelerating fit to data from tests using fresh samples

Test	(MPa) Stress	log A Intercept	B Slope	ConA	ConB	DW	Slope Significance	(min) tm
C9-9#8	3.99	1.903	-1.264	0.149	0.053	1.734	572.615	366
C9-9#9	4.25	1.592	-1.124	0.129	0.122	1.811	85.460	10
U9-9#9	6.38	1.504	-1.059	0.097	0.034	1.758	962.546	383
U9-9#11	6.38	1.607	-1.373	0.059	0.030	2.375	2035.032	52
U9-9#17	3.99	1.840	-1.131	0.114	0.043	2.417	688.650	240
U9-9#21	6.38	1.817	-1.447	0.131	0.066	1.671	481.304	52
U10-9#2	7.18	1.844	-1.313	0.154	0.053	1.914	615.810	478
S9-9#7	4.78	1.887	-1.077	0.064	0.029	1.649	1360.900	77
S9-9#21	4.78	2.122	-1.175	0.093	0.059	1.585	396.513	22
S9-9#9	4.25	1.705	-1.065	0.070	0.023	1.704	2207.271	857
S9-9#11	4.25	1.850	-1.122	0.114	0.038	1.696	874.360	620
S9-9#15	3.99	2.092	-1.401	0.098	0.047	1.677	889.559	59
S9-9#17	3.99	1.977	-1.234	0.088	0.029	1.707	1787.414	597
S10-9#2	3.99	2.167	-1.344	0.072	0.025	1.691	2967.781	461

Con = confidence limits on following parameter

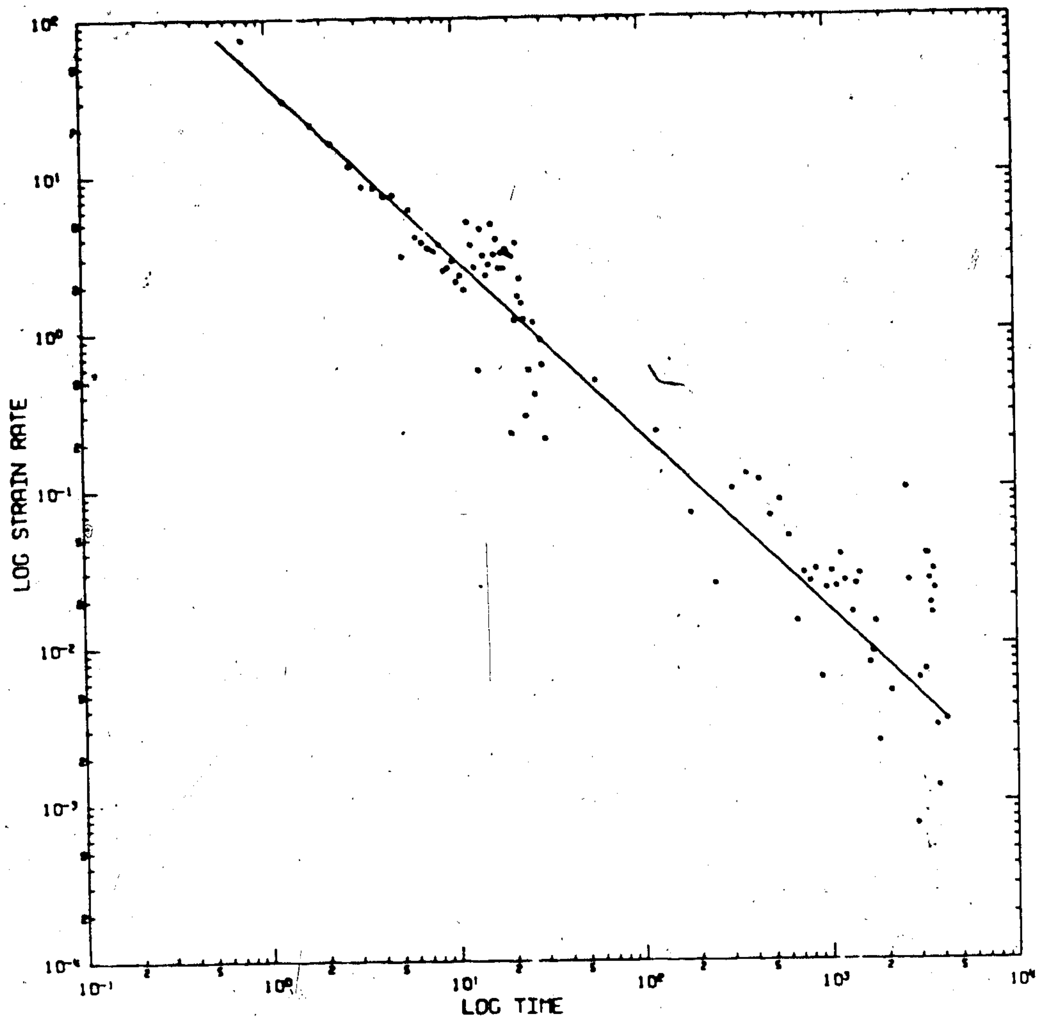
DW = Durbin Watson statistics

tm = mean of the logarithm of time



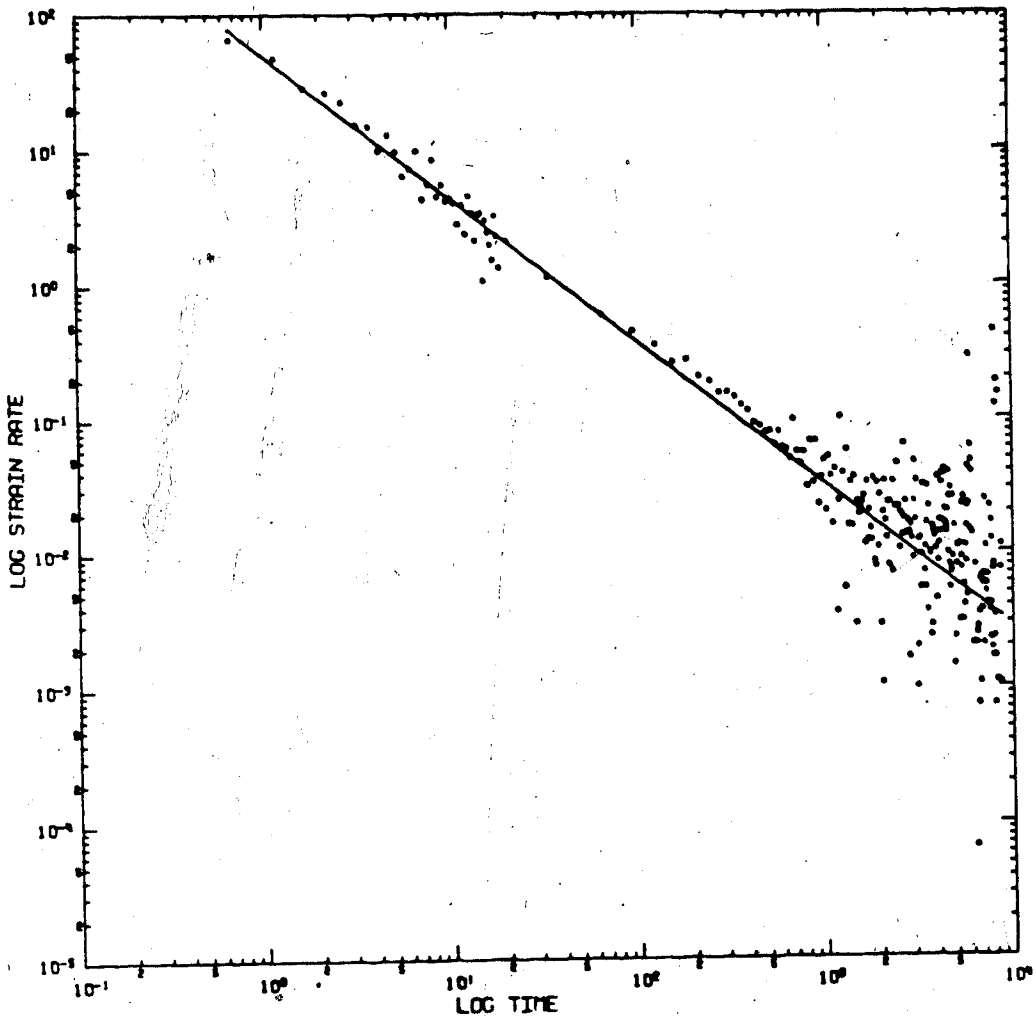
Axial Stress = 3.99 MPa

Figure 4.1 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test C9-9#8



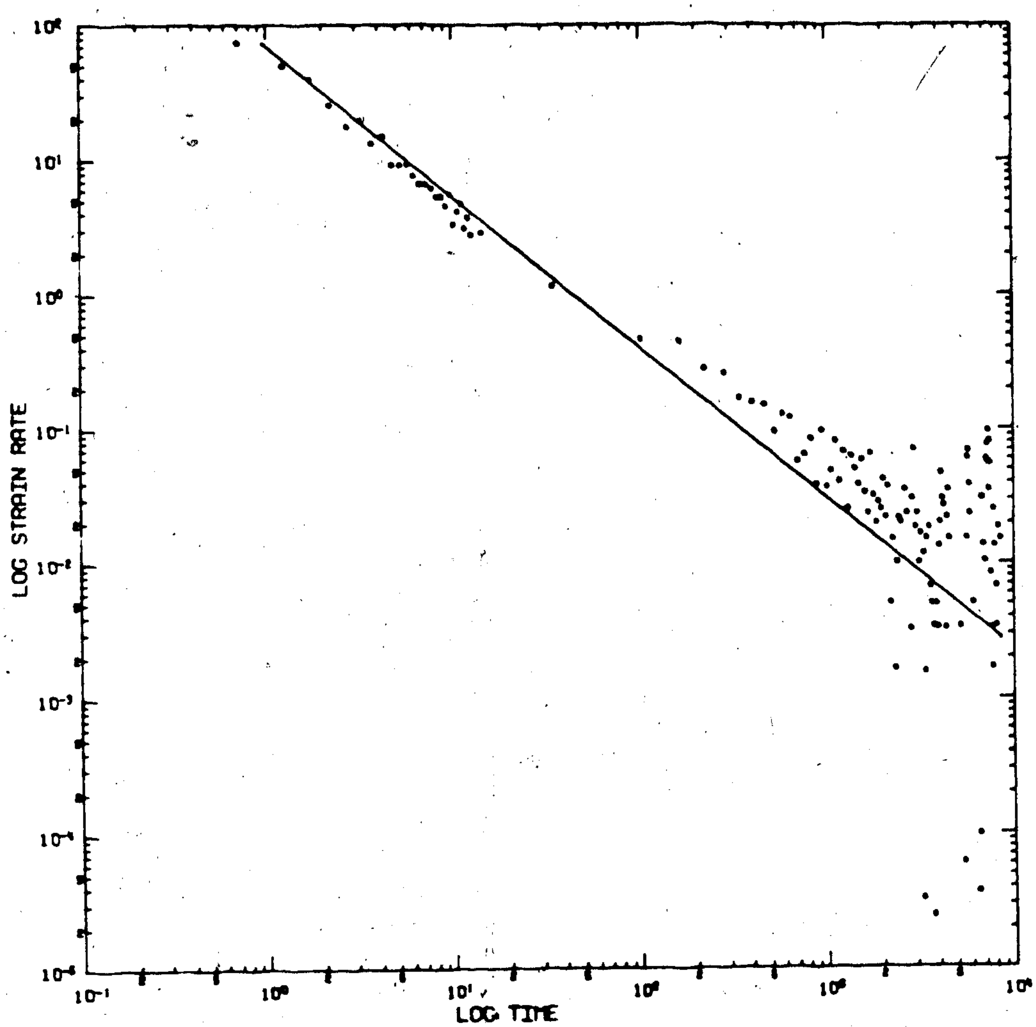
Axial Stress = 4.25 MPa

Figure 4.2 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test C9-9#9



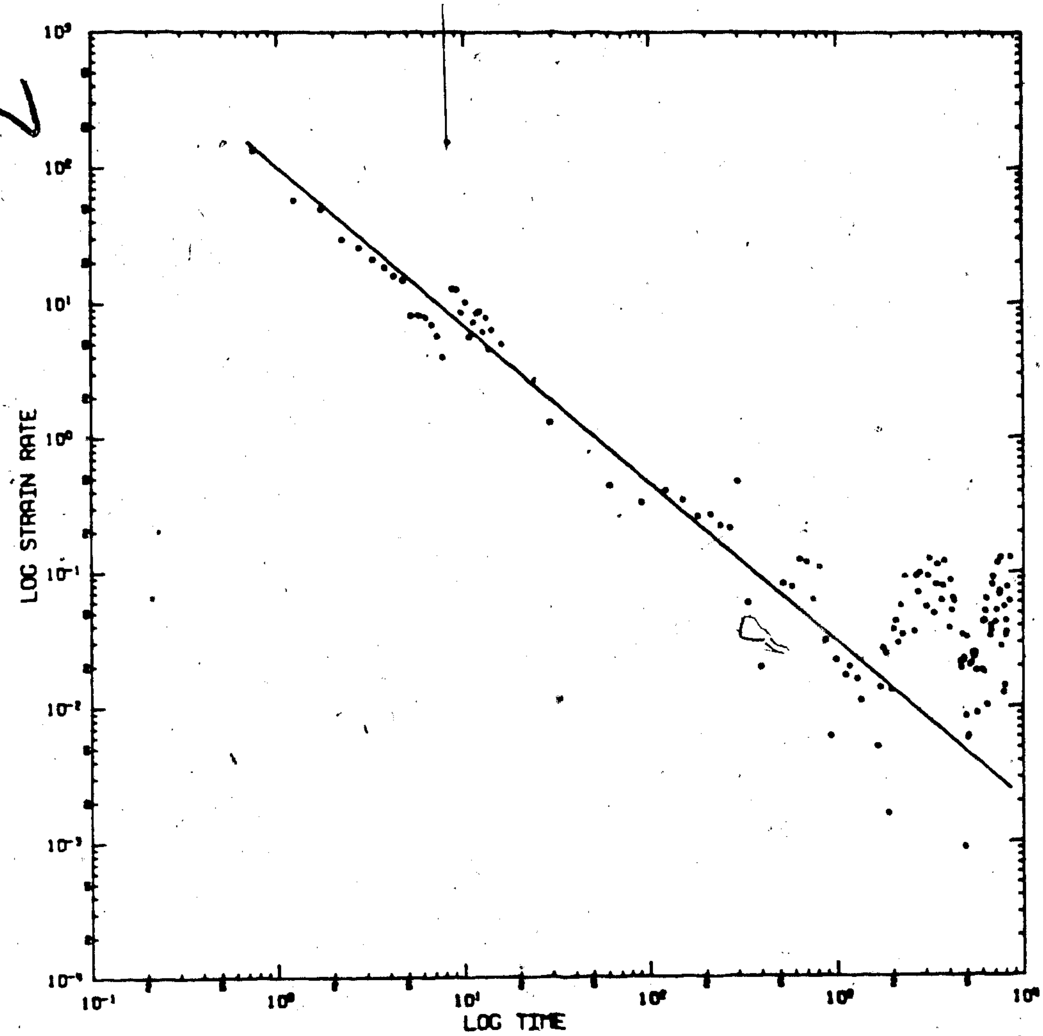
Axial Stress = 4.25 MPa

Figure 4.3 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test S9-9#9



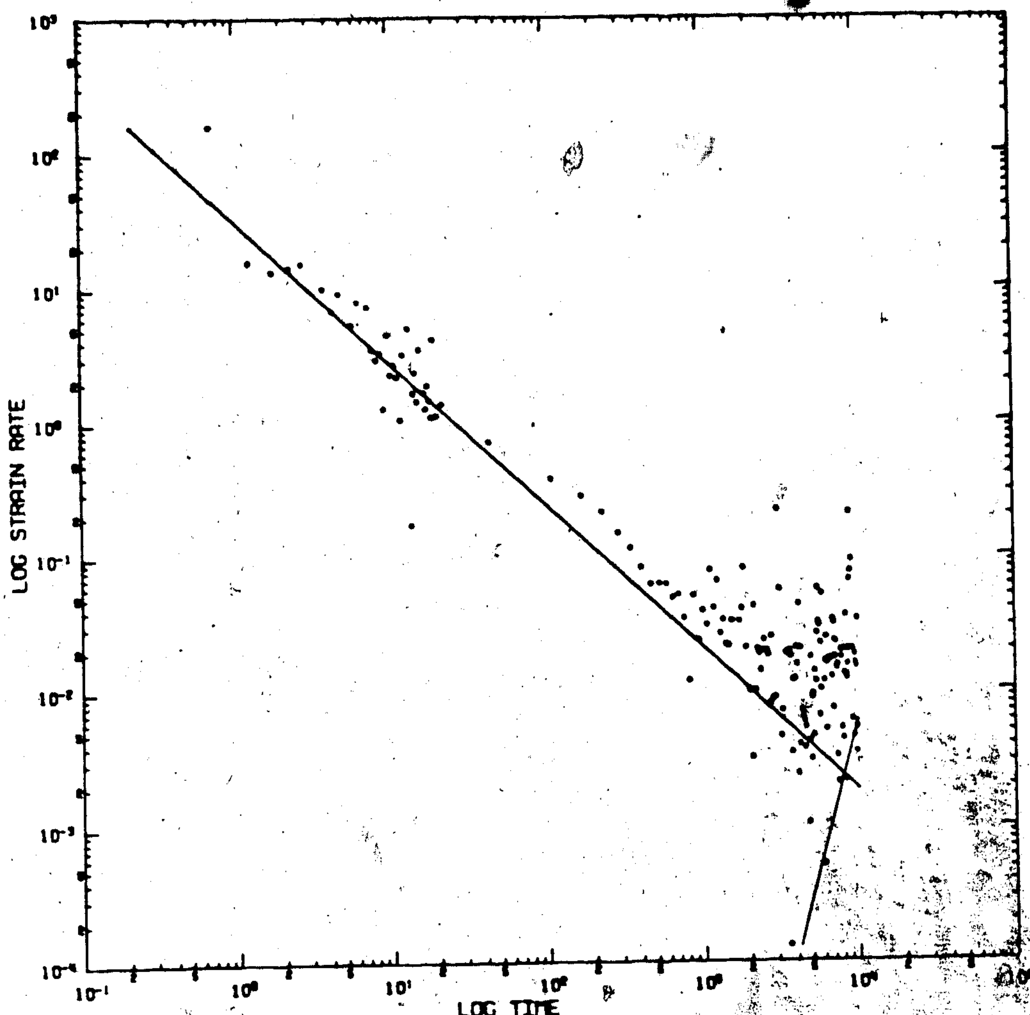
Axial Stress = 4.25 MPa

Figure 4.4 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test S9-9#11



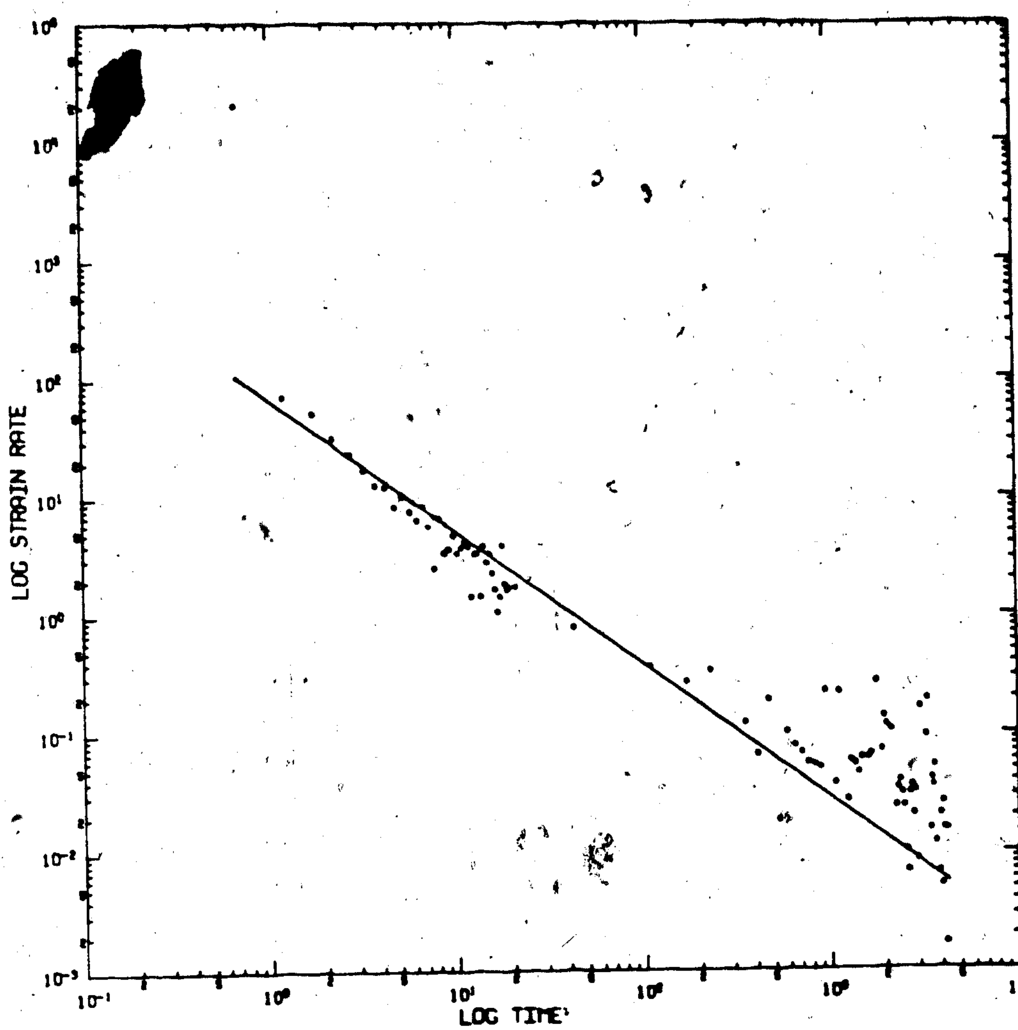
Axial Stress = 4.78 MPa

Figure 4.5 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test S9-9#21



Axial Stress = 6.38 MPa

Figure 4.6 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test U9-9#9



Axial Stress = 3.99 MPa

Figure 4.7 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test U9-9#17 samples from the second source. Figure 4.8 and Figure 4.9 are results from the U-tests. Figure 4.10 to Figure 4.16 are plots from the results of the C-tests. There were no S-tests carried out with samples from the second source. Table 4.2 presents a summary of the decelerating fit of all the tests carried out with samples from the second source.

In the decelerating fit of a regression line to experimental data presented in Figure 4.1 to Figure 4.16, one can observe that as time increases the data scattered more about the regression line. This is due to the fact that the observations were affected by the change of the ambient temperature. At the beginning of the test, the strain rate is high and therefore not significantly affected by the temperature effect. With the strain rate decreasing, it comes to a point where the temperature effects becomes significant and this explains the scattering of data as time increases.

All except one of the double logarithm plots presented here are decelerating fits of the test results. The result from Test U9-9#9 is the only test that showed accelerating creep, as illustrated in Figure 4.6. Table 4.3 summarized the parameters of the accelerating fit. Test U9-9#9 was carried out with a relatively high stress and long duration. There were other tests with approximately the same axial stresses but shorter durations, therefore there were no accelerating creep. The axial stress and duration of all tests are summarized in Table 2.2.

Table 4.2 Summary of decelerating fit to data from tests using da Fontoura's samples

Test	(MPa) Stress	log A Intercept	B Slope	ConA	ConB	DW	Slope Significance	(min) tm
UT6C	2.92	1.715	-1.089	0.040	0.016	1.701	4444.102	152
UT6F	1.86	1.738	-1.041	0.047	0.020	1.714	2798.874	124
UT6F2	2.39	1.876	-1.082	0.084	0.026	2.296	1773.229	1140
UT6D	2.39	1.578	-0.913	0.062	0.022	2.053	1652.110	338
UT6D2	2.39	1.717	-0.940	0.077	0.027	2.414	1218.440	444
UT6D3	2.92	1.865	-1.082	0.180	0.051	1.732	459.033	2891
CT6A1	1.86	1.818	-1.125	0.069	0.024	1.703	2119.307	372
CT6A2	2.66	1.269	-0.958	0.115	0.037	2.064	657.122	748
CT6A3	2.66	1.754	-1.186	0.127	0.042	1.691	783.276	571
CT6A4	2.66	1.559	-0.919	0.195	0.154	1.608	35.451	14
CT6A5	3.72	1.646	-0.955	0.065	0.021	1.917	2114.035	843
CT6A6	3.72	1.619	-1.008	0.049	0.018	1.691	3069.792	246
CT6A7	3.72	1.779	-1.041	0.099	0.035	2.294	880.733	379
CT6A8	4.78	1.717	-0.941	0.054	0.019	1.921	2436.323	427
CT6A9	5.32	1.811	-1.043	0.054	0.021	1.696	2490.586	238

Con = confidence limits on following parameter

DW = Durbin Watson statistics

tm = mean of the logarithm of time

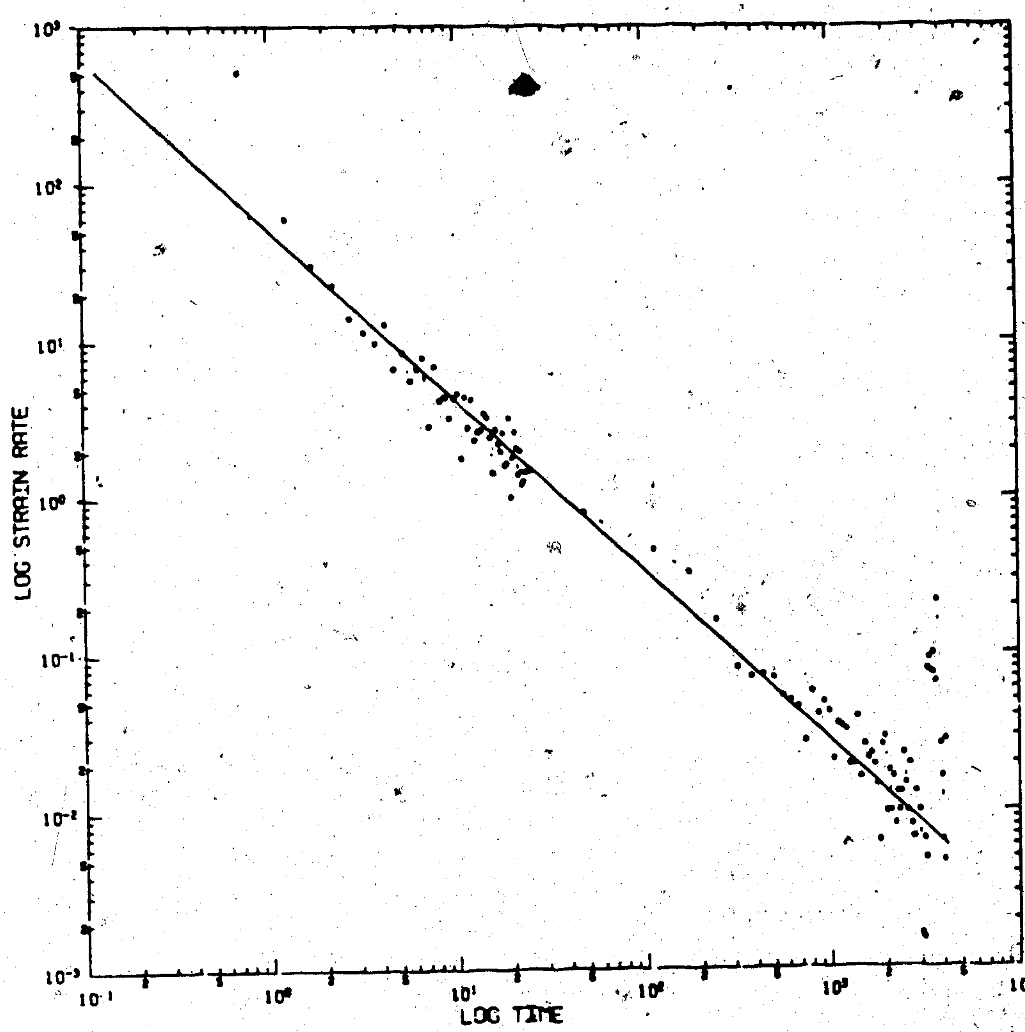
Table 4.3 Summary of accelerating fit

	U9-9#9 Accelerating Fit
Stress (MPa)	6.38
Intercept, Log A	-19.333
Slope, B	4.272
ConA	3.492
ConB	0.888
DW	6.401
Slope Significance	23.180
tm (min)	8590

Con = confidence limits on following parameter

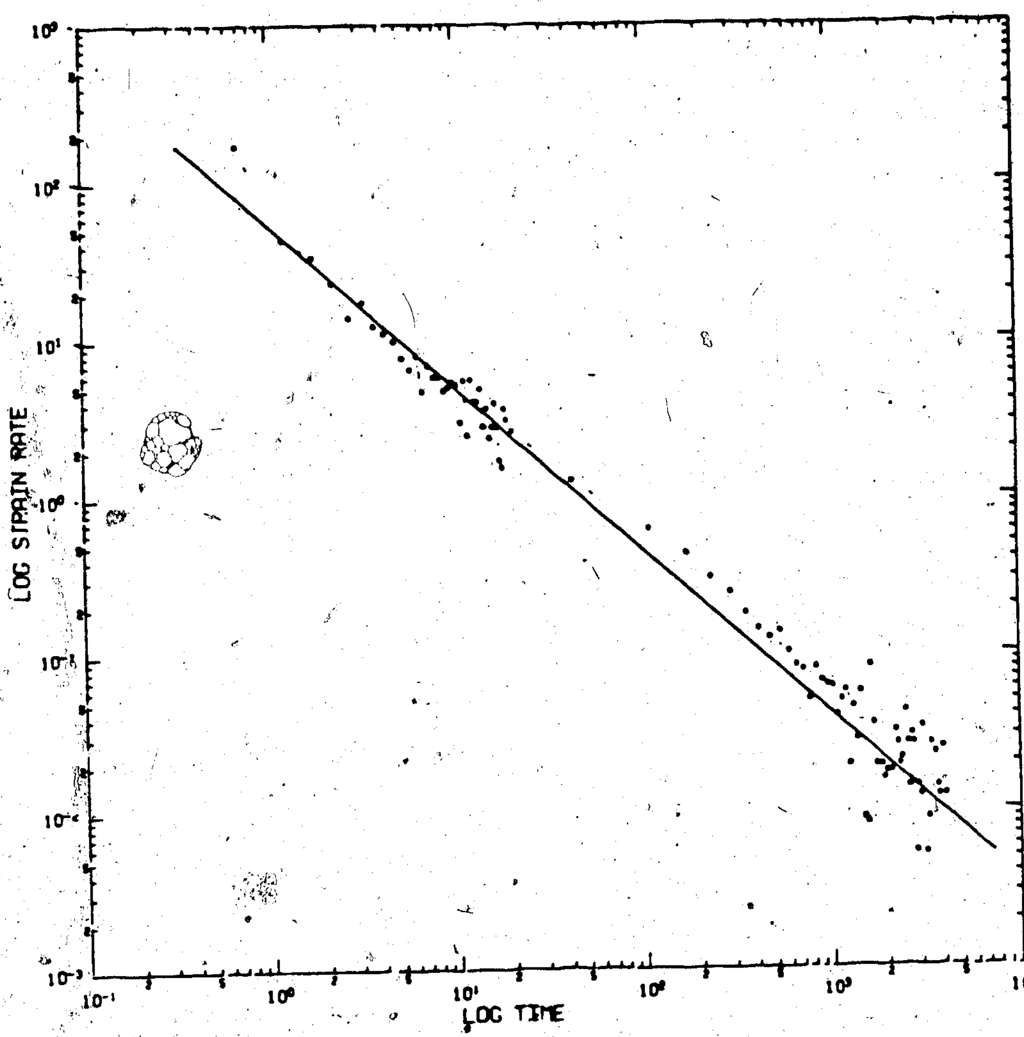
DW = Durbin Watson Statistics

tm = mean of the logarithm of time



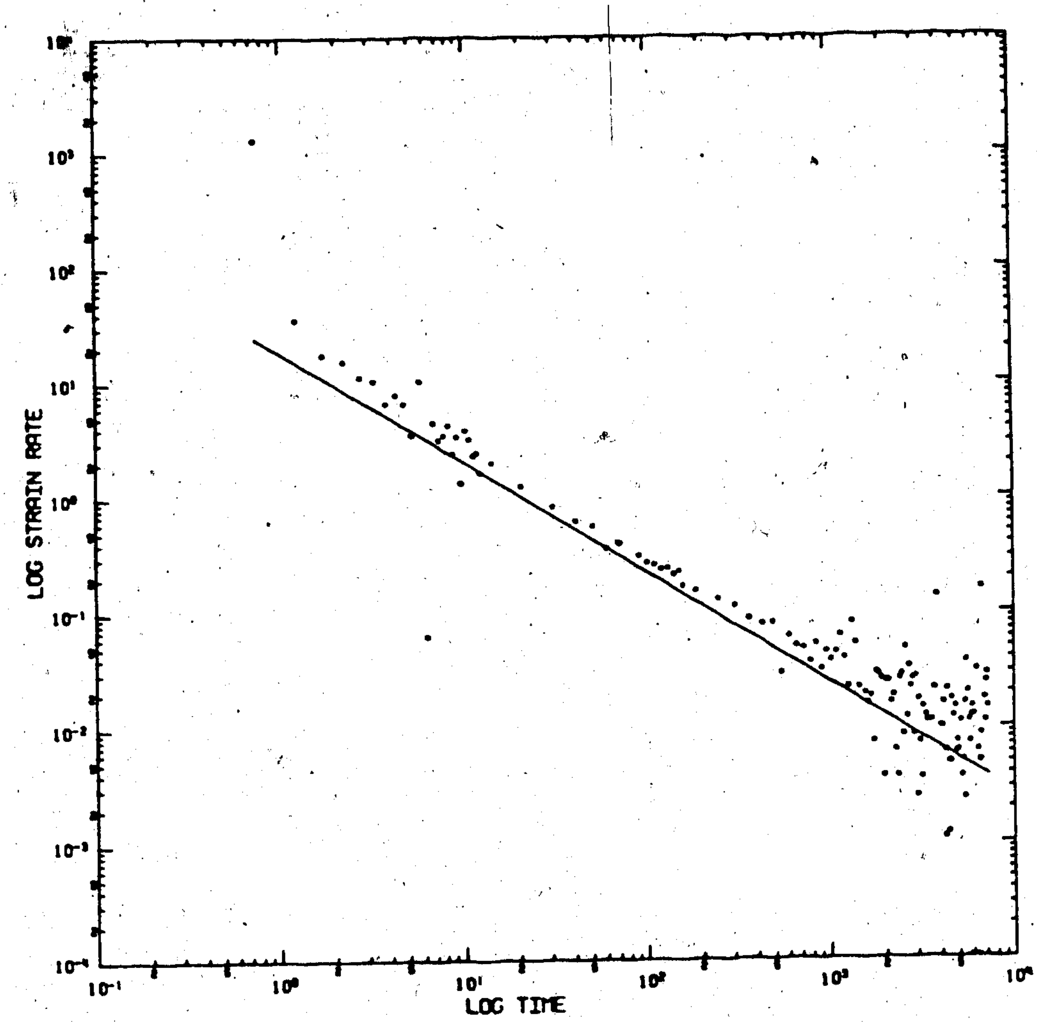
Axial Stress = 2.92 MPa

Figure 4.8 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test UT6C



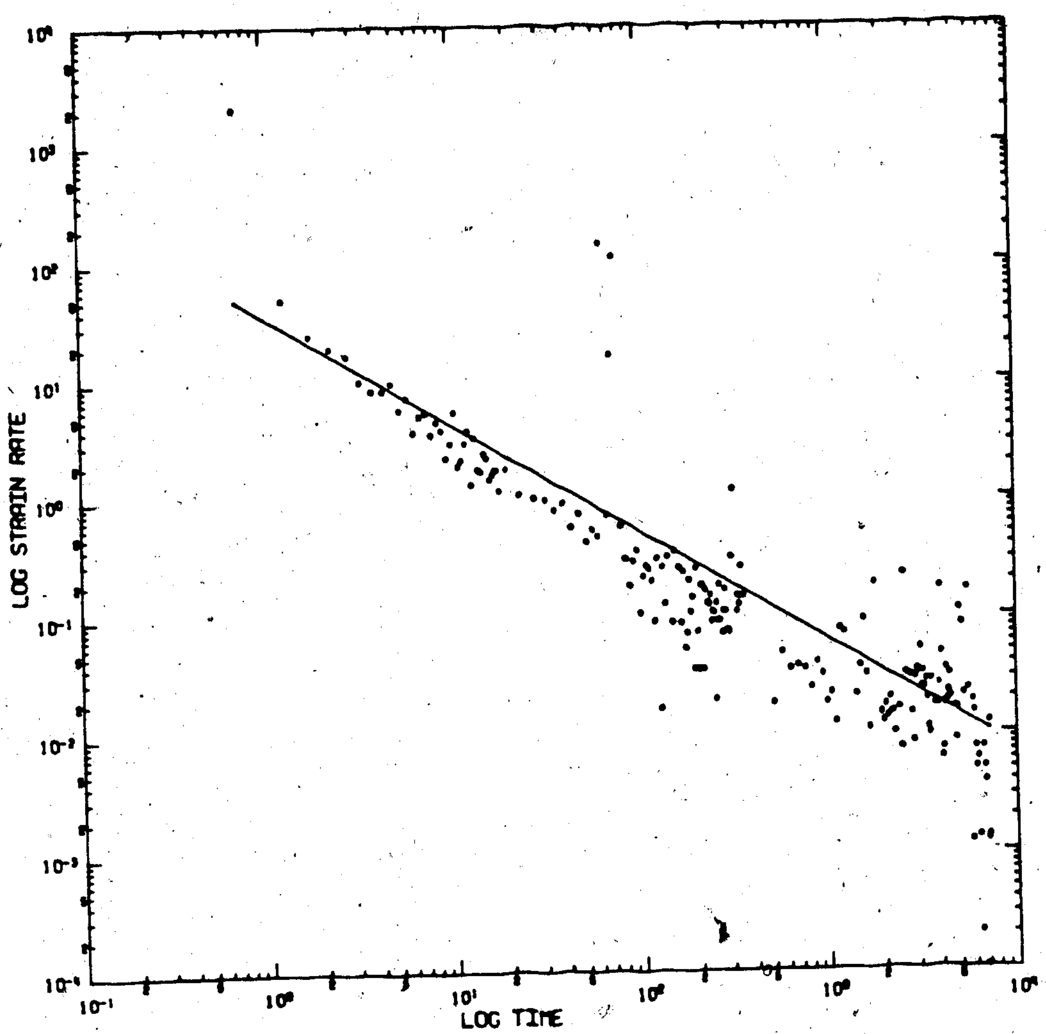
Axial Stress = 1.86 MPa

Figure 4.9 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test UT6F



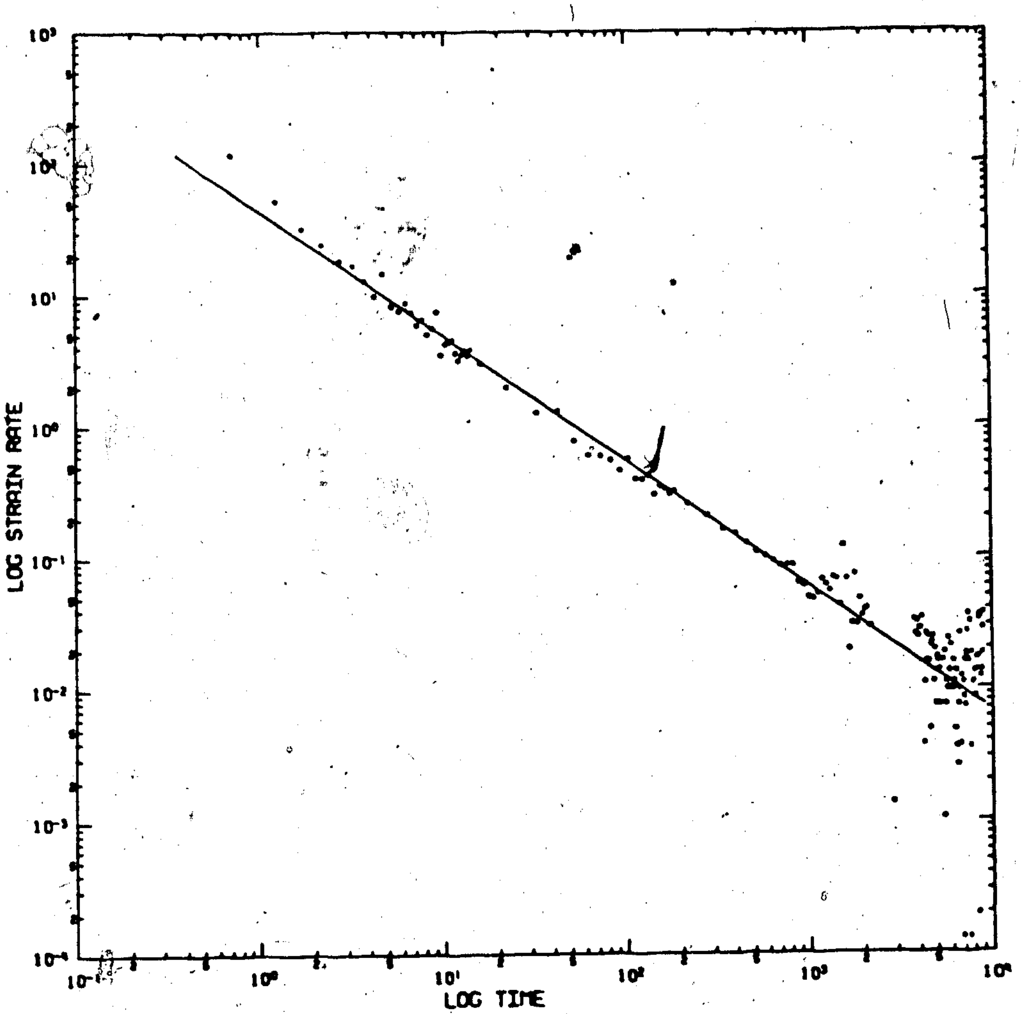
Axial Stress = 2.66 MPa

Figure 4.10 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test CT6A2



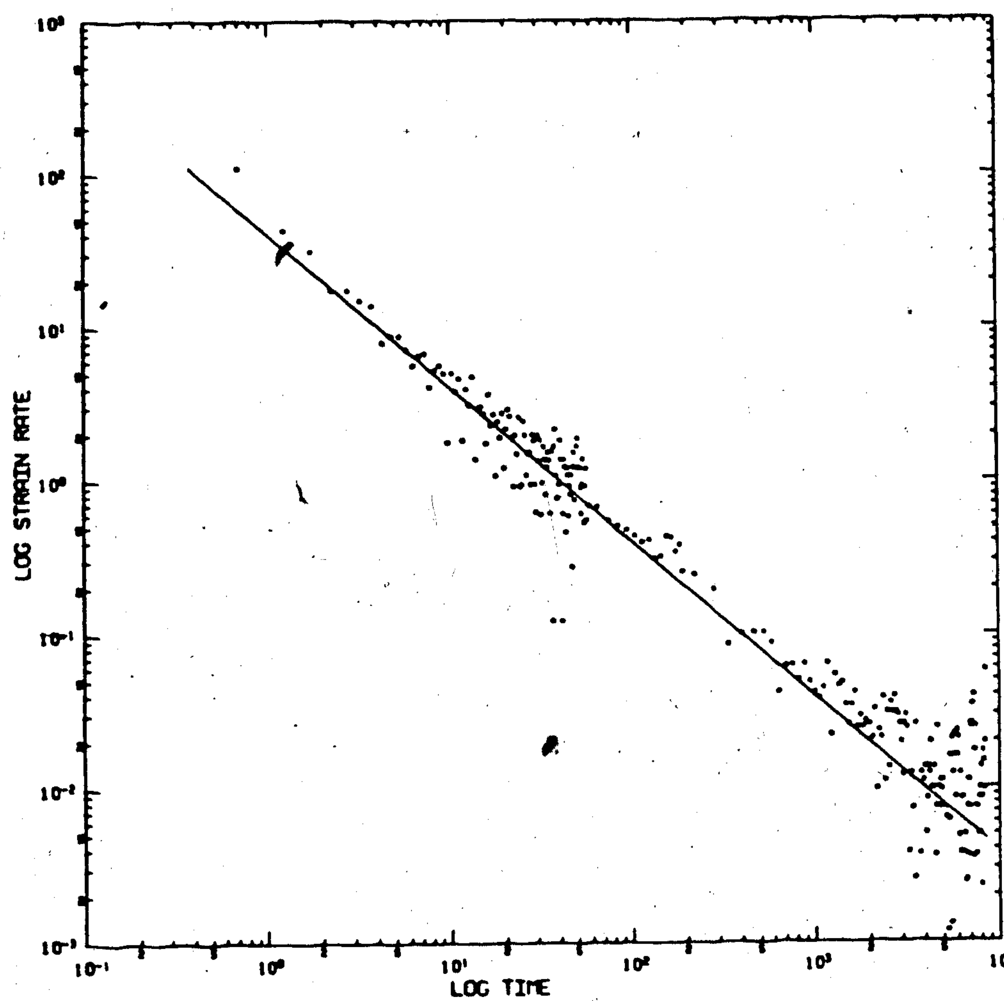
Axial Stress = 2.66 MPa

Figure 4.11 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test CT6A4.



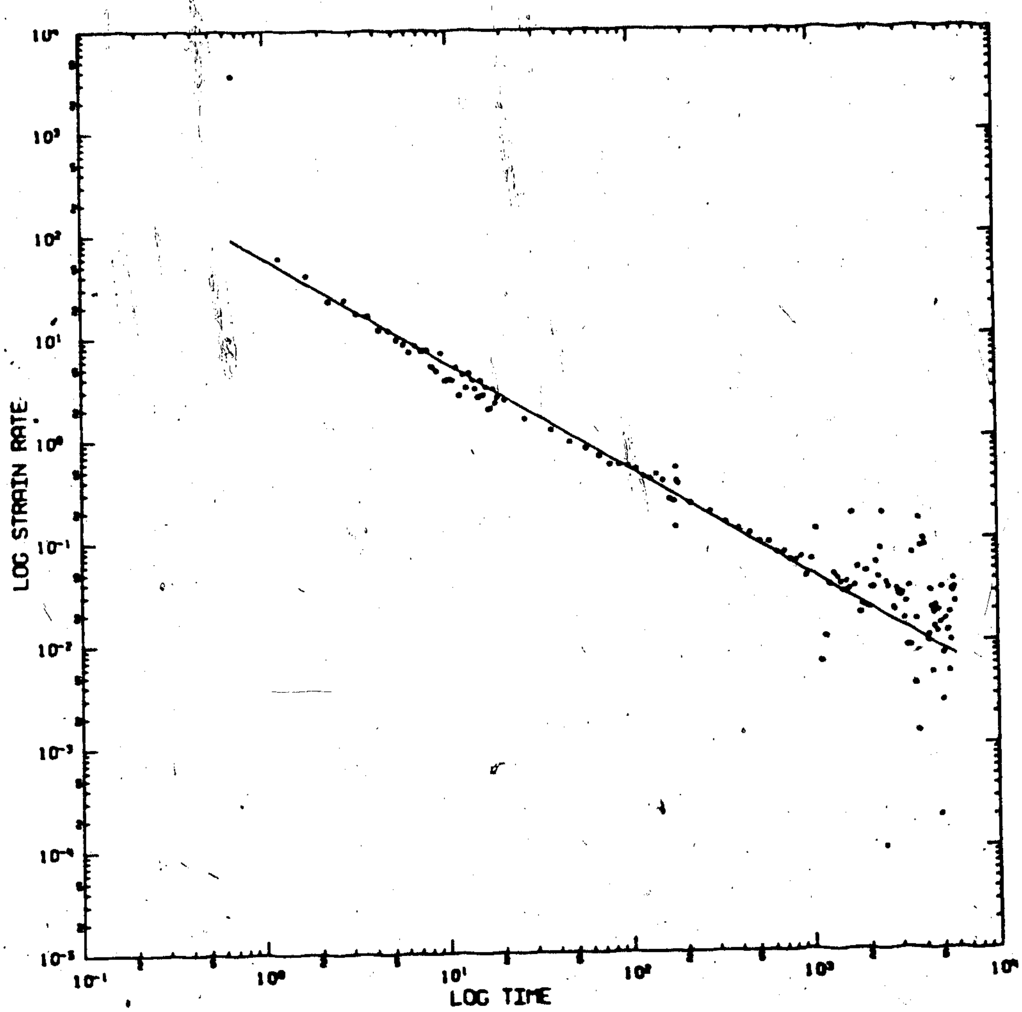
Axial Stress = 3.72 MPa

Figure 4.12 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test CT6A5



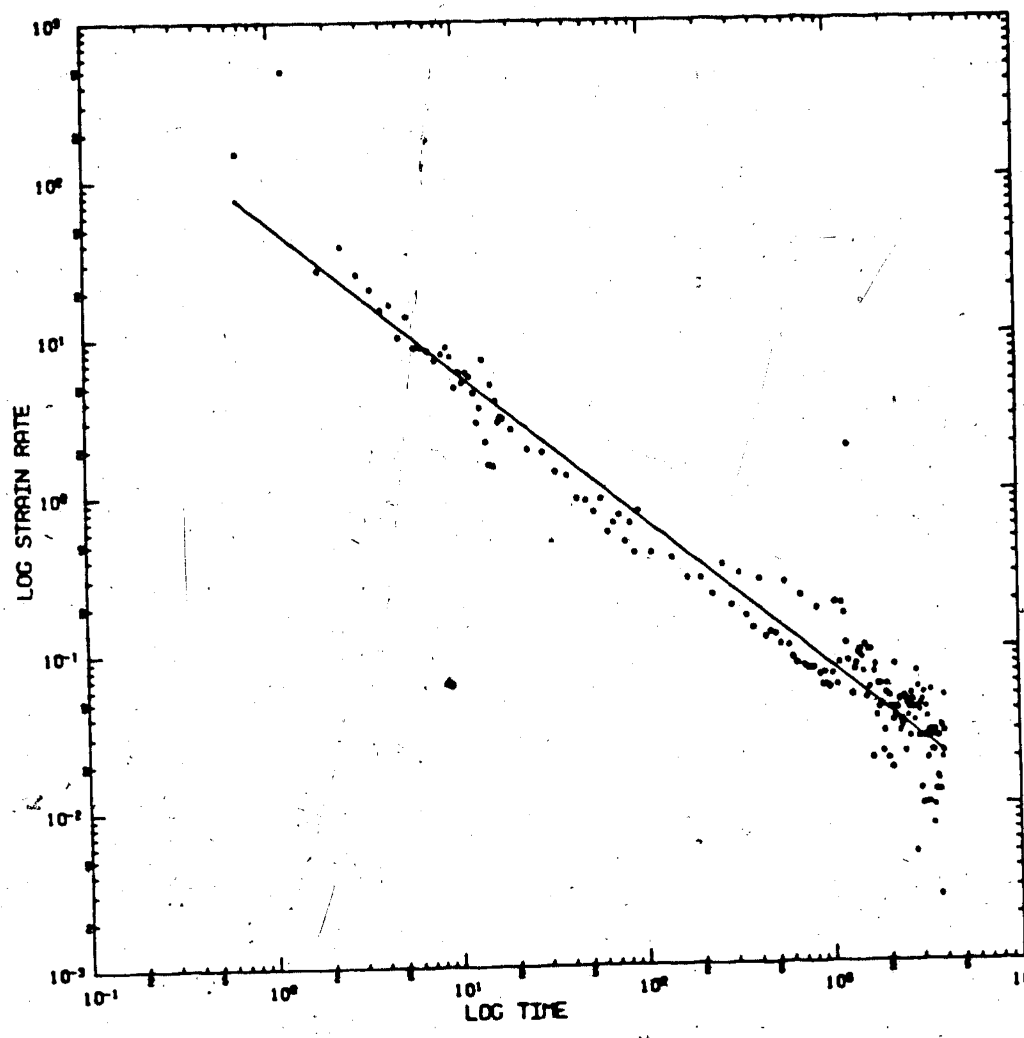
Axial Stress = 3.72 MPa

Figure 4.13 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test CT6A6



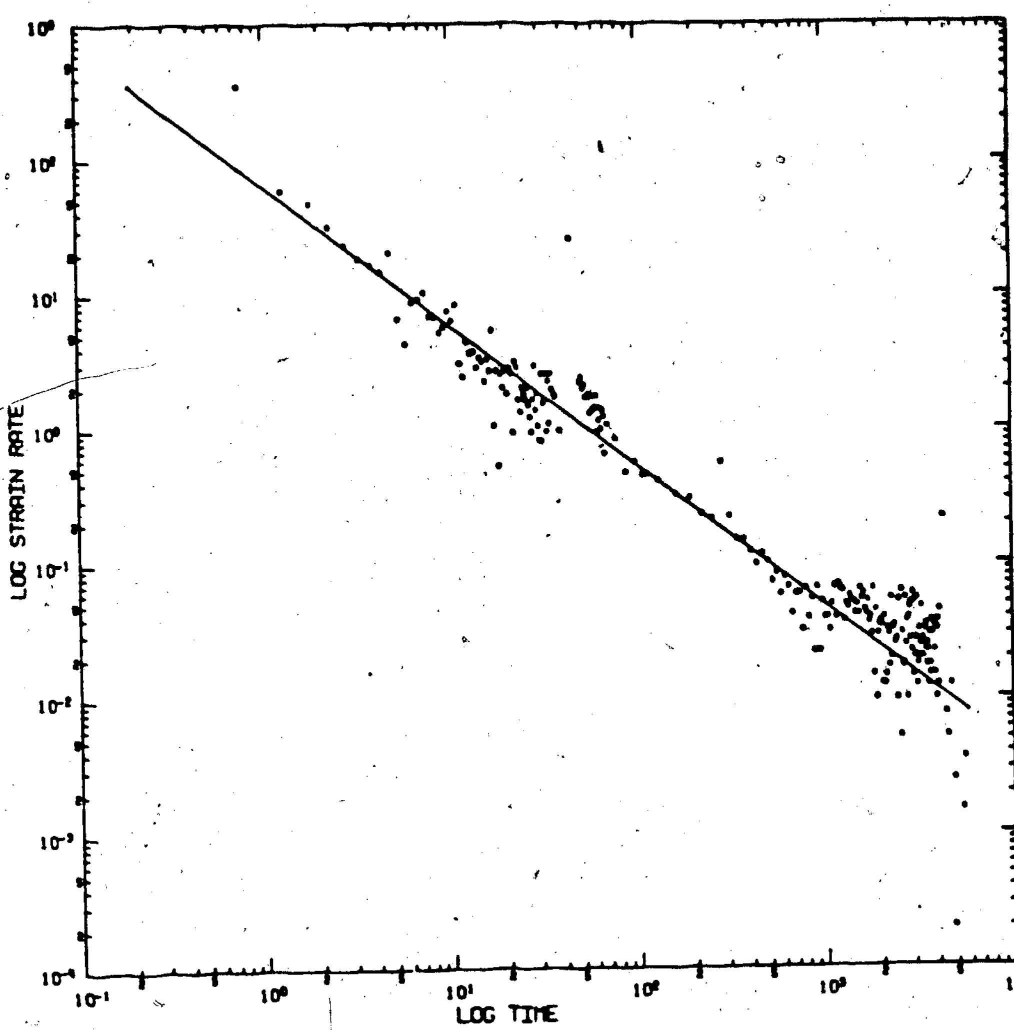
Axial Stress = 3.72 MPa

Figure 4.14 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test CT6A7



Axial Stress = 4.78 MPa

Figure 4.15 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test CT6A8



Axial Stress = 5.32 MPa

Figure 4.16 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test CT6A9

4.2 Comparison with da Fontoura's Test Results

da Fontoura (1980) reported nine single stage creep tests on Wabamun Coal. The method of data analysis was similar to the one mentioned in Section 3.3, except that there was no computer program employed to evaluate accelerating creep. Table 4.4 summarizes da Fontoura's results of nine single stage creep tests.

All of da Fontoura's tests summarized in Table 4.4 were confined tests, with confining pressure ranging from 208 kPa to 553 kPa (da Fontoura, 1980). The effect of confining pressure is to decrease the strain per cracking event and so decreases strain rate and postpones the onset of accelerating creep (Lama, 1978, pp.251-253). The test results summarized in Table 4.1 are from tests carried out with samples which are of a different orientation to da Fontoura's samples. Therefore, the results in Table 4.1 and Table 4.4 can be compared only qualitatively.

Results summarized in Table 4.2 were from tests performed on samples from the second source, samples not used by da Fontoura (1980). Comparing the results of the confined tests in Table 4.2 to results in Table 4.4, the results in Table 4.2 had higher one minute strain rate (strain rate at one minute) values and slightly steeper slopes. da Fontoura (1980) showed that the one minute strain value of the regression analysis was stress level dependent but there was no indication of any relationship between the slope value and the stress level. One can argue that samples

Table 4.4 Summary of regression analysis on single stage creep tests reported by da Fontoura

Test	(MPa) Dev. Stress	log A Intercept	B Slope
CT1	0.70	1.439	-0.896
CT2	0.50	1.380	-0.856
CT3	1.60	1.274	-0.819
CT4	2.20	1.473	-0.882
CT6	2.18	1.479	-1.040
CT7/St1	2.88	1.417	-0.931
CT7/St2	6.00	2.322	-0.810
CT8	3.57	1.428	-0.919
CT9	4.02	1.566	-0.994

not used by da Fontoura were desiccated, even though they were stored in the moisture room, however for a considerably long period of time (about three years). There were more cracks observed in these samples than in the fresh samples. As the samples were weakened by desiccation, the stress level would increase because of the reduced strength. This might be the reason for the high one minute strain values reported in Table 4.2 as compared to da Fontoura's results in Table 4.4. The higher values of B shown in Table 4.2 are probably due to the closure of cracks as load is applied.

4.3 Results from Additional Tests

Two more tests were carried out using Jeremic's (Personal Communication) laboratory apparatus, which were described in detail in Section 3.4. The tests were labelled J9-9#9 and J9-9#11, J stands for the type of tests using Jeremic's apparatus.

There is a slight difference between the laboratory set up and Jeremic's original apparatus. A LVDT is used instead of a dial gauge to monitor the deformation of the sample. The LVDT is a 24-DCDT-250 LVDT manufactured by Hewlett Packard, with a displacement range of ±6.35 millimetres. The LVDT was clamped on to the hydraulic ram and the advance of the ram was recorded as the axial deformation of the sample. A power supply unit capable of providing input voltage of 24 volts was used to feed the LVDT. The displacement was monitored by the Hewlett Packard 3054 data logger and all the observations were stored on a disc with the use of a HP82901M Flexible Disc Drive Unit.

The tests were uniaxial compression test with a constant load applied by a hydraulic ram driven by a hand pump. For Test J9-9#9, the axial stress was 10.65 MPa. The test lasted for approximately twelve days before rupture occurred. The axial stress for Test J9-9#11 was 9.74 MPa and the test lasted for about fourteen days until rupture. In both tests, there were slight bulging in the sample and some spalling from the sample as the test went on. This will result in a reduction of the cross section of the sample taking the load and a consequent increase in the stress acting on the load bearing portion of the sample. It is possible then that these tests are not true creep tests, that is they were not carried out under constant stress.

The double logarithm plots of strain rate versus time of the results from Test J9-9#9 and Test J9-9#11 are presented in Figure 4.17 and Figure 4.18 respectively. The regression analysis for both tests are summarized in Table 4.5.

For the results from Test J9-9#11, fifteen observations had to be truncated from the end of the input file before an accelerating creep law could be fitted to the data. Observations were taken once every two hours at the end of the test, fifteen observations would be equivalent to thirty hours in actual time. The reason for the truncation of the data is that there was too much scatter towards the end of

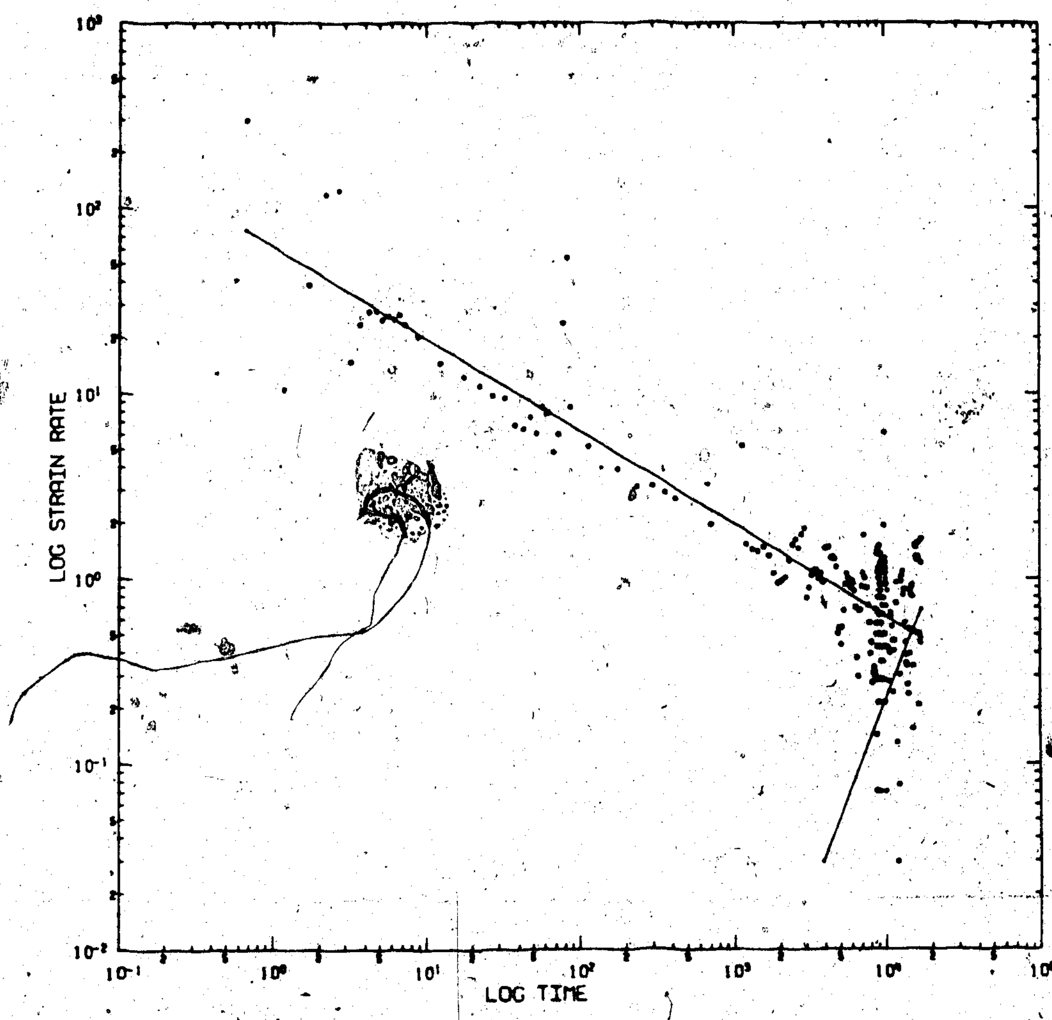
Table 4.5 Summary of fits to Test J9-9#9 and Test J9-9#11

	J9-9#9		J9-9#11	
	Decelerating	Accelerating	Decelerating	Accelerating
Stress (MPa)	10.65	10.65	9.74	9.74
Intercept, log A	2.166	-12.841	1.722	-93.139
Slope, B	-0.770	3.053	-0.492	21.737
ConA	0.110	1.628	0.030	26.448
ConB	0.092	0.405	0.011	6.188
DW	1.662	1.705	1.763	1.942
Slope Significance	70.098	53.783	102.465	10.552
tm (min)	11	10520	364	18793
Total Fit, R		388.931		380.018

Con = confidence limit on following parameter

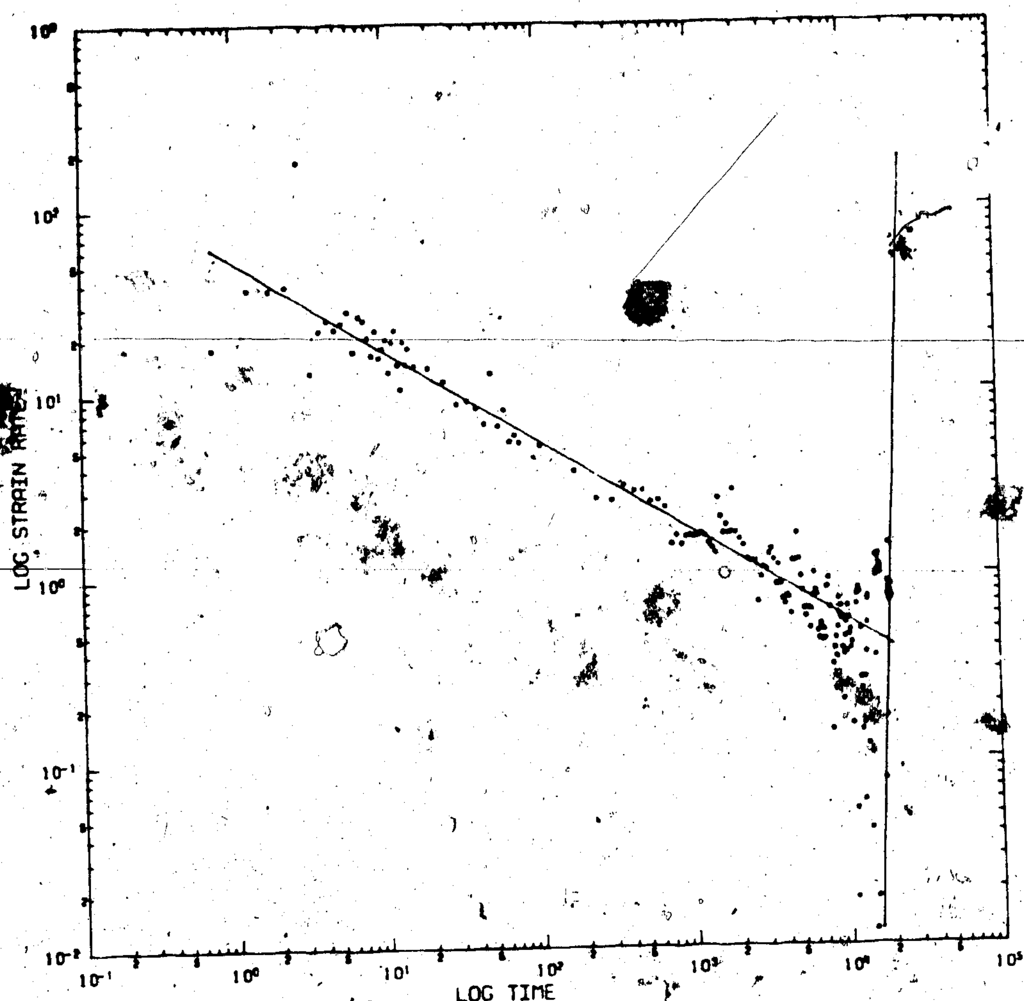
DW = Durbin Watson statistics

[illegible] = mean of the logarithm of time



Axial Stress = 10.65 MPa

Figure 4.17 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test J9-9#9



Axial Stress = 9.74 MPa

Figure 4.18 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test J9-9#11 the test, which creates a problem for the least squares calculation. The scatter is most likely due to the fluctuation in deformation caused by the falling of spalls of material, which will result in a reduction of the cross section of the sample and a consequent increase in the stress and deformation rate. The spalling observed in Test J9-9#11 was more severe than in Test J9-9#9. This would indicate that the stress and deformation rate increase in Test J9-9#11 was higher and the consequent fluctuation in deformation was higher too.

The variability of the material is also an important factor to the deformation properties. [illegible] from the same sampling site may have [illegible] different deformation properties (Kaiser and Maloney, [illegible]) and this is reflected in the experimental observations. The variability of the material is shown by the results from Test J9-9#9, where no data truncation is required for a good fit.

5. Final Remarks

5.1 Discussion of Test Results

The test results from each laboratory test were fitted to a decelerating power law and the decelerating fits to all the tests were summarized in Table 4.1 and Table 4.2. The results in Table 4.1 were from tests carried out with fresh samples from the sampling site, while Table 4.2 contained results from tests performed on samples not used by da Fontoura (1980).

da Fontoura's samples were drilled from a block sample with their long axis parallel to their bedding planes and at an angle of 30° with the major cleat. This orientation would give the sample the minimum axial strength due to the presence of the major cleat at 30° to the long axis (Hoek and Brown, 1980, pp. 157-165), and it would also cause pre-existing cracks that were parallel to the cleavage to rupture in shear when loaded axially in compression. For samples that were drilled with their long axes perpendicular to their bedding planes, cracks that were parallel to the bedding would be closed but would not rupture in shear as load is applied.

By comparing the C-test results in Table 4.1 and Table 4.2, one can calculate the strain rates by assigning a log t value to the power laws and find out that the C-tests in Table 4.2 are creeping at a faster rate than those in Table 4.1 as time increases. For example, compare test C9-9#8 from

Table 4.1 to test CT6A6 from Table 4.2. When (log t) is 1.0, (log $\dot{\epsilon}$) for test C9-9#8 and CT6A6 are 0.639 and 0.611 respectively. When (log t) is 2.0, (log $\dot{\epsilon}$) for test C9-9#8 is -0.625 as compared to -0.397 for test CT6A6. This showed that samples drilled with their axes at 30° to the joint are creeping more rapidly than those samples drilled with their axes perpendicular to the bedding planes. This is the kind of result that one would expect as a result of difference in orientation in the two types of samples.

The slope values in Table 4.1 were higher than those reported in Table 4.2. This could probably be explained by the difference in orientation of the samples. The slope value is a strain-hardening parameter measuring the rate of the decrease of strain rate with time. Cruden (1970) suggested that for slope values that are less than -1, the creep strains will approach a finite value. For slope values that are greater than -1, the creep strain will increase to a critical creep strain where accelerating creep begins. There was only one test, Test U9-9#9, showed accelerating creep. This test has a slope of -1.059 for the decelerating fit, which is the least value of slope in Table 4.1. Taking the confidence limit of the slope value into account, Test U9-9#9 could have a slope value greater than -1.

Test U9-9#9 was the only test in which an accelerating creep regression line could be fitted to the data. The accelerating creep shown was not as prolonged as the Star-Key Coal test because the test was not carried out to rupture.

In the C-tests, the application of confining pressure restricted the lateral displacement of the samples and they became stronger (Jaeger and Cook, 1969, pp. 86-88). Confining pressure also decreases strain rate and strain per cracking event, which in turn postpones the onset of the accelerating creep.

Hoek (1965) showed that rock strengths are moisture sensitive. The strength of rock is reduced when 'wet' and the influence of moisture is more pronounced in the case of materials such as coal (Hoek, 1965, pp. 118-122). In Table 4.1, results from the S-tests did not show any distinct difference from other type of tests. This may be due to the fact that samples for the S-tests were submerged in water for only 24 hours prior to testing, while in Hoek's report, 'wet' referred to samples submerged in water for 120 days.

Cruden (1974) developed a static fatigue law which relates the strength of the material to the time that it had been under stress. The form of the law depends on the relationship between stress and creep rate, i.e., the form of the stress dependence of the creep rate. In an attempt to find the form of the stress dependence of the creep rate of coal, tests were grouped by the source of samples and then grouped again by the type of tests. As the slope values of the decelerating fits from most of the test results were less than -1 and a wide range of stresses was not used in each group of tests, the form of stress dependence of the creep rate could not be found.

The same static fatigue law was applied to test results reported by da Fontoura (1980). The form of stress dependence of the creep rate could not be found either because the points on the double logarithm plot of the ratio of the strain rates versus the ratio of the stresses were too scattered for a significant linear regression.

The test results presented in Table 4.1 and Table 4.2 all showed a slope value of the decelerating fit of less than -1. This prevented the calculation of the critical strain for the onset of the accelerating creep. Tests carried out with Jeremic's apparatus, Test J9-9#9 and Test J9-9#11 were the only tests that had an accelerating fit and the slope of the decelerating fit greater than -1. By integrating the decelerating power law and taking the intersects of the decelerating and accelerating fitted lines as the time when accelerating creep started. The critical strains for Test J9-9#9 and Test J9-9#11 were calculated as 1.5251 and 1.5276 percent strains, respectively.

In this research program, the variability of the coal represents a major source of problems. From the results of the sample characterization presented in Table 2.1, one can calculate the mean and the standard deviation of the compressional elastic wave velocities, Vp. The standard error of the mean can be calculated by dividing the standard deviation by the mean. The standard error of the mean of the compressional elastic wave velocities of the fresh samples is calculated as 0.1378 and for da Fontoura's samples is 0.0505. Cruden (1969) listed values of the compressional elastic wave velocities of samples of Carrara Marble and Pennant Sandstone. The standard error of the mean of the compressional elastic wave velocities of Carrara Marble is 0.0384 and for Pennant Sandstone is 0.0075. By comparing these figures, one can conclude that coal is a more variable material than Carrara Marble and Pennant Sandstone.

Kaiser and Maloney (1982) investigated the deformation properties of a Sub-bituminous coal mass from the same site by conducting a series of compression tests on large block samples of coal. The variability of the Young's Modulus, E, of the coal mass was between 0.95 GPa to 3.25 GPa for one sample and between 0.45 GPa to 2.90 GPa for the other sample. They concluded that coal is a highly heterogeneous material and the bulk, K, and the Young's Modulus, E, can vary widely within a small area. Therefore, one can reasonably argue that the lack of obvious stress dependence of the creep rate in the test results is due to the variability of the coal samples.

da Fontoura (1980) suggested that for the decelerating power law, the one minute strain rate , A, is stress dependent but the slope, B, is essentially independent of the stress applied. Using the test results of the single stage creep tests reported by da Fontoura (1980) in Table 4.4, the plots of (log A) versus (stress) and B versus stress were presented in Figure 5.1 and Figure 5.2, respectively.

In da Fontoura's results, the result from creep test CT7/st2 was excluded from Figure 5.1 and Figure 5.2 because it was the second stage of a multiple stage creep test. In the legend for both Figure 5.1 and Figure 5.2, the first letter represents the type of test, the numbers represent the angle between the sample axis and the major joint or the bedding planes. The last two letters in the legend stand for the initials of the person who reported the tests. The infilled symbols are tests with sample axes perpendicular to bedding planes. The crosses are tests carried out using Jeremic's apparatus.

In Figure 5.1, the one minute strain rate, A, has a unit of micro-strains per minute. There were no obvious stress dependence of A after the exclusion of test CT7/st2 from da Fontoura's results. Results from laboratory tests reported in Section 4.1 were also plotted in Figure 5.1, they seemed to support the same statement.

The plot of slope, B, versus stress is presented in Figure 5.2. For each group of tests represented by the legend, there seemed to be no direct relationship between the slope of the decelerating power law and the stress applied.

Therefore, it is reasonable to suggest that for a selection of coal specimens subject to single stage creep tests, the one minute strain rate and the slope of the fitted decelerating power law show no clear dependence on

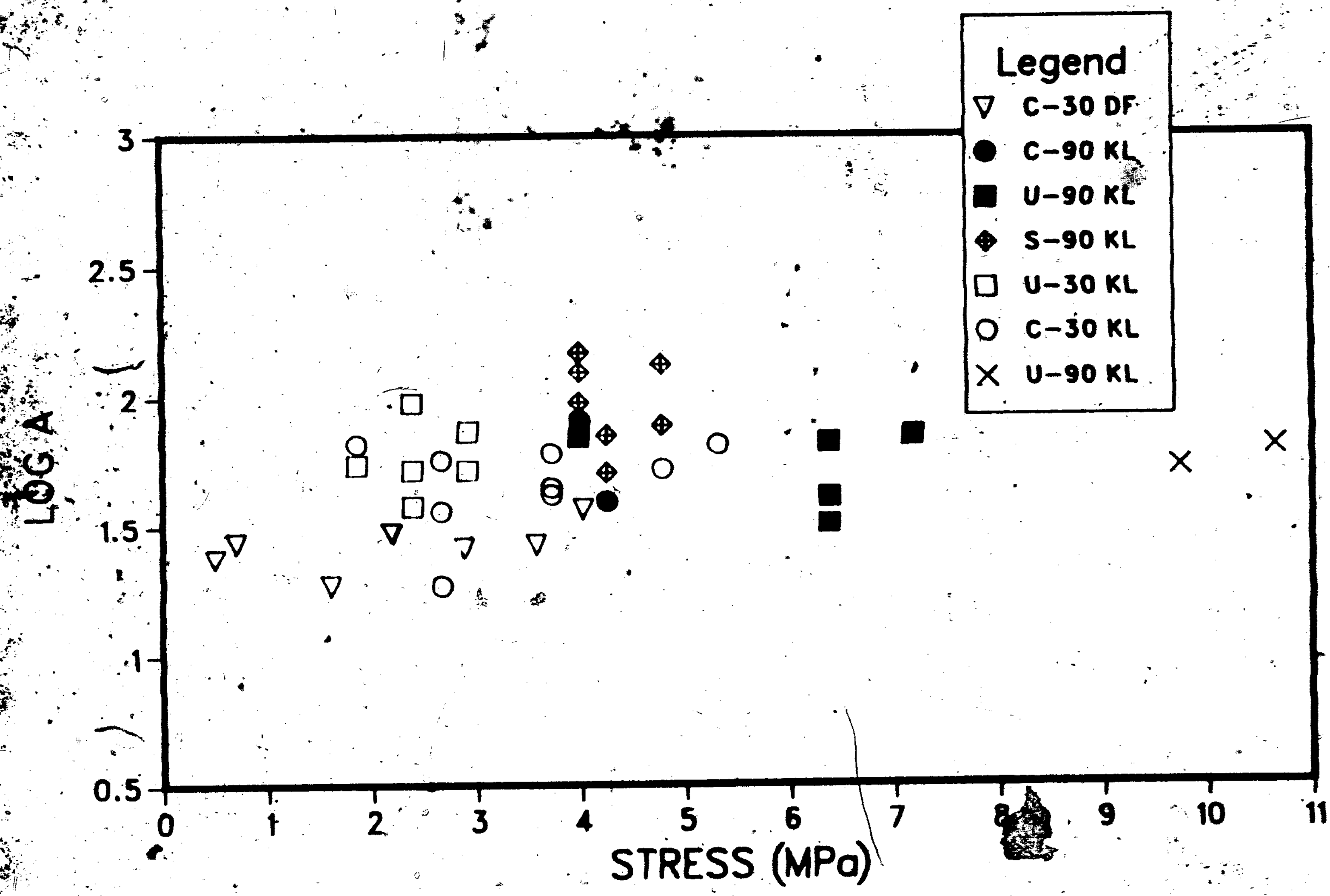


Figure 5.1 Plot of (log A) vs (stre

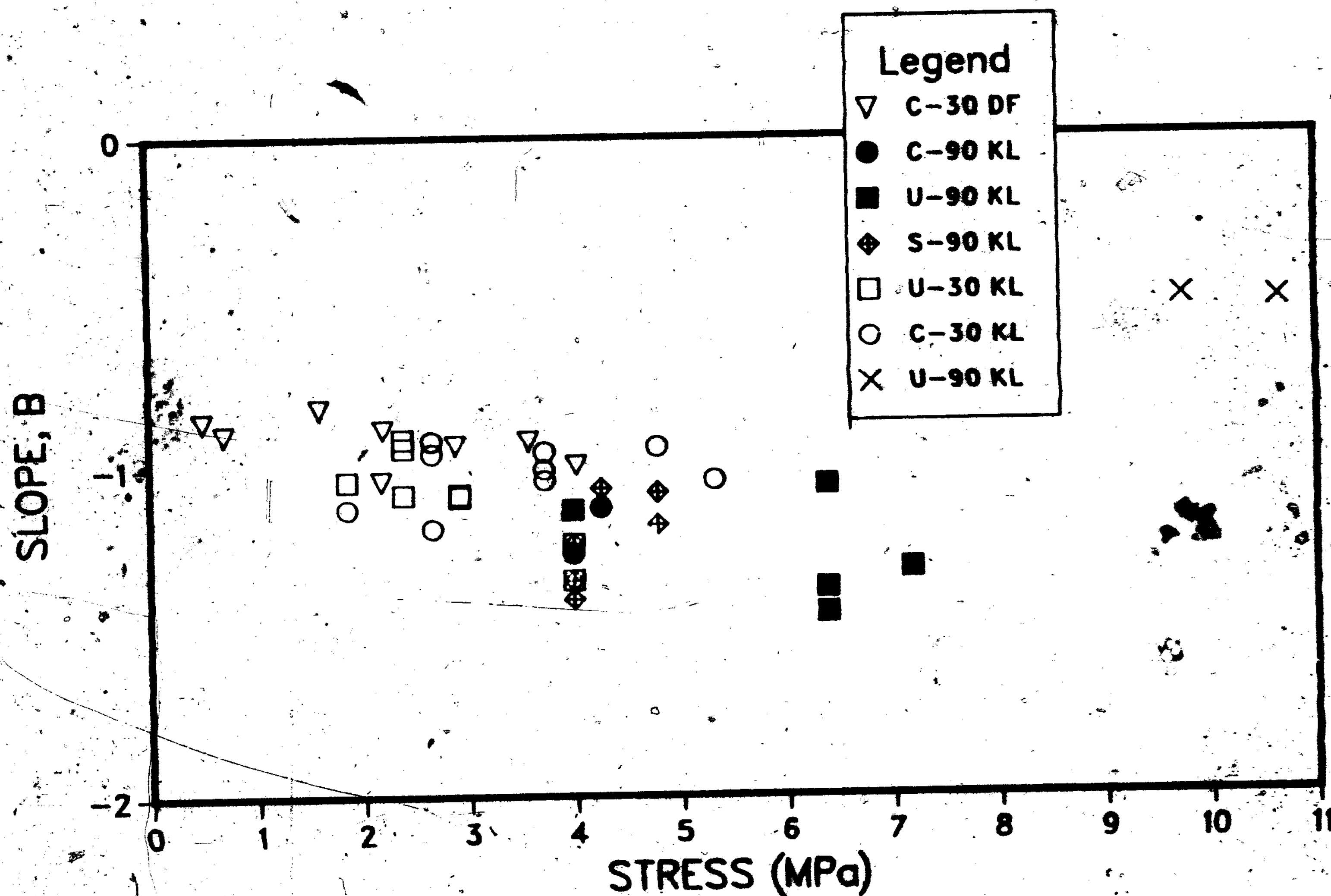


Figure 5.2 Plot of (Slope, B) vs (Stress)

the stress applied.

For tests at higher stresses, samples with parameter B less than -1 are creeping under stresses below their long term strength. Examination of Figure 5.2 shows that the parameter B of the tests represented by the crosses are greater than -1, thus they are creeping under stresses above their long term strength. Test U9-9#9 could possibly be creeping under a stress above its long term strength because its B value is so close to 1 and it appears to have shown accelerating creep.

5.2 Summary and Conclusion

Coal samples were obtained from the Highvale Mine, Alberta. These samples together with those not used by da Fontoura (1980) were used for the creep experiments. The creep rig shown in Figure 2.3 was used and all the experimental observations were conditioned, processed and analyzed with the computer package CPACK.

The experimental data were first fitted with a decelerating power law as suggested by Cruden (1971a), and the fitting of an accelerating power law was also investigated. The test results from the Star-Key Coal test carried out by Jeremic (Personal Communication) showed that it is possible to describe the accelerating creep with an accelerating power law. The results from this experimental program were summarized in Table 4.1 and Table 4.2. Most of the double logarithm plots of strain rate versus time were shown in Figure 4.1 to Figure 4.16 and the rest of the plots were put together in Appendix B.

For those experiments that showed accelerating creep, the use of an accelerating power law seemed to describe the accelerating creep adequately. Therefore it may be concluded that the entire creep curve can be described by two power laws as follow:

$$\epsilon = At^{B} + Ct^{D} \qquad (3.4)$$

The attempt to find the stress dependence of the creep rate of a model coal pillar was frustrated by the variability of the material. The Young's Modulus, E, of coal can vary widely within a relatively small area, which indicates that samples from the same sampling site can have much different deformation properties. This suggests that the parameters of the creep curves determined in the tests cannot be reliably be scaled up for design purposes.

5.3 Recommendations

To avoid the problem of material variability, one may match samples by the value of compressional elastic wave velocity, Vp, from a much larger group of samples. However, one major problem is that sampling in coal is not an easy task.

Another alternative is to perform increment tests. Cruden (1983) suggested that the stress dependence of creep rate can be determined by an increment test on a single rock specimen. Such a test eliminates variation caused by variation of physical properties between specimens.

Further research, using one of these two alternatives might allow the determination of the physical parameters controlling the creep of coal. However, results from both alternatives may be misleading. The heterogeneity of coal induces stress concentration which may accelerate creep, and cause failure modes which may not appear in more uniform specimens.

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APPENDIX A

CPACK USER's MANUAL

PROGRAM: CPACK

This program analyzes data from creep experiments to identify both the decelerating and accelerating components of creep.

CPACK calls the Subroutine CRED to reduce the experimental data and compute engineering strains.

The Subroutine BFIT is then called to convert the strains into strain rates, and to obtain a best fit of a power law to the initial portion of the strain rate data.

The best fit decelerating strain is then computed in the Subroutine INTEG by integrating the power law expressions for decelerating strain rate obtained in BFIT. This decelerating strain is then subtracted from the experimental strain to leave accelerating strain.

BFIT is called again to fit a power law to the accelerating strains computed in INTEG. On this call to BFIT, a fit is made of the latter portion of the data.

At this point the user has the option of calling subroutine CFIT, which generates a table of fit parameters and statistics for a number of trial fits of the accelerating data. This allows the user to select the optimum overall fit of a power law expression to the data.

Subroutine CPLOT is then called to produce two plots of the data: Time vs Strain rate, and Log Time vs Log Strain rate.

Capabilities

> The maximum number of records of data is 1000.

> The program can accept data in the standard form indicated below, or in user specified forms.

> The maximum number of LVDTs is two.

> User responses to prompts must be in capital letters, or if numbers, must be terminated with a comma.

> The first minutes of a creep experiment may show strains that reflect changes of the load on the specimen. These changes may cause problems in the program. Judgement should therefore be used in selecting the first records to be processed.

> If the data does not contain accelerating creep, the program will likely generate error messages on the second call to BFIT. If this is anticipated, the user can choose to plot the decelerating creep data before the program attempts to isolate accelerating creep.

> The graphs that subroutine CPLOT can generate are optional.

INPUT

UNIT 4 - Disk - Input Data File

The standard input data file is described in Table 1, although other formats can be specified by the user in the prompt sequence.

Record length is 109 bytes. Twelve variables are read in each record with the format (7X, 5I2, IX, I5, 2I3, 4G20).

This file is output from an HP 3054 Data Logger.

TABLE 1 - INPUT DATA FILE FORMAT

VARIABLE NO.	COLUMNS	SPECIFICATIONS
1	008 - 009	Integer, Time - Month
2	010 - 011	Integer, Time - Day
3	012 - 013	Integer, Time - Hour
4	014 - 015	Integer, Time - Minute
5	016 - 017	Integer, Time - Second
9	030 - 049	Real, Load
10	050 - 069	Real, Cell Pressure
11	070 - 089	Real, Defl. Reading LVDT #1
12	090 - 109	Real, Defl. Reading LVDT #2

UNIT 5 - Terminal-User Responses to Interactive Prompts

The user is prompted for the sample dimensions, and the input data file format, if it deviates from the standard format. If the plotting option is chosen, the user is asked to input the length, scale, and origin of each axis, for the Time vs Strain Rate graph. The default for these parameters is a 10in X 10in graph containing the entire range of data.

OUTPUT

UNIT 6 - Terminal - Interactive Prompts

UNIT 7 - Printer

The maximum record length is 84 bytes. Sample dimensions and a table of strain and time are output on this unit. In addition, a table of transformed data, and fit parameters are printed for each strain gauge, for both accelerating and decelerating creep. A table of fit parameters for a number of trial fits can also be output, if desired, to allow the user to select the optimum overall fit.

UNIT 9 - Output File - PDF

PDF is the Plot Description File. This is the information required by the Calcomp plotter to plot the graphs.

UNIT 98 - Output File - Summary

Output in the form of a summary for each plot is contained in - summary.

STORAGE REQUIREMENTS

Code: CPACK Bytes: 57, 344

Disc Pages: 14

SUBROUTINES

CRED

Reduces experimental creep data, and computes engineering strain

SOLUTION

The time clock readings are converted to elapsed time in hours.

Engineering microstrains, ESTRN(J), are computed from the deflection readings, RDEF(J), using the following algorithm:

VDEF(J) = RDEF(J) - RDEF(1)

ESTRN(J) = (VDEF(J)/XLEN) X 1000000 X FACT

Where XLEN is the sample length and FACT is the LVDT calibration factor.

CRED writes the sample parameters, initial readings, and a table of time and engineering strain.

Calling Sequence: CALL CRED (DIAM, XLEN, NRR, E1, E2, TT, XANS1, IANS3, ISAM1, ISAM2, EZPST, ESTRN1, ESTRN2)

DIAM - Sample Diameter

XLEN - Sample Length

NRR - Number of records passed on to BFIT

XANS1 - Interactive response re: Is data in Standard Form?

IANS3 - Number of deflection guages

ISAM1, ISAM2 - Sample number

EZPST - Elapsed time

ESTRN1 - Engineering strain for LVDT #1

ESTRN2 - Engineering strain for LVDT #2

TT, E1 and E2 are identical to the above three variables respectively, except that the first record is deleted. These three are the variables passed on to BFIT.

BFIT

Fits a power law to the experimental data.

SOLUTION

The strains are made consistently, increasing by using an averaging technique, outlined on p. 113 (Cruden, 1971a) which smooths out the portions of the data where the strains decreases. These strains are then converted to strain rates. Logarithms of time and strain rate are then taken, to allow a least squares linear regressions to fit a power law to the data.

The program computes the Durbin Watson Statistic and the Test of Slope Significance (Cruden, 1971) to evaluate the goodness of fit. If the Durbin Watson Statistic is less than the tabulated upper limit, or if the Slope Significance is less than 10, the last record is deleted and the fitting process is repeated with the remaining records. This continues until the statistical limits are satisfied, and a fit of the initial portion of the data is achieved. This yields a power law expression for the strain rate of decelerating creep.

On the second call to BFIT the data contains accerelating creep strains, output from subroutine INTEG.

The program proceeds as for decelerating creep on the first call, except that each time the statistical limits orient satisifed, it deletes the earliest record, until a satisfactory fit of the latter portion of the data is achieved. The program then writes the remaining data records in the fit, along with the slope, intercept, and other statistical parameters, including the confidence limits on the slope and intercept.

The estimates of the slope and intercept follow the statistical t-distributions, so to obtain the percentile values of confidence limits of these estimates, the user should consult the widely available t-distribution tables, and determine the percentile value that corresponds to the confidence limit listed in the output, for the number of degrees of freedom associated with the data. A fit is made for each strain gauge.

<u>Calling Sequence:</u> CALL BFIT (NRR, E1, E2, TT, L, N, BB0, BB1, XANS1, IANS3, LT, LE, W1, EEM1, NC1, K, OO, FF, DW, MMM, ANSM3, NRF)

Variables not defined previously:

L - Indicates type of data

L = 1 - decelerating creep

L = 2 - accelerating creep

N - record number

BB0 - array containing intercepts of fitted lines

BB1 - array containing slopes of fitted lines

The following variables are either passed to, or received from subroutine CFIT:

LT, LE, and W1 - arrays that contain log time, log strain rate, and the record weighting respectively, calculated in the first iteration of BFIT.

NC1 - number of records in above arrays

EEM1 - intermediate value used in calculating the slope significance statistic.

K - number of the first record used in the fit of the accerelating creep data

OO - counter to terminate CFIT

FF - slope significance statistic

DW - Durbin Watson statistic

MMM - LVDT counter

ANSM3 - Interactive response that indicates whether or not to use CFIT

NRF - number of the last record used in the fit of the decelerating creep data

INTEG

Integrates the power law expressions for decelerating strain rate to obtain decelerating strain for each record.

SOLUTION

INTEG takes the fit parameters for decelerating strain rate from the first call to BFIT, and performs an integration to obtain the decelerating strain that corresponds to the best fit strain rate, according to equations [2] and [4] on page 520 of Cruden, 1971b.

The strain due to accelerating creep is then obtained by subtracting the decelerating strains from the experimental strains.

This is done for the data from both strain gauges.

Calling Sequence: CALL INTEG (E1, E2, BB0, BB1, NRR, TT, L, XANS1, IANS3)

CFIT

The fit of a power law to the data that is achieved in subroutine BFIT is a satisfactory fit, not a best fit, because the fitting process is stopped once the minimum statistical requirements are satisfied. The fits that this gives are usually close to optimum for decelerating creep, but can be significantly different from optimum for accelerating creep.

In CFIT a number of trial fits of the accelerating creep that satisfy the minimum statistical requirements are examined, to identify the best fit of the accelerating creep and the best overall fit.

SOLUTION

CFIT calculates the strain rates for the overall fit, by combining the fits of the decelerating and accelerating components. It then calculates the ratio, R, of the square of the scatter of the data points about their mean to the squares of the scatter about this overall fit, a measure of the goodness of fit.

The range of data used to calculate the accelerating creep fit is then decreased to the next smallest range that meets the statistical requirements. Control is then transferred back to subroutine BFIT, which fits a power law to this new range of data. The resulting accelerating fit parameters are transferred to CFIT, which evaluates the overall fit obtained with the new parameters.

This process is repeated until the overlap between the accelerating and decelerating creep goes to zero, or until the accelerating strain rate come to within one third of the decelerating strain rate at the beginning of the range of data used for the fit of accelerating creep.

The parameter and statistics corresponding to each trial fit are tabulated, to allow the user to identify the best fit.

Calling Sequence: CALL CFIT (EEM1, LT, LE, W1, BB0, BB1, NC1, K, 00, FF, DW, MMM, NRR, NRF)

All of these variables have been defined previously.

CPLOT

Produces plots of Time vs Strain Rate, and Log Time vs Log Strain Rate with best fit lines.

SOLUTION

CPLOT calculates strain rates for both the experimental strain output from CRED, and the accelerating strain calculated in INTEG, and then eliminates all of the negative strain rates.

If the user desires a Time vs Strain Rate graph, the program calculates and writes the extreme values for this graph, and then prompts the user for axis parameters.

The CIVE Subroutine GRAPH is then called to plot Time vs Experimental Strain Rate.

If the user desires a Log Time vs Log Strain Rate graph, the coordinates of the best fit lines are calculated, and GRAPH is called to plot: experimental strain rates, deceleration best fit line and, if available, acceleration best fit line.

The CIVE subroutine GRAPH has an interactive prompt sequence consisting of the following six Menu Options:

1. Plot
2. Blow-up
3. Redraw
4. Subpictures
5. Mts-sds
6. Continue

The user simply responds to the prompt by inputing the number of the desired option. Normally the user would choose Option 1, followed by Option 6, if a hard copy of the plot is desired. For more detailed information, consult the documentation for GRAPH, in the Library file:

CIVE: GRAPH.DOC.

One set of graphs is produced for each strain gauge.

Calling Sequence: CALL CPLOT (ESTRN1, ESTRN2, ELPST, BB0, BB1, NRR, ISAM1, ISAM2, XANS1, IANS3, ANSM1)

Variables not defined previously:

ANSM1 - user response to prompts indicates if user wants decelerating creep data plotted separately.

The command to execute this program is as follows:

```
$run CIVE:CPACK 4=DATA 7=-FILE T=4SEC
```

Note: A time limit should be specified, and four seconds is adequate for data files with less than 500 records.

The command to obtain a hard copy of the graphs generated in the program is as follows:

```
$run *CALCOMPQ PAR=FILE=-PDF FORM=WDWH
```

REFERENCES

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CPACK Program Listing

```
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
CCCCC                                                      CCCCC
CCCCC                      PROGRAM CPACK                   CCCCC
CCCCC                                                      CCCCC
CCCCC        A PACKAGE OF PROGRAMS THAT WILL REDUCE        CCCCC
CCCCC        CREEP DATA, AND FIT A POWER LAW TO IT,        CCCCC
CCCCC        SEPARATING THE DATA INTO ACCELERATING         CCCCC
CCCCC                AND DECELERATING CREEP                CCCCC
CCCCC                                                      CCCCC
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc

      DIMENSION N(1000),BB0(2,2),BB1(2,2),E1(1000),E2(1000),
     *          TT(1000),ELPST(1000),ESTRN1(1000),ESTRN2(1000),
     *          LT(2,1000),LE(2,1000),W1(2,1000),EEM1(2),NC1(2)
C
      CALL CRED (DIAM,XLEN,NRR,E1,E2,TT,XANS1,IANS3,
     *           ITN1,ITN2,ELPST,ESTRN1,ESTRN2)
C
      REAL Y/'Y'/
      DATA MMM/1/
      OO=O
      K=O
      L=1
      NFIT=O
      WRITE(7,100)
  100 FORMAT(//20('*'),' FIT OF DECELERATING CREEP DATA TO ',
     *'POWER LAW ',20('*'))
C
C     INTERACTIVE PROMPT
C
      WRITE(6,200)
  200 FORMAT('WOULD YOU LIKE THE DECELERATING CREEP DATA'/
     *'PLOTTED BEFORE THE PROGRAM ATTEMPTS TO ISOLATE'/
     *'ACCELERATING CREEP?')
      READ(5,300) ANSM1
  300 FORMAT(A1)
      ANSM2=O.
C
      WRITE(6,202)
  202 FORMAT('WOULD YOU LIKE THE PROGRAM TO EXAMINE THE '/
     *'ACCELERATING DATA FOR AN OPTIMUM FIT?')
      READ(5,302) ANSM3
  302 FORMAT(A1)
C
      CALL BFIT (NRR,E1,E2,TT,L,N,BBO,BB1,XANS1,IANS3,LT,LE,
     *           W1,EEM1,NC1,K,OO,FF,DW,MMM,ANSM3,NRF,NFIT)
C
      IF(ANSM1.EQ.Y) GO TO 60
C
   50 CALL INTEG(E1,E2,BBO,BB1,NRR,TT,L,XANS1,IANS3)
C
      L=2
      WRITE(7,101)
  101 FORMAT(//20('*'),' FIT OF ACCELERATING CREEP DATA TO ',
     *'POWER LAW ',20('*'))
C
   55 CALL BFIT (NRR,E1,E2,TT,L,N,BBO,BB1,XANS1,IANS3,LT,LE,
     *           W1,EEM1,NC1,K,OO,FF,DW,MMM,ANSM3,NRF,NFIT)
```

```
C
      IF(ANSM3.NE.Y) GO TO 60
      IF(DO.EQ.2) GO TO 60
      CALL CFIT(EEM1,LT,LE,W1,BB0,BB1,NC1,K,DO,FF,DW,MMM,NRR,NRF)
C
      K=K+1
      GO TO 55
C
   60 CALL CPLOT(ESTRN1,ESTRN2,ELPST,BB0,BB1,NRR,ITN1,ITN2,
     *            XANS1,IANS3,ANSM1,ANSM2)
C
      IF(ANSM1.NE.Y) GO TO 999
      IF(NFIT.EQ.1) GO TO 555
C
C     INTERACTIVE PROMPT
C
      WRITE(6,201)
  201 FORMAT('WOULD YOU LIKE THE PROGRAM TO ATTEMPT TO FIT'/
     *'YOUR DATA TO ACCELERATING CREEP AS WELL?')
      READ(5,301) ANSM2
  301 FORMAT(A1)
      IF(ANSM2.NE.Y) GO TO 999
      ANSM1=O.
      GO TO 50
  555 WRITE(6,401)
  401 FORMAT('THE ENTIRE SET OF DATA IS FITTED TO THE'/
     *'DECELERATING CREEP')
  999 STOP
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCC                                                        CCCCC
CCCCC                    SUBROUTINE CRED                     CCCCC
CCCCC               REDUCES EXPERIMENTAL DATA                CCCCC
CCCCC                                                        CCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      SUBROUTINE CRED (DIAM,XLEN,NRR,E1,E2,TT,XANS1,IANS3,
     *ITN1,ITN2,ELPST,ESTRN1,ESTRN2)
      DIMENSION RLOAD(1000),RDEF1(1000),RDEF2(1000),IMN(1000),
     *          TIME(1000),VDEF1(1000),VDEF2(1000),IDY(1000),
     *          ESTRN2(1000),RCELLP(1000),ESTRN1(1000),
     *          IHR(1000),IMI(1000),ISE(1000),ELPST(1000),
     *          E1(1000),E2(1000),TT(1000),VAR(12,1000),XNAME(12)
C
C
      REAL Y/'Y'/,H/'H'/,M/'M'/,TH/'TH.'/,R1/'R1.'/,R2/'R2.'/,
     *DU/'DU.'/,TM/'TM.'/,TN/'TN.'/,TD/'TD.'/,TS/'TS.'/,FACT/1.0/,
     *YYY/'y'/,NNN/'n'/
      REAL IMN/1000*0./,IDY/1000*0./,IHR/1000*0./,
     *     IMI/1000*0./,ISE/1000*0./
C
C     PROMPTS FOR INPUT PARAMETERS
C
      WRITE(6,150)
  150 FORMAT('THIS PROGRAM ACCEPTS DATA IN THE FOLLOWING FORMAT:'/
     *'LABEL,TIME CLOCK,3 COUNTERS,LOAD,CELL PRESSURE,DEF.1,DEF.2'
     */'IS YOUR DATA IN THIS FORM? (Y,N)')
   11 READ(5,250)XANS1
```

```
  250 FORMAT(A1)
      IF(XANS1.NE.YYY.AND.XANS1.NE.NNN) GO TO 12
      WRITE(6,261)
  261 FORMAT('*ERROR* ALL RESPONSES MUST BE IN UPPER CASE LETTERS,'
     */'RE-ENTER RESPONSE TO PREVIOUS QUESTION:')
      GO TO 11
   12 WRITE(6,151)
  151 FORMAT('DO YOU HAVE AN LVDT CALIBRATION FACTOR?')
      READ(5,251)XANS2
  251 FORMAT(A1)
      IF(XANS2.NE.Y) GO TO 199
      WRITE(6,160)
  160 FORMAT('INPUT THE LVDT CALIBRATION FACTOR (MULTIPLIER):')
      READ(5,260)FACT
  260 FORMAT(F10.5)
  199 WRITE(6,152)
  152 FORMAT('INPUT DIAMETER(MM),LENGTH(MM),AND WEIGHT(GM),'
     */'SEPARATED BY COMMAS:')
      READ(5,252)DIAM,XLEN,WEIG
  252 FORMAT(3F10.3)
      WRITE(6,153)
  153 FORMAT('INPUT SAMPLE NUMBER (8 CHARACTER MAX.):')
      READ(5,253)ISAM1,ISAM2
  253 FORMAT(2A4)
      WRITE(6,154)
  154 FORMAT('INPUT TEST NUMBER (8 CHARACTER MAX.):')
      READ(5,254)ITN1,ITN2
  254 FORMAT(2A4)
C
C     WRITE INPUT PARAMETERS
C
      WRITE(7,20)ITN1,ITN2
   20 FORMAT(/,'TEST NUMBER      = ',2A4)
      WRITE(7,21) ISAM1,ISAM2
   21 FORMAT(/,'SAMPLE NUMBER    = ',2A4)
      WRITE(7,22) XLEN,DIAM,WEIG
   22 FORMAT(/,'SAMPLE LENGTH    = ',F10.3,' mm',
     *        /,'SAMPLE DIAMETER  = ',F10.3,' mm',
     *        /,'SAMPLE WEIGHT    = ',F10.3,' gm')
      IF(XANS1.EQ.Y) GO TO 23
C
C     PROMPT FOR INPUT FORMAT (NON-STANDARD)
C
      WRITE(6,155)
  155 FORMAT('INPUT NUMBER OF ELEMENTS IN EACH LINE (+ COMMA):')
      READ(5,255)NV
  255 FORMAT(I2)
      WRITE(6,156)
  156 FORMAT('INPUT NUMBER OF STRAIN GAUGES (LVDTS);(1 OR 2):')
      READ(5,256)IANS3
  256 FORMAT(I1)
      WRITE(6,157)
  157 FORMAT(5X,'THE ONLY DATA THAT THIS PROGRAM REQUIRES FOR INPUT'
     */'IN DEVICE 4, IS TIME AND DISPLACEMENT. LIST THE ELEMENTS IN'/
     *'ONE LINE OF YOUR INPUT DATA, IN PROPER ORDER, USING "R1"'/
     *'FOR THE FIRST STRAIN GAUGE READING, "R2" FOR THE SECOND (IF'/
     *'THERE IS ONE), AND "TN","TD","TH","TM","TS", FOR THE TIME'/
     *'IN: MONTHS,DAYS,HOURS,MINUTES,AND SECONDS (YOU MAY HAVE ONLY'
     */'ONE OF THESE TIME PARAMETERS). USE THE DUMMY VARIABLE "DU"'/
     *'FOR ALL OTHER VALUES. (SEPARATE THE ELEMENTS WITH COMMAS)')
```

```
C
C     READS NON-STANDARD DATA
C
        READ(5,257)(XNAME(J),J=1,NV)
    257 FORMAT(12A3)
        L=0
      5 L=L+1
        READ(4,300,END=8)(VAR(K,L),K=1,NV)
        N=L
        GO TO 5
      8 K=0
      9 K=K+1
        IF(XNAME(K).NE.TH) GO TO 6
        DO 16 L=1,N
     16 IHR(L)=VAR(K,L)
        GO TO 39
      6 IF(XNAME(K).NE.R1) GO TO 7
        DO 17 L=1,N
     17 RDEF1(L)=VAR(K,L)
        GO TO 39
      7 IF(XNAME(K).NE.R2) GO TO 31
        DO 18 L=1,N
     18 RDEF2(L)=VAR(K,L)
        GO TO 39
     31 IF(XNAME(K).NE.TN) GO TO 32
        DO 42 L=1,N
     42 IMN(L)=VAR(K,L)
        GO TO 39
     32 IF(XNAME(K).NE.TD) GO TO 33
        DO 43 L=1,N
     43 IDY(L)=VAR(K,L)
        GO TO 39
     33 IF(XNAME(K).NE.TH) GO TO 34
        DO 44 L=1,N
     44 IHR(L)=VAR(K,L)
        GO TO 39
     34 IF(XNAME(K).NE.TM) GO TO 35
        DO 45 L=1,N
     45 IMI(L)=VAR(K,L)
        GO TO 39
     35 IF(XNAME(K).NE.TS) GO TO 39
        DO 46 L=1,N
     46 ISE(L)=VAR(K,L)
     39 IF(K.LT.NV) GO TO 9
    300 FORMAT(12G20)
C
C
     56 DO 51 K=1,N
        RLOAD(K)=0.0
     51 RCELLP(K)=0.0
        IF(IANS3.EQ.2) GO TO 55
        DO 52 K=1,N
     52 RDEF2(K)=0.0
        GO TO 55
C
C     READS STANDARD DATA
C
     23 J=0
        WRITE(6,158)
    158 FORMAT('DOES YOUR TIME CLOCK HAVE A DOUBLE DIGIT MONTH?')
```

```
      READ(5,258)XANS3
  258 FORMAT(A1)
   30 J=J+1
      IF(XANS3.EQ.Y)GO TO 47
      READ(4,40,END=55) IMN(J),IDY(J),IHR(J),IMI(J),ISE(J),ICTR,
     *           I1,IO,RLOAD(J),RCELLP(J),RDEF1(J),RDEF2(J)
   40 FORMAT(7X,5G2.1X,I5,2I3,4G20)
      GO TO 48
   47 READ(4,49,END=55) IMN(J),IDY(J),IHR(J),IMI(J),ISE(J),ICTR,
     *           I1,IO,RLOAD(J),RCELLP(J),RDEF1(J),RDEF2(J)
   49 FORMAT(8X,5G2.1X,I5,2I3,4G20)
   48 N=J
      GO TO 30
C
C
   55 RILOAD=RLOAD(1)
      RCELLP(1)=RCELLP(1)
      ALVDT1=RDEF1(1)
      BLVDT2=RDEF2(1)
C
C     WRITES INITIAL READINGS
C
      WRITE(7,70) RILOAD,RCELLP(1),ALVDT1,BLVDT2
   70 FORMAT(/,'INITIAL LOAD              = ',F10.3,' KN',
     *       /,'INITIAL CELL PRESSURE     = ',F10.3,' KPA',
     *       /,'INITIAL READING FOR LVDT1 = ',F17.10,' mm',
     *       /,'INITIAL READING FOR LVDT2 = ',F17.10,' mm')
C
C     CONVERTS TIME FROM CLOCK READING TO HOURS
C
   59 IMNST=IMN(1)
      DO 50 J=1,N
   60 TIME(J)=(IDY(J)*24.)+IHR(J)+((IMI(J)+ISE(J)/60.)/60.)
      IF(IMN(J).EQ.IMN(1)) GO TO 50
      IF(IMN(1).NE.4.OR.IMN(1).NE.6.OR.IMN(1).NE.9.OR.IMN(1).NE.11)
     *GO TO 61
      IDY(J)=IDY(J)+30
      GO TO 63
   61 IF(IMN(1).NE.2)GO TO 62
      IDY(J)=IDY(J)+28
      GO TO 63
   62 IDY(J)=IDY(J)+31
      IF(IMN(1).EQ.12)GO TO 64
   63 IMN(J)=IMN(J)-1
      GO TO 60
   64 IMN(J)=12
      GO TO 60
   50 CONTINUE
C
C     INITIALIZES VARIABLES
C
      ELPST(1)=0.
      VDEF1(1)=0.
      VDEF2(1)=0.
      ESTRN1(1)=0.
      ESTRN2(1)=0.
C
C     CALCULATES ELAPSED TIME, LOAD, CELL P., AND ENGG. STRAIN
C
      DO 80 J=2,N
```

```
      VDEF1(J)=RDEF1(J)-RDEF1(1)
      VDEF2(J)=RDEF2(J)-RDEF2(1)
      ELPST(J)=TIME(J)-TIME(1)
      RLOAD(J)=RLOAD(J)-RILOAD
      RCELLP(J)=RCELLP(J)-RCELLP(1)
      ESTRN1(J)=(VDEF1(J)/XLEN)*1000000.*FACT
      ESTRN2(J)=(VDEF2(J)/XLEN)*1000000.*FACT
   80 CONTINUE
      RLOAD(1)=0.
C
C     WRITES TIME, LOAD, CELL P., AND ENGG. STRAIN
C
      WRITE(7,90)
   90 FORMAT(/,1X,'NUMBER',4X,'TIME',9X,'LOAD',8X,'CELL PRESSURE',
     *        2(3X,'ENGG. STRAIN  '),/,11X,'HOURS',9X,'KN',14X,
     *        'KPA',9X,'#1 (MICRO)',7X,'#2 (MICRO)')
      DO 100 J=1,N
      WRITE(7,110) J,ELPST(J),RLOAD(J),RCELLP(J),ESTRN1(J),ESTRN2(J)
  110 FORMAT(2X,I3,3X,F9.3,3X,E13.6,2X,E13.6,3X,F11.3,6X,F11.3)
  100 CONTINUE
C
C     DELETES FIRST LINE OF DATA
C
      NRR=0
      NRR=N-1
      DO 85 I=1,NRR
      E1(I)=ESTRN1(I+1)
      E2(I)=ESTRN2(I+1)
   85 TT(I)=ELPST(I+1)
      RETURN
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCC                                                          CCCCC
CCCCC                     SUBROUTINE BFIT                      CCCCC
CCCCC               FITS A POWER LAW TO THE DATA               CCCCC
CCCCC                BY RESTRICTION ON DW & FF                 CCCCC
CCCCC                                                          CCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      SUBROUTINE BFIT (NRR,E1,E2,TT,L,N,BBO,BB1,XANS1,IANS3,LT,LE,
     *                 W1,EEM1,NC1,K,DD,FF,DW,MMM,ANSM3,NRF,NFIT)
      DIMENSION T(1000),A(10),AT(1000),E1(1000),E2(1000),
     *W(1000),B(1000),EA(1000),AE(1000),N(1),BBO(2,2),BB1(2,2),
     *DENT(48),VDEF(1000),DLOAD(1000),TT(1000),DUMMY(1000),
     *E(1000),EE(1000),ER(1000),LT(2,1000),LE(2,1000),W1(2,1000),
     *EEM1(2),NC1(2),NRF(2)
      REAL Y/'Y'/,BLANK/'     '/,LT,LE
C
C
      Z=0
      IF(DD.GT.0) Z=1
      IF(DD.EQ.0) K=1
      MM=0
  700 MM=MM+1
      IF(ANSM3.EQ.Y.AND.L.EQ.2) MM=MMM
      NR=NRR
      IF(MM.EQ.1)GO TO 710
      DO 705 II=1,NR
```

```
          N(II)=II
      705 DUMMY(II)=E2(II)
          GO TO 720
      710 DO 715 II=1,NR
          N(II)=II
      715 DUMMY(II)=E1(II)
      720 CONTINUE
C
C     PROMPT TO DETERMINE LIMIT FOR SLOPE SIGNIFICANCE
C
          IF(L.EQ.2.OR.MM.EQ.2) GO TO 515
          WRITE(6,200)
      200 FORMAT('INPUT DESIRED LIMIT FOR TEST OF SLOPE SIGNIFICANCE IF'
         */'OTHER THAN 10. (REAL NUMBER, TERMINATED WITH A COMMA):')
          READ(5,100)FFL
      100 FORMAT(G4)
          IF(FFL.LT.0.1) FFL=10.
C
C     SMOOTHS DATA TO INCREASING POSITIVELY
C
      515 I=K-1
          J=K-1
       12 I=I+1
          J=J+1
          AE(I)=DUMMY(J)
          AT(I)=TT(J)*60.
          W(I)=1.0
       11 IF(I .EQ.K) GO  TO 12
       14 IF(AE(I)-AE(I-1)) 13, 13, 4
       13 AE(I-1)=(AE(I)*W(I)+AE(I-1)*W(I-1))/(W(I)+W(I-1))
          AT(I-1)=(AT(I)*W(I)+AT(I-1)*W(I-1))/(W(I)+W(I-1))
          W(I-1)=W(I)+W(I-1)
          I=I-1
          IF(I-K-1) 12,14,14
        4 CONTINUE
          IF(J.LT.NR)GO TO 12
C
C     INITIALIZES VARIABLES
C
          WW=0.
          BB=0.
          CONB1=0.
          CONBO=0.
          TE=0.
          DW=0.
          EER=0.
          EEM=0.
          EES=0.
          SUMT=0.
          SUMET=0.
          SUMT2=0.
          SUME=0.
          SUME2=0.
          SXX=0.0
          DWW=0.
          SXY=0.0
          WWA=0
          AF=0.
          M=K+1
          NC=I
```

```
C
C     CALCULATES LOG STRAIN RATE, LOG TIME
C
      DO 1 J=M,NC
      ER(J)=(AE(J)-AE(J-1))/(AT(J)-AT(J-1))
      T(J)=(ALOG10(AT(J))+ALOG10(AT(J-1)))/2.0
    6 W(J)=(W(J)+W(J-1))/2.
      E(J)=ALOG10(ER(J))
      WW=WW+W(J)
      EE(J)=0.
      SUMT=SUMT+T(J)*W(J)
      SUME=SUME+E(J)*W(J)
      SUMET=SUMET+E(J)*T(J)*W(J)
      SUME2=SUME2+E(J)*E(J)*W(J)
    1 SUMT2=SUMT2+T(J)*T(J)*W(J)
      SUME2=SUME2-SUME*SUME/WW
      SUMT2=SUMT2-SUMT*SUMT/WW
      SUMET=SUMET-SUME*SUMT/WW
      FME=SUME/WW
      FMT=SUMT/WW
      DO 7 J=M,NC
      SXY=SXY+(T(J)-FMT)*(E(J)-FME)*W(J)
    7 SXX=SXX+W(J)*(T(J)-FMT)**2
C
C     USES LEAST SQUARES TO FIT DATA
C
      B1=SXY/SXX
      BO=FME-FMT*B1
      DO 2 J=M,NC
      EE(J)=BO+B1*T(J)
      EES=EES+(EE(J)-E(J))*W(J)
      EA(J)=E(J)-EE(J)
      EER=EER+W(J)*(EE(J)-E(J))**2
      EEM=EEM+W(J)*(EE(J)-FME)**2
      IF(J.LE.M)GO TO 2
      DW=DW+(EA(J)-EA(J-1))**2
      DWW=DWW+EA(J)*EA(J)
    2 CONTINUE
      SSDYX=EER
      EER=EER/(WW-2.)
      FF=EEM/EER
      CONB1=SQRT(EER/SUMT2)
      CONBO=CONB1*SQRT((SUMT2*WW+SUMT*SUMT)/(WW*WW))
      DW=DW/DWW
C
C     TRANSFER VARIABLES FOR SUBROUTINE CFIT
C
      IF(DO.EQ.2.AND.Z.EQ.O) DO=0
C
      IF(NR.NE.NRR.OR.L.NE.1) GO TO 111
      EEM1(MM)=EEM
      NC1(MM)=NC
      DO 21 J=1,NC
      LE(MM,J)=E(J)
      LT(MM,J)=T(J)
   21 W1(MM,J)=W(J)
C
C     CHECKS DW AND FF
C
  111 NDF=NR-K+1
```

```
      IF(NDF.LE.20) DU=1.36+(NDF-15)*0.01
      IF(NDF.GT.20.AND.NDF.LE.30) DU=1.41+(NDF-20)*0.008
      IF(NDF.GT.30.AND.NDF.LE.40) DU=1.49+(NDF-30)*0.005
      IF(NDF.GT.40.AND.NDF.LE.50) DU=1.54+(NDF-40)*0.005
      IF(NDF.GT.50.AND.NDF.LE.60) DU=1.59+(NDF-50)*0.003
      IF(NDF.GT.60.AND.NDF.LE.95) DU=1.62+(NDF-60)*0.002
      IF(NDF.GT.95) DU=1.69
      IF(DW.GT.DU.AND.FF.GT.FFL) GO TO 817
      IF(L.EQ.1) NR=NR-1
      IF(L.EQ.2) K=K+1
      GO TO 515
C
C
C
      NDIFF=NRR-NR
      IF(NDIFF.EQ.0) NFIT=1
      IF(ANSM3.NE.Y) GO TO 8
      IF(L.EQ.1) GO TO 8
      IF(DO.EQ.2) GO TO 8
      BBO(L,MM)=BO
      BB1(L,MM)=B1
      GO TO 702
C
C     WRITES DATA AND STATISTICS
C
    8 WRITE(7,206)MM
  206 FORMAT(///30X,'       DATA FROM LVDT NO.',I2,//)
  416 CONTINUE
      WRITE(7,208)
  208 FORMAT(9X,'TRANSFORMED DATA')
      WRITE(7,209)
  209 FORMAT(11X,'TIME',5X,'STR RATE, E',5X,'LOG E',9X,'LOG EE',4X,
     *'LOG E - LOG EE',4X,'W')
      WRITE(7,216)
  216 FORMAT(11X,'(MIN)',3X,'(MICRO.E/MIN)')
      DO 9 J=M,NC
      T(J)=10**(T(J))
      WRITE(7,106)T(J),ER(J),E(J),EE(J),EA(J),W(J)
  106 FORMAT(7X,F12.4,2X,F12.6,3(1X,E13.6),F7.2)
    9 CONTINUE
      WRITE(7,210)
  210 FORMAT(//,9X,'FIT PARAMETERS')
      WRITE(7,105)BO
  105 FORMAT(11X,' INTERCEPT, BO',16X,E15.6)
      WRITE(7,115)B1
      WRITE(7,158)CONBO
      WRITE(7,157)CONB1
      WRITE (7,159)DW
  157 FORMAT(11X,' CONFIDENCE LIMIT ON B1     T.  ',F12.7)
  115 FORMAT(11X,' SLOPE, B1                      ',F12.7)
  158 FORMAT(11X,' CONFIDENCE LIMIT ON BO     T.  ',F12.7)
  159 FORMAT(11X,' DURBIN WATSON STATISTIC          ',F7.3)
      WRITE(7,180) NDF
  180 FORMAT(11X,' DEGREE OF FREEDOM FOR DW         ',I3)
      WRITE(7,181) DU
  181 FORMAT(11X,' UPPER LIMIT FOR DW               ',F7.3)
      WRITE(7,156)FF
  156 FORMAT(11X,' TEST OF SLOPE SIGNIFICANCE       ',F9.3)
      WRITE (7,211)
  211 FORMAT(//,9X,'DATA FOR COMPARISON TESTS')
```

```
      WW=WW-2.
      WRITE(7,122)WW
  122 FORMAT(11X,' WEIGHTING ',F6.1)
      WRITE(7,104)FME,FMT
      WRITE(7,214)SUME2,SUMT2
  104 FORMAT(11X,' MEAN STRAIN  ',F11.3,
     *'    MEAN TIME ',F11.3)
      WRITE(7,213)SUMET,SSDYX
  214 FORMAT(11X,' SSDY ',5X,F11.3,' SSDX      ',F11.3)
  213 FORMAT(11X,' SPDXY',5X,F11.3,' SSDYX     ',F11.3)
      WRITE(7,212)
  212 FORMAT(/,9X,'CHECK')
      WRITE(7,107)EES
  107 FORMAT(11X,' SUM OF RESIDUALS',14X,F12.6)
      WRITE(7,124) K
  124 FORMAT(///,11X,' DATA STARTS AT #',I3)
      WRITE(7,125) NR
  125 FORMAT(11X,' DATA ENDS AT #',I3)
C
C     INITIALIZES COUNTERS FOR SUBROUTINE CFIT, IF USED
C
      IF(L.EQ.1)NRF(MM)=NR
      IF(ANSM3.EQ.Y.AND.L.EQ.2) GO TO 704
      GO TO 703
  704 MMM=2
      K=1
      Z=0
C
C     DIRECTS PROGRAM ACCORDING TO PROGRAM OPTIONS IN EFFECT
C
  703 BBO(L,MM)=BO
      BB1(L,MM)=B1
      IF(XANS1.EQ.Y) GO TO 701
      IF(IANS3.EQ.1) GO TO 702
  701 IF(MM.EQ.2)GO TO 702
      GO TO 700
  702 CONTINUE
      RETURN
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCC                                                    CCCCC
CCCCC                  SUBROUTINE INTEG                  CCCCC
CCCCC         INTEGRATES STRAIN RATE TO DETERMINE        CCCCC
CCCCC                ACCELERATING STRAIN                 CCCCC
CCCCC                                                    CCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCGCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      SUBROUTINE INTEG(E1,E2,BBO,BB1,NRR,TT,JJ,XANS1,IANS3)
      DIMENSION EDIFF(1000),E(1000),EE(1000),E1(1000),BBO(2,2),
     *          BB1(2,2),TT(1000),E2(1000)
      REAL Y/'Y'/
C
C
      MM=0
      NR=NRR
   20 MM=MM+1
      IF(MM.EQ.2) GO TO 43
      DO 40 I=1,NR
```

```
   40 E(I)=E1(I)
C
C     INTEGRATES STRAIN RATE EQUATION, TO GET STRAINS
C
   43 B0=BB0(JJ,MM)
      B1=BB1(JJ,MM)
      B0=10.**B0
      B1=B1+1
      B0=B0/B1
      IF(B1)12,12,13
   12 DO 9 I=1,NR
      TERM=0.000001/TT(I)
    9 EE(I)=-(B0)*(10**(-6*B1))*(1-(TERM**(-B1)))
      GO TO 2
   13 DO 1 I=1,NR
    1 EE(I)=B0*((TT(I)**B1)-(10**(-6*B1)))
C
C     SUBTRACTS DECELERATING STRAIN FROM EXPERIMENTAL STRAIN
C
    2 DO 21 I=1,NR
   21 EDIFF(I)=E(I)-EE(I)
C
C
      IF(MM.EQ.2) GO TO 15
      DO 30 I=1,NR
      E1(I)=EDIFF(I)
   30 E(I)=E2(I)
      IF(XANS1.EQ.Y) GO TO 20
      IF(IANS3.EQ.1) GO TO 999
      GO TO 20
   15 DO 31 I=1,NR
   31 E2(I)=EDIFF(I)
  999 RETURN
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCC                                                          CCCCC
CCCCC                    SUBROUTINE CFIT                       CCCCC
CCCCC                OPTIMIZES THE FIT OF THE                  CCCCC
CCCCC              POWER LAW EXPRESSION TO THE                 CCCCC
CCCCC                 ENTIRE RANGE OF DATA                     CCCCC
CCCCC                                                          CCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      SUBROUTINE CFIT(EEM1,LT,LE,W1,BB0,BB1,NC1,K,OO,
     *                FF,DW,MMM,NRR,NRF)
      DIMENSION LT(2,1000),LE(2,1000),W1(2,1000),
     *          BB0(2,2),BB1(2,2),EEM1(2),NC1(2),NRF(2)
      REAL LT,LE
C
C
      MM=MMM
      WW=0
      M=0
      M=K+1
      NC=NC1(MM)
      EER=0
C
C     CALCULATES R FOR CURRENT ACCELERATING CREEP PARAMETERS
```

```
C
      DO 1 J=2,NC
      DE=BB0(1,MM)+(LT(MM,J)*BB1(1,MM))
      AE=BB0(2,MM)+(LT(MM,J)*BB1(2,MM))
      EE=ALOG10((10**AE)+(10**DE))
      EER=EER+W1(MM,J)*(EE-LE(MM,J))**2
    1 WW=WW+W1(MM,J)
      EER=EER/(WW-2.)
      R=EEM1(MM)/EER
      IF(OO.NE.0) GO TO 2
C
C     WRITES TABLE OF FIT STATISTICS
C
      WRITE(7,100)MM
  100 FORMAT(//,22X,'PARAMETERS FOR EVALUATING TOTAL FIT,',
     *'LVDT NO.: ',I1,//
     *34X,'ACCELERATING CREEP',18X,'TOTAL FIT'/
     *16X,'RANGE     INTERCEPT,B0     SLOPE,B1',6X,'R',8X,'DW',8X,'R')
    2 WRITE(7,101)K,NRR,BB0(2,MM),BB1(2,MM),FF,DW,R
  101 FORMAT(14X,I3,' - ',I3,E15.6,F12.7,2F9.3,2X,F9.3)
C
C     TEST TO SEE IF DATA MEETS TERMINATING CRITERIA
C
      EA=BB0(2,MM)+(LT(MM,M)*BB1(2,MM))
      ED=BB0(1,MM)+(LT(MM,M)*BB1(1,MM))
      EA=EA+0.1
      OO=1
      IF(EA.GE.ED.OR.M.GE.NRF(MM)) GO TO 3
      GO TO 4
    3 OO=2
      K=K-1
    4 RETURN
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCC                                                              CCCCC
CCCCC                     SUBROUTINE CPLOT                         CCCCC
CCCCC                     MAKES PLOTS OF :                         CCCCC
CCCCC                    STRAIN RATE VS TIME                       CCCCC
CCCCC                           AND                                CCCCC
CCCCC                LOG STRAIN RATE VS LOG TIME                   CCCCC
CCCCC                                                              CCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

      SUBROUTINE CPLOT(ESTRN1,ESTRN2,ELPST,BB0,BB1,NRR,
     *                ITN1,ITN2,XANS1,IANS3,ANSM1,ANSM2)
      DIMENSION ESTRN1(1),ESTRN2(1),ELPST(1),BB0(2,2),BB1(2,2),
     *          AE(1000),E(1000),T(1000),AT(1000),DX(4),DY(4),
     *          LABELS(24),OPTNS(25),TE(1000)
      REAL LOG/'LOG '/,Y/'Y '/,TWO/'TWO '/,ONE/'ONE '/,BLANK/'    '/
C
C     INITIALIZE VECTORS
C
      REAL LABELS/'TEST',' NO.',':   ',2*'    ',' LVD','T NO',
     *'.:  ','    ',4*'    ','TIME',3*'    ','STRA','IN R',
     *'ATE ',4*'    '/,ITN1,ITN2
      REAL OPTNS /1.0,24*'NO  '/
C
C     DETERMINE IF IN BATCH MODE
```

```
C
      CALL CREPLY(&8)
      GO TO 9
    8 OPTNS(4)=1
C
C     PROMPTS TO DETERMINE DESIRED PLOTS
C
    9 WRITE(6,200)
  200 FORMAT('  WOULD YOU LIKE A LOG STRAIN RATE - LOG TIME PLOT?(Y,N)')
      READ(5,300)ANS1
  300 FORMAT(A1)
      WRITE(6,201)
  201 FORMAT('  WOULD YOU LIKE A STRAIN RATE - TIME PLOT?(Y,N)')
      READ(5,301)ANS2
  301 FORMAT(A1)
      IF(ANS1.NE.Y.AND.ANS2.NE.Y) GO TO 1000
      IF(ANSM2.EQ.Y) GO TO 111
C
C    LOAD GRAPH
C
      INTEGER LOADF, GRAPH, LSWS/Z00800040/
      GRAPH = LOADF ('CIVE:GRAPH+*IG+*PLOTLIB ', 0, LSWS, 0 )
C
C
C
  111 MM=0
   50 MM=MM+1
      IF(MM.EQ.2)GO TO 1
      LABELS(4)=ITN1
      LABELS(5)=ITN2
C
C  CALCULATES STRAIN RATE AND TIME
C
      DO 10 J=1,NRR
      AE(J)=ESTRN1(J+1)
   10 AT(J)=ELPST(J+1)*60
      GO TO 3
    1 DO 11 J=1,NRR
      AE(J)=ESTRN2(J+1)
   11 AT(J)=ELPST(J+1)*60
      TJ=0
    3 DO 12 J=2,NRR
      E(J)=(AE(J)-AE(J-1))/(AT(J)-AT(J-1))
      TJ=(ALOG10(AT(J))+ALOG10(AT(J-1)))/2.0
   12 T(J)=10**TJ
      IF(MM.EQ.1) GO TO 15
      XX=TWO
      GO TO 16
   15 XX=ONE
   16 CONTINUE
      LABELS(9)=XX
C
C  DETERMINE MAXIMUM AND MINIMUM VALUES
C
      J=1
   25 J=J+1
      EMIN=E(J)
      EMAX=E(J)
      IF(E(J).LE.0.0)GO TO 25
   20 J=J+1
```

```
      IF(EMIN.LE.E(J).OR.E(J).LE.0.0)GO TO 21
      EMIN=E(J)
   21 IF(EMAX.GE.E(J))GO TO 22
      EMAX=E(J)
   22 IF(J.LT.NRR) GO TO 20
C
C    DELETES NEGATIVE STRAIN RATES
C
      J=2
      I=2
      TE(I)=T(J)
   57 IF(E(I).LE.0.0) GO TO 37
      I=I+1
   37 J=J+1
      E(I)=E(J)
      TE(I)=T(J)
      IF(J.LT.NRR) GO TO 57
      IND=0
      IND=I-1
      IF(E(I).LE.0.) IND=IND-1
      IF(ANS2.NE.Y) GO TO 4
C
C  PROMPT FOR STRAIN RATE - TIME PLOT PARAMETERS
C
      WRITE(6,202)
      WRITE(6,203)EMIN
      WRITE(6,204)EMAX
      WRITE(6,205)T(NRR)
  202 FORMAT('  FOLLOWING ARE THE EXTREME VALUES IN THE T VS E PLOT:')
  203 FORMAT('  MINIMUM STRAIN RATE:  ',F12.6)
  204 FORMAT('  MAXIMUM STRAIN RATE:  ',F12.6)
  205 FORMAT('  FINAL TIME:           ',F10.3)
      WRITE(6,206)
  206 FORMAT(' INPUT DESIRED STRAIN RATE VALUE AT ORIGIN OF Y AXIS
     *(TERMINATE WITH COMMA):')
      READ(5,302)OPTNS(11)
  302 FORMAT(E20.0)
    6 WRITE(6,207)
  207 FORMAT(' INPUT DESIRED Y AXIS SCALE (UNITS/INCH):')
      READ(5,303)OPTNS(12)
  303 FORMAT(E20.0)
      IF(OPTNS(12).LT.1000000) GO TO 7
      WRITE(6,220)
  220 FORMAT('*** ERROR *** ALL INPUT VALUES MUST BE TERMINATED BY A
     *COMMA')
      GO TO 6
    7 WRITE(6,208)
  208 FORMAT(' INPUT DESIRED LENGTH OF Y AXIS (INCHES):')
      READ(5,304)OPTNS(13)
  304 FORMAT(E20.0)
      WRITE(6,209)
  209 FORMAT(' INPUT DESIRED X AXIS (TIME) SCALE (UNITS/INCH):')
      READ(5,305)OPTNS(9)
  305 FORMAT(E20.0)
      WRITE(6,210)
  210 FORMAT(' INPUT DESIRED LENGTH OF X AXIS (INCHES):')
      READ(5,306)OPTNS(10)
  306 FORMAT(E20.0)
C
C
```

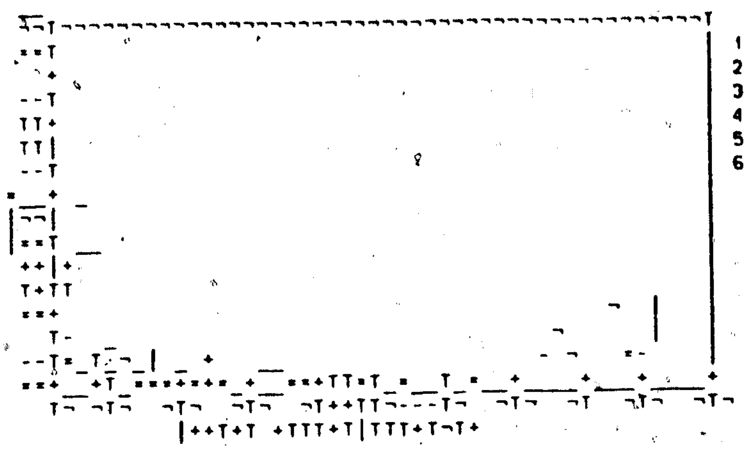
```
      OPTNS(6)=1.0
      OPTNS(7)=1.0
      OPTNS(16)=0
      OPTNS(21)=1.0
      OPTNS(24)=BLANK
      OPTNS(8)=0
      OPTNS(22)=1
      OPTNS(23)=0.04
      LABELS(13)=BLANK
      LABELS(17)=BLANK
C     ND=NRR-1
C
      CALL STARTF (GRAPH,TE(2),E(2),IND,LABELS,-1,OPTNS)
C
    4 IF(ANS1.EQ.Y)GO TO 5
      GO TO 60
C
C CALCULATES AXIS VALUES FOR LOG E - LOG T PLOT
C
    5 XA=ALOG10(T(2))
      OPTNS(8)=FLOAT(IFIX(XA))-1
      XE=0
      XE=ALOG10(T(NRR))
      XE=FLOAT(IFIX(XE))+1
      OPTNS(9)=XE-OPTNS(8)
      XC=10.
      YA=ALOG10(EMIN)
      OPTNS(11)=FLOAT(IFIX(YA))-1
      YE=ALOG10(EMAX)
      YE=FLOAT(IFIX(YE))+1
      OPTNS(12)=YE-OPTNS(11)
      OPTNS(6)=2.0
      OPTNS(7)=2.0
      OPTNS(17)=1.0
      OPTNS(18)=2.0
      OPTNS(20)=0.08
      OPTNS(21)=1.0
      OPTNS(22)=1
      OPTNS(23)=0.04
      LABELS(13)=LOG
      LABELS(17)=LOG
C
      CALL STARTF (GRAPH,TE(2),E(2),IND,LABELS,1,OPTNS)
C
C  CALCULATES AND PLOTS BEST FIT LINES FOR LOG E - LOG T PLOT
C
      K=0
   40 K=K+1
      IF(ANSM1.NE.Y) GO TO 41
      IF(K.EQ.2) GO TO 60
      NC=-2
      GO TO 42
   41 NC=K+1
      IF(K.EQ.2)NC=-2
   42 ND=4
      OPTNS(21)=2.0
      OPTNS(22)=4
      OPTNS(23)=0.01
      D=0
      DX(1)=T(2)
```

```
      D=BB1(K,MM)*ALOG10(DX(1))+BB0(K,MM)
      DY(1)=10**D
      DX(2)=T(NRR)
      D=BB1(K,MM)*ALOG10(DX(2))+BB0(K,MM)
      DY(2)=10**D
      DY(3)=EMIN
      D=(ALOG10(DY(3))-BB0(K,MM))/BB1(K,MM)
      DX(3)=10**D
      DY(4)=EMAX
      D=(ALOG10(DY(4))-BB0(K,MM))/BB1(K,MM)
      DX(4)=10**D
C
      DO 43 KK=1,4
   43 IF(DY(KK).LT.0.0000001) DY(KK)=0.0000001
C
C
      CALL STARTF (GRAPH,DX,DY,ND,LABELS,NC,OPTNS)
C
      IF(K.LT.2)GO TO 40
C
C
   60 IF(MM.EQ.2)GO TO 999
      IF(XANS1.EQ.Y) GO TO 50
      IF(IANS3.EQ.1) GO TO 999
      GO TO 50
C
C
  999 CALL STARTF (GRAPH,TE(2),E(2),IND,LABELS,0,OPTNS)
C
C
 1000 RETURN
      END
```

Sample Run

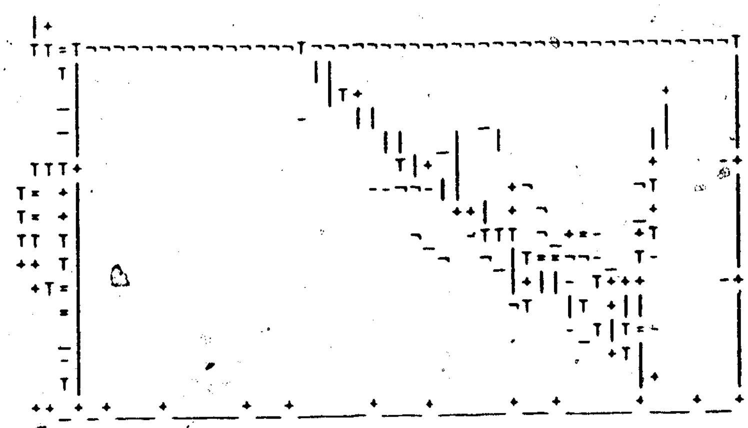
```
University of Alberta - Computing Services   Device  VR02   Task   6462
# sig gs22
# Password?
?
# Term,Low,Internal/Teaching,Research
#  Last signon was: 23:32.23
#  User "GS22" signed on at  23:36 22 on Wed Jul 11/84
# $RUN CPACK 4=STAR5 7=-P T=4S
  THIS PROGRAM ACCEPTS DATA IN THE FOLLOWING FORMAT:
  LABEL,TIME CLOCK,3 COUNTERS,LOAD,CELL PRESSURE,DEF.1:DEF.2
  IS YOUR DATA IN THIS FORM? (Y,N)
  NO
  DO YOU HAVE AN LVDT CALIBRATION FACTOR?
  YES
  INPUT THE LVDT CALIBRATION FACTOR (MULTIPLIER)
  0 02,
  INPUT DIAMETER(MM),LENGTH(MM),AND WEIGHT(GM),
  SEPARATED BY COMMAS:
  54.76,49.2,0.0,
  INPUT SAMPLE NUMBER (8 CHARACTER MAX.):
  STARKEY5
  INPUT TEST NUMBER (8 CHARACTER MAX.):
  STARKEY5
  INPUT NUMBER OF ELEMENTS IN EACH LINE (+ COMMA):
  10,
  INPUT NUMBER OF STRAIN GAUGES (LVDTS):(1 OR 2):
  1,
     THE ONLY DATA THAT THIS PROGRAM REQUIRES FOR INPUT
  IN DEVICE 4, IS TIME AND DISPLACEMENT. LIST THE ELEMENTS IN
  ONE LINE OF YOUR INPUT DATA, IN PROPER ORDER, USING "R1"
  FOR THE FIRST STRAIN GAUGE READING, "R2" FOR THE SECOND (IF
  THERE IS ONE), AND "TN","TD","TH","TM","TS", FOR THE TIME
  IN: MONTHS,DAYS,HOURS,MINUTES,AND SECONDS (YOU MAY HAVE ONLY
  ONE OF THESE TIME PARAMETERS). USE THE DUMMY VARIABLE "DU"
  FOR ALL OTHER VALUES. (SEPARATE THE ELEMENTS WITH COMMAS)
  DU,DU,DU,DU,TH,DU,R1,DU,DU,DU,
  WOULD YOU LIKE THE DECELERATING CREEP DATA
  PLOTTED BEFORE THE PROGRAM ATTEMPTS TO ISOLATE
  ACCELERATING CREEP?
  NO
  WOULD YOU LIKE THE PROGRAM TO EXAMINE THE
  ACCELERATING DATA FOR AN OPTIMUM FIT?
  YES
  INPUT DESIRED LIMIT FOR TEST OF SLOPE SIGNIFICANCE IF
  OTHER THAN 10. (REAL NUMBER, TERMINATED WITH A COMMA):

   WOULD YOU LIKE A LOG STRAIN RATE - LOG TIME PLOT?(Y,N)
  YES
   WOULD YOU LIKE A STRAIN RATE - TIME PLOT?(Y,N)
  YES
   FOLLOWING ARE THE EXTREME VALUES IN THE T VS E PLOT:
   MINIMUM STRAIN RATE:       0.028226
   MAXIMUM STRAIN RATE:       3.387532
   FINAL TIME:          228028 500
  INPUT DESIRED STRAIN RATE VALUE AT ORIGIN OF Y AXIS      (TERMINATE WITH COMMA):
  0.0,
  INPUT DESIRED Y AXIS SCALE (UNITS/INCH):
  0.4,
  INPUT DESIRED LENGTH OF Y AXIS (INCHES):
  10.,
```

```
INPUT DESIRED X AXIS (TIME) SCALE (UNITS/INCH)
25000 .
INPUT DESIRED LENGTH OF X AXIS (INCHES)
10. .

  GRAPH   PRELIMINARY VERSION. DEC. 1, 1982

  PLOT FILE NAME IS -PDF

  SUMMARY FILE NAME IS -SUMMARY
```



```
OPTION
1. PLOT
2. BLOW-UP
3. REDRAW
4. SUBPICTURES
5. MTS-SDS
6. CONTINUE
```

```
  SELECT MENU OPTION
? 1

  SELECT MENU OPTION
? 6
```



```
OPTION
1. PLOT
2. BLOW-UP
3. REDRAW
4. SUBPICTURES
5. MTS-SDS
6. CONTINUE
```

SELECT MENU OPTION
? 1

SELECT MENU OPTION
? 6

Input File

1	0.0.0.0.12..0.969 .0.12411 .0.
2	0.0.0.0.16..0.982.5.0.13790 .0.
3	0.0.0.0.33..0.988..0.13445 25.0.
4	0.0.0.0.39 .0.991..0.13790..0.
5	0.0.0.0.58..0.992.8.0.13790..0.
6	0.0.0.0.64..0.993.7.0.13790 .0.
7	0.0.0.0.66..0.994..0.13790..0.
8	0.0.0.0.71..0.994.5.0.13790..0.
9	0.0.0.0.82..0.995..0.13790 .0.
10	0.0.0.0.89..0.996..0.13790..0.
11	0.0.0.0.95..0.996.2.0.13790 .0.
12	0.0.0.0.106..0.997.2.0.13790..0.
13	0.0.0.0.112..0.998 3.0.13790 .0.
14	0.0.0.0.129 .0.998.8.0.13790..0.
15	0.0.0.0.136..0.1000 .0.13790 .0.
16	0.0.0.0.182..0.1002 3.0.13790 .0.
17	0.0.0.0.206 .0.1003 2.0.13790..0.
18	0.0.0.0.211..0.1004.7.0.13790 .0.
19	0.0.0.0.226..0.1005 1.0.13790 .0.
20	0.0.0.0.235..0.1005.5.0.13790 .0.
21	0.0.0.0.274..0.1007.2.0.13790 .0.
22	0.0.0.0.281..0.1008.8.0.13790 .0.
23	0.0.0.0.326..0.1009.8.0.13790 .0.
24	0.0.0.0.346..0.1011..0.13790 .0.
25	0.0.0.0.370..0.1012..0.13790 .0.
26	0.0.0.0.382..0.1012.2.0.13790..0.
27	0.0.0.0.393..0.1013..0.13790 .0.
28	0.0.0.0.401..0.1013.8.0.13790 .0.
29	0.0.0.0.417..0.1014..0.13790 .0.
30	0.0.0.0.522..0.1017..0.13790 .0.
31	0.0.0.0.537..0.1018..0.13790..0.
32	0.0.0.0.561..0.1018.4.0.13790..0.
33	0.0.0.0.585..0.1019..0.13790..0.
34	0.0.0.0.591..0.1019..0.13790..0.
35	0.0.0.0.610..0.1019.8.0.13790..0.
36	0.0.0.0.642..0.1020.5.0.13790..0.
37	0.0.0.0.686..0.1022..0.13790 .0.
38	0.0.0.0.706 .0.1022.5.0.13790 .0.
39	0.0.0.0.736..0.1023 1.0.13790 .0.
40	0.0.0.0.808 .0.1025..0.13790 .0.
41	0.0.0.0.849 .0.1026.2.0.13790 .0.
42	0.0.0.0.876 .0.1027.2.0.13790 .0.
43	0.0.0.0.973 .0.1028.8.0.13790 .0.
44	0.0.0.0.1020 .0.1029.1.0.13790 .0.
45	0.0.0.0.1071..0.1030.9.0.13790 .0.
46	0.0.0.0.1185..0.1032 2.0.13790 .0.
47	0.0.0.0.1210..0.1032.9.0.13790..0.
48	0.0.0.0.1264..0.1033.2.0.13790..0.
49	0.0.0.0.1281..0.1033.6.0.13790..0.
50	0.0.0.0.1353..0.1033.4.0.13790..0.
51	0.0.0.0.1381..0.1033.3.0.13790..0.
52	0.0.0.0.1402..0.1034 1.0.13790..0.
53	0.0.0.0.1449..0.1035.9.0.13790 .0.
54	0.0.0.0.1523..0.1037.6.0.13790..0.
55	0.0.0.0.1545..0.1037 6.0.13790 .0.
56	0.0.0.0.1571..0.1037.8.0.13790..0.
57	0.0.0.0.1593 .0.1038 2.0.13790.,0.
58	0.0.0.0.1617..0.1038.6.0.13790..0.
59	0.0.0.0.1693..0.1039.6.0.13790 .0.
60	0.0.0.0.1762..0.1039.9.0.13790 .0.

61	0.0.0.0.1785 .0.1040 1.0.13790 .0.
62	0.0.0.0.1881..0.1040.9.0.13790..0.
63	0.0.0.0.1905..0.1041.2.0.13790..0.
64	0.0.0.0.1929 .0.1041 7.0.13790..0.
65	0.0.0.0.1953..0.1042 .0.13790..0.
66	0.0.0.0.2025..0.1042.9.0.13790..0.
67	0.0.0.0.2049..0.1043.1.0.13790..0.
68	0.0.0.0.2073 .0.1043 1.0.13790..0.
69	0.0.0.0.2121..0.1043.1.0.13790..0.
70	0.0.0.0.2193..0.1042.7.0.13790..0..
71	0.0.0.0.2216 .0.1042 6.0.13790..0.
72	0.0.0.0.2240 .0.1043..0.13790..0.
73	0.0.0.0.2265 .0.1042 8.0.13790..0.
74	0.0.0.0.2361..0.1043 2.0.13790..0.
75	0.0.0.0.2385 .0.1043.3.0.13790..0.
76	0.0.0.0.2409..0.1043..0.13790..0.
77	0.0.0.0.2439..0.1042.7.0.13790..0.
78	0.0.0.0.2460..0.1042.6.0.13790..0.
79	0.0.0.0.2540..0.1043.8.0.13790..0.
80	0.0.0.0.2552..0.1044..0.13790..0.
81	0.0.0.0.2580..0.1044.2.0.13790..0.
82	0.0.0.0.2601..0.1044.3.0.13790..0.
83	0.0.0.0.2722.5.0.1046..0.13790..0.
84	0.0.0.0.2890..0.1047..0.13790..0.
85	0.0.0.0.3009..0.1050.6.0.13790..0.
86	0.0.0.0.3056..0.1052..0.13790..0.
87	0.0.0.0.3082 .0.1052.8.0.13790..0.
88	0.0.0.0.3201 .0.1058.7.0.13790..0.
89	0.0.0.0.3272..0.1066 .0.13790..0.
90	0.0.0.0.3371..0.1072.4.0.13790..0.
91	0.0.0.0.3466..0.1073 .0.13790..0.
92	0.0.0.0.3560..0.1075.2.0.13790..0.
93	0.0.0.0.3610..0.1082.4.0.13790..0.
94	0.0.0.0.3661..0.1084.5.0.13790..0.
95	0.0.0.0.3730..0.1088..0.13790 .0.
96	0.0.0.0.3800 .0.1090..0.13790..0.
97	0.0.0.0.3825..0.1092.7.0.13790..1.

Output File

TEST NUMBER = STARKEY5

SAMPLE NUMBER = STARKEY5

SAMPLE LENGTH = 49.200 mm
SAMPLE DIAMETER = 54 760 mm
SAMPLE WEIGHT = 0.0 gm

INITIAL LOAD = 0.0 KN
INITIAL CELL PRESSURE = 0.0 KPA
INITIAL READING FOR LVDT1 = 969.0000000000 mm
INITIAL READING FOR LVDT2 = 0.0 mm

NUMBER	TIME HOURS	LOAD KN	CELL PRESSURE KPA	ENGG. STRAIN #1 (MICRO)	ENGG. STRAIN #2 (MICRO)
1	0.0	0.0	0.0	0.0	0.0
2	4.000	0.0	0.0	5487.801	0.0
3	21.000	0.0	0.0	7723.574	0.0
4	27.000	0.0	0.0	8943.086	0.0
5	46.000	0.0	0.0	9674.813	0.0
6	52.000	0.0	0.0	10040.629	0.0
7	54.000	0.0	0.0	10162.598	0.0
8	59.000	0.0	0.0	10365.852	0.0
9	70.000	0.0	0.0	10569.105	0.0
10	77.000	0.0	0.0	10975.609	0.0
11	83.000	0.0	0.0	11056.887	0.0
12	94.000	0.0	0.0	11463.395	0.0
13	100.000	0.0	0.0	11910.586	0.0
14	117.000	0.0	0.0	12113.836	0.0
15	124.000	0.0	0.0	12601.621	0.0
16	170.000	0.0	0.0	13536.602	0.0
17	194.000	0.0	0.0	13902.418	0.0
18	199.000	0.0	0.0	14512.172	0.0
19	214.000	0.0	0.0	14674.832	0.0
20	223.000	0.0	0.0	14837.395	0.0
21	262.000	0.0	0.0	15528.434	0.0
22	269.000	0.0	0.0	16178.879	0.0
23	314.000	0.0	0.0	16585.383	0.0
24	334.000	0.0	0.0	17073.168	0.0
25	358.000	0.0	0.0	17479.672	0.0
26	370.000	0.0	0.0	17560.953	0.0
27	381.000	0.0	0.0	17886.176	0.0
28	389.000	0.0	0.0	18211.398	0.0
29	405.000	0.0	0.0	18292.680	0.0
30	510.000	0.0	0.0	19512.191	0.0
31	525.000	0.0	0.0	19918.695	0.0
32	549.000	0.0	0.0	20081.250	0.0
33	573.000	0.0	0.0	20325.199	0.0
34	579.000	0.0	0.0	20325.199	0.0
35	598.000	0.0	0.0	20650.422	0.0
36	630.000	0.0	0.0	20934.941	0.0
37	674.000	0.0	0.0	21544.699	0.0
38	694.000	0.0	0.0	21747.938	0.0
39	724.000	0.0	0.0	21991.898	0.0
40	796.000	0.0	0.0	22764.219	0.0
41	837.000	0.0	0.0	23251.996	0.0
42	864.000	0.0	0.0	23658.496	0.0
43	961.000	0.0	0.0	24308.938	0.0
44	1008.000	0.0	0.0	24430.918	0.0

45	1059.000	0.0	0.0	25162.559	0.0
46	1173.000	0.0	0.0	25691.016	0.0
47	1198.000	0.0	0.0	25975.559	0.0
48	1252.000	0.0	0.0	26097.516	0.0
49	1269.000	0.0	0.0	26260.176	0.0
50	1341.000	0.0	0.0	26178.797	0.0
51	1369.000	0.0	0.0	26138.219	0.0
52	1390.000	0.0	0.0	26463.438	0.0
53	1437.000	0.0	0.0	27195.059	0.0
54	1511.000	0.0	0.0	27886.199	0.0
55	1533.000	0.0	0.0	27886.199	0.0
56	1559.000	0.0	0.0	27967.477	0.0
57	1581.000	0.0	0.0	28130.039	0.0
58	1605.000	0.0	0.0	28292.699	0.0
59	1681.000	0.0	0.0	28699.219	0.0
60	1750.000	0.0	0.0	28821.078	0.0
61	1773.000	0.0	0.0	28902.457	0.0
62	1869.000	0.0	0.0	29227.598	0.0
63	1893.000	0.0	0.0	29349.559	0.0
64	1917.000	0.0	0.0	29552.816	0.0
65	1941.000	0.0	0.0	29674.777	0.0
66	2013.000	0.0	0.0	30040.598	0.0
67	2037.000	0.0	0.0	30121.957	0.0
68	2061.000	0.0	0.0	30121.957	0.0
69	2109.000	0.0	0.0	30121.957	0.0
70	2181.000	0.0	0.0	29959.297	0.0
71	2204.000	0.0	0.0	29918.719	0.0
72	2228.000	0.0	0.0	30081.277	0.0
73	2253.000	0.0	0.0	29999.996	0.0
74	2349.000	0.0	0.0	30162.578	0.0
75	2373.000	0.0	0.0	30203.258	0.0
76	2397.000	0.0	0.0	30081.277	0.0
77	2427.000	0.0	0.0	29959.297	0.0
78	2448.000	0.0	0.0	29918.719	0.0
79	2528.000	0.0	0.0	30406.496	0.0
80	2540.000	0.0	0.0	30487.797	0.0
81	2568.000	0.0	0.0	30569.059	0.0
82	2589.000	0.0	0.0	30609.758	0.0
83	2710.500	0.0	0.0	31300.797	0.0
84	2878.000	0.0	0.0	31707.297	0.0
85	2997.000	0.0	0.0	33170.738	0.0
86	3044.000	0.0	0.0	33739.816	0.0
87	3070.000	0.0	0.0	34065.039	0.0
88	3189.000	0.0	0.0	36463.379	0.0
89	3260.000	0.0	0.0	39430.879	0.0
90	3359.000	0.0	0.0	42032.457	0.0
91	3454.000	0.0	0.0	42276.418	0.0
92	3548.000	0.0	0.0	43170.695	0.0
93	3598.000	0.0	0.0	46097.496	0.0
94	3649.000	0.0	0.0	46951.195	0.0
95	3718.000	0.0	0.0	48373.977	0.0
96	3788.000	0.0	0.0	49186.977	0.0
97	3813.000	0.0	0.0	50284.496	0.0

******************** FIT OF DECELERATING CREEP DATA TO POWER LAW ********************

DATA FROM LVDT NO. 1

TRANSFORMED DATA

TIME (MIN)	STR RATE, E' (MICRO E/MIN)	LOG E	LOG EE	LOG E - LOG EE	W
549.9077	2.191935	0.340828E+00	0.856889E+00	-0.516061E+00	1.00
1428.7019	3.387532	0.529883E+00	0.441976E+00	0.879077E-01	1.00
2114.5154	0.641865	-0.192556E+00	0.271600E+00	-0.464156E+00	1.00
2934.4822	1.016156	0.696047E-02	0.129189E+00	-0.122229E+00	1.00
3179.4292	1.016406	0.706724E-02	0.943499E-01	-0.872826E-01	1.00
3386.6707	0.677513	-0.169082E+00	0.669088E-01	-0.235991E+00	1.00
3855.8955	0.307960	-0.511505E+00	0.105209E-01	-0.522026E+00	1.00
4404.9922	0.967866	-0.141846E-01	-0.473347E-01	0.331501E-01	1.00
4796.6172	0.225770	-0.646333E+00	-0.843477E-01	-0.561985E+00	1.00
5299.7188	0.615921	-0.210475E+00	-0.127693E+00	-0.827819E-01	1.00
5817.2070	1.242198	0.941908E-01	-0.168180E+00	0.262370E+00	1.00
6489.9844	0.199265	-0.700570E+00	-0.215739E+00	-0.484830E+00	1.00
7226.9219	1.161393	0.649793E-01	-0.262479E+00	0.327458E+00	1.00
8711.3477	0.338761	-0.470107E+00	-0.343661E+00	-0.126445E+00	1.00
10896.2109	0.254039	-0.595099E+00	-0.440912E+00	-0.154187E+00	1.00
11789.0313	2.032513	0.308033E+00	-0.475137E+00	0.783170E+00	1.00
12381.8086	0.180734	-0.742961E+00	-0.496456E+00	-0.246505E+00	1.00
13107.1992	0.301042	-0.521373E+00	-0.521197E+00	-0.175893E-03	1.00
14502.8438	0.295316	-0.529713E+00	-0.565168E+00	0.354553E-01	1.00
15928.5742	1.548678	0.189961E+00	-0.605918E+00	0.795879E+00	1.00
17437.7852	0.150557	-0.822299E+00	-0.645257E+00	-0.177042E+00	1.00
19430.6875	0.406488	-0.390953E+00	-0.692284E+00	0.301331E+00	1.00
20747.4570	0.282294	-0.549298E+00	-0.720778E+00	0.171480E+00	1.00
21836.9688	0.112891	-0.947342E+00	-0.743019E+00	-0.204323E+00	1.00
22527.5273	0.492762	-0.307363E+00	-0.756549E+00	0.449186E+00	1.00
23098.6875	0.677547	-0.169060E+00	-0.767429E+00	0.598369E+00	1.00
23815.1289	0.084668	-0.107228E+01	-0.780704E+00	-0.291577E+00	1.00
27268.6094	0.193573	-0.713155E+00	-0.839551E+00	0.126396E+00	1.00
31046.6602	0.451671	-0.345178E+00	-0.895938E+00	0.550760E+00	1.00
32211.9141	0.112885	-0.947363E+00	-0.911949E+00	-0.354140E-01	1.00
33740.1914	0.150586	-0.822215E+00	-0.932094E+00	0.109878E+00	1.50
35213.7031	0.246381	-0.608393E+00	-0.950669E+00	0.342276E+00	1.25
36827.3516	0.148187	-0.829189E+00	-0.970140E+00	0.140951E+00	1.13
39097.6328	0.230969	-0.636447E+00	-0.996137E+00	0.359690E+00	1.06
41035.5195	0.169365	-0.771176E+00	-0.101716E+01	0.245984E+00	1.03
42530.3516	0.135534	-0.867952E+00	-0.103271E+01	0.164756E+00	1.02
45548.6719	0.178778	-0.747686E+00	-0.106250E+01	0.314817E+00	1.01
48974.5039	0.198283	-0.702713E+00	-0.109402E+01	0.391304E+00	1.00
51023.4766	0.250926	-0.600454E+00	-0.111183E+01	0.511375E+00	1.00
54672.4805	0.111760	-0.951715E+00	-0.114185E+01	0.190132E+00	1.00
59053.0117	0.043255	-0.136396E+01	-0.117534E+01	-0.188618E+00	1.00
61990.9844	0.239098	-0.621424E+00	-0.119644E+01	0.575017E+00	1.00
66872.3750	0.077260	-0.111205E+01	-0.122938E+01	0.117332E+00	1.00
71125.8750	0.189695	-0.721943E+00	-0.125618E+01	0.534234E+00	1.00
73482.0000	0.037641	-0.142434E+01	-0.127034E+01	-0.153998E+00	1.00
77317.6875	0.021273	-0.167216E+01	-0.129245E+01	-0.379714E+00	2.00
81467.4375	0.070954	-0.114902E+01	-0.131517E+01	0.166145E+00	1.50
84798.1875	0.259440	-0.585963E+00	-0.133258E+01	0.746621E+00	1.25
88733.3125	0.135518	-0.868004E+00	-0.135230E+01	0.484292E+00	1.63
92423.2500	0.036611	-0.143638E+01	-0.137000E+01	-0.663815E-01	1.31
94197.3750	0.123153	-0.909553E+00	-0.137826E+01	0.468711E+00	1.16
95576.9375	0.112958	-0.947082E+00	-0.138458E+01	0.437502E+00	1.08
98553.3125	0.089149	-0.104988E+01	-0.139791E+01	0.348026E+00	1.04
102908.8750	0.029435	-0.153114E+01	-0.141670E+01	-0.114438E+00	1.02
105687.5000	0.058970	-0.122937E+01	-0.142828E+01	0.198914E+00	1.01

109221 7500	0 056448	-0 124835E+01	-0.144258E+01	0 194224E+00	1 00
112857 4375	0 084695	-0 107214E+01	-0 145681E+01	0.384664E+00	1 00
114297 5000	0 141151	-0 850315E+00	-0 146232E+01	0 612000E+00	1 00
115737.3125	0 084695	-0 107214E+01	-0 146776E+01	0 395614E+00	1 00
118599 7500	0 084681	-0 107222E+01	-0 147837E+01	0 406157E+00	1 00
124917 1250	0 000692	-0 315963E+01	-0 150093E+01	-0 165871E+01	4 00
135628 0625	0 007782	-0.210889E+01	-0 153668E+01	-0 572213E+00	3 50

FIT PARAMETERS
INTERCEPT, BO 0 359890E+01
SLOPE, B1 -1 0006285
CONFIDENCE LIMIT ON BO T 0 5185753
CONFIDENCE LIMIT ON B1 T 0 1145718
DURBIN WATSON STATISTIC 1 677
DEGREE OF FREEDOM FOR DW 75
UPPER LIMIT FOR DW 1 650
TEST OF SLOPE SIGNIFICANCE 76 249

DATA FOR COMPARISON TESTS
WEIGHTING 69 5
MEAN STRAIN -0 895 MEAN TIME 4 491
SSDY 43 673 SSDX 22 827
SPDXY -22 835 SSDYX 20 825

CHECK
SUM OF RESIDUALS -0 001285

DATA STARTS AT # 1
DATA ENDS AT # 75

FIT PARAMETERS FROM PREVIOUS ITERATION
TEST OF SLOPE SIGNIFICANCE 77 291
DURBIN WATSON STATISTIC 1 500

******************** FIT OF ACCELERATING CREEP DATA TO POWER LAW ********************

PARAMETERS FOR EVALUATING TOTAL FIT, LVDT NO.: 1

	ACCELERATING CREEP				TOTAL FIT
RANGE	INTERCEPT, BO	SLOPE, B1	R	DW	R
56 - 96	-0 311423E+02	5 7150812	44 210	1 588	46 491
57 - 96	-0 349556E+02	6 4425755	62 142	1 844	47 474
60 - 96	-0.417652E+02	7.7399416	90 227	1 617	48 796
61 - 96	-0 448557E+02	8 3275833	112 218	2 630	49 215
62 - 96	-0.492026E+02	9 1533813	197 507	1 609	49 609
63 - 96	-0 440275E+02	8 1738224	57 144	1 681	49 039
64 - 96	-0 435989E+02	8 0928059	52 815	1 690	48 973

DATA FROM LVDT NO. 1

TRANSFORMED DATA

TIME (MIN)	STR RATE, E (MICRO.E/MIN)	LOG E	LOG EE	LOG E - LOG EE	W
149530.1875	0.019336	-0.171364E+01	-0.172083E+01	0.718498E-02	9.50
167579.1250	0.016897	-0.177220E+01	-0.132031E+01	-0.451883E+00	5.25
176213.5000	0.182511	-0.738711E+00	-0.114372E+01	0.405012E+00	3.13
181223.9375	0.179970	-0.744800E+00	-0.104518E+01	0.300381E+00	2.06
183417.8125	0.187042	-0.728061E+00	-0.100290E+01	0.274838E+00	1.53
187735.7500	0.314885	-0.501848E+00	-0.921112E+00	0.419264E+00	1.27
193457.9375	0.676174	-0.169942E+00	-0.815582E+00	0.645641E+00	1.13
198547.1875	0.418027	-0.378796E+00	-0.724319E+00	0.345523E+00	1.07
204369.5000	0.023469	-0.162950E+01	-0.622742E+00	-0.100676E+01	1.03
210040.2500	0.139765	-0.854600E+00	-0.526550E+00	-0.328050E+00	1.02
214373.8125	0.957121	-0.190331E-01	-0.454773E+00	0.435740E+00	1.01
217404.0000	0.260870	-0.583576E+00	-0.405441E+00	-0.178135E+00	1.00
220999.5000	0.325762	-0.487099E+00	-0.347778E+00	-0.139321E+00	1.00
225169.7500	0.176027	-0.754421E+00	-0.282074E+00	-0.472347E+00	1.00
228028.5000	0.714471	-0.146015E+00	-0.237747E+00	0.917320E-01	1.00

FIT PARAMETERS

INTERCEPT, B0		-0.435989E+02
SLOPE, B1		8.0928059
CONFIDENCE LIMIT ON B0	T.	5.8610058
CONFIDENCE LIMIT ON B1	T.	1.1169233
DURBIN WATSON STATISTIC		1.690
DEGREE OF FREEDOM FOR DW		33
UPPER LIMIT FOR DW		1.505
TEST OF SLOPE SIGNIFICANCE		52.815

DATA FOR COMPARISON TESTS

WEIGHTING	30.0		
MEAN STRAIN	-1.135	MEAN TIME	5.247
SSDY	11.981	SSDX	0.116
SPDXY	0.943	SSDYX	4.340

CHECK

SUM OF RESIDUALS 0.001468

DATA STARTS AT # 64

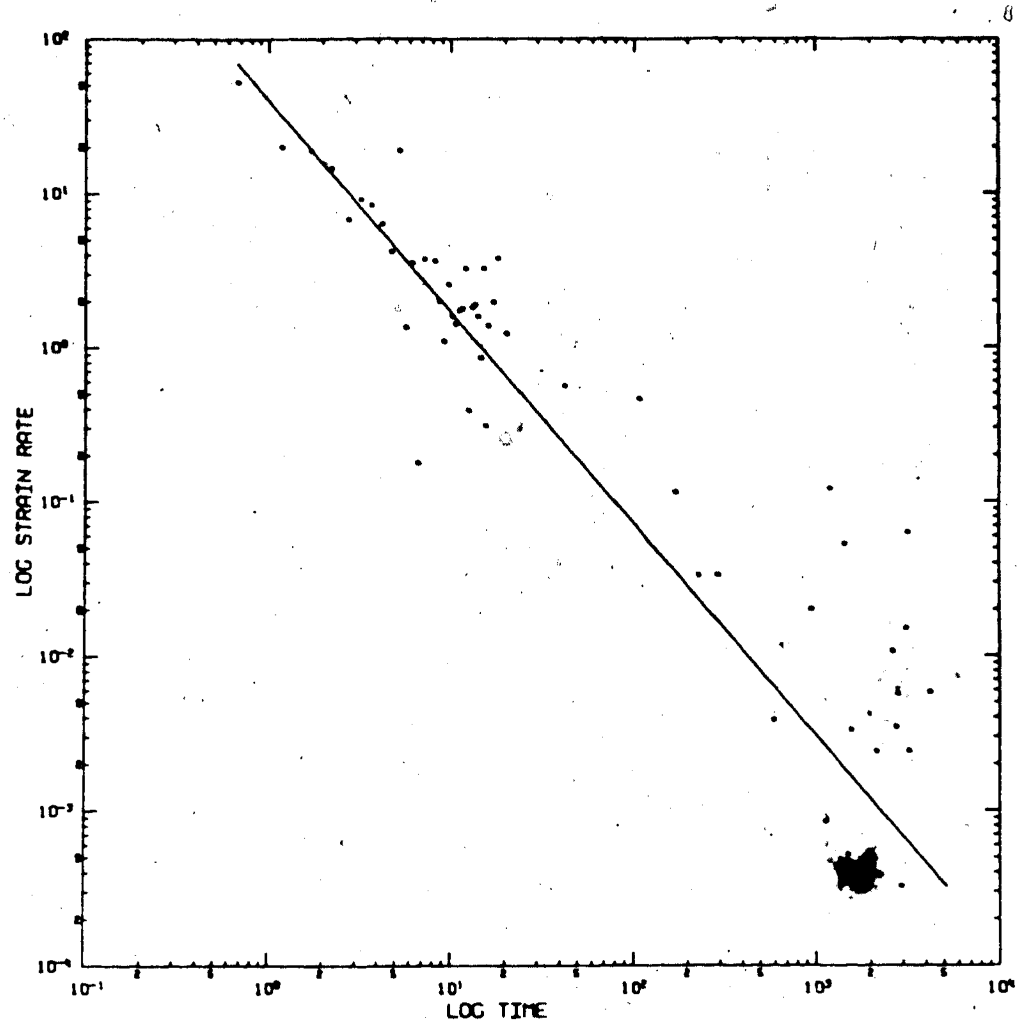
DATA ENDS AT # 96

FIT PARAMETERS FROM PREVIOUS ITERATION

TEST OF SLOPE SIGNIFICANCE	74.130
DURBIN WATSON STATISTIC	1.412

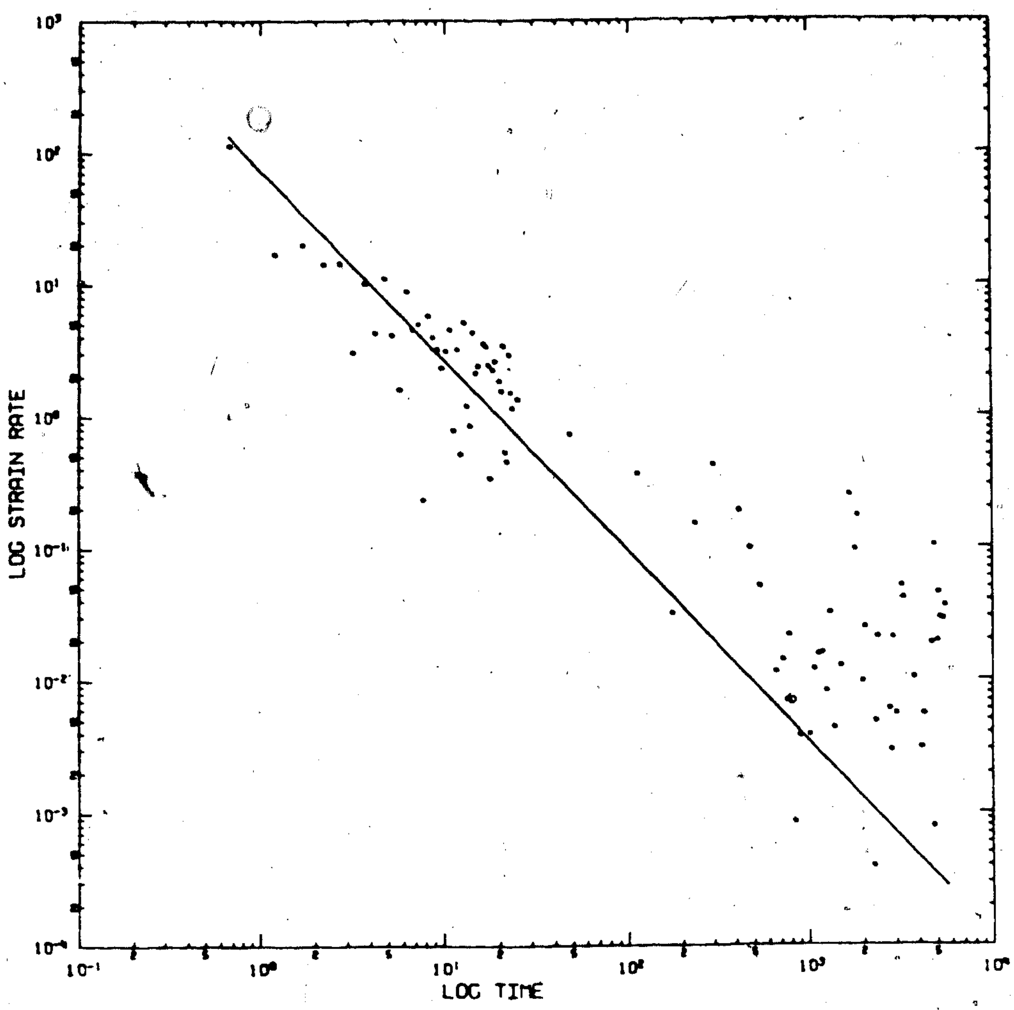
APPENDIX B

ADDITIONAL TEST RESULTS



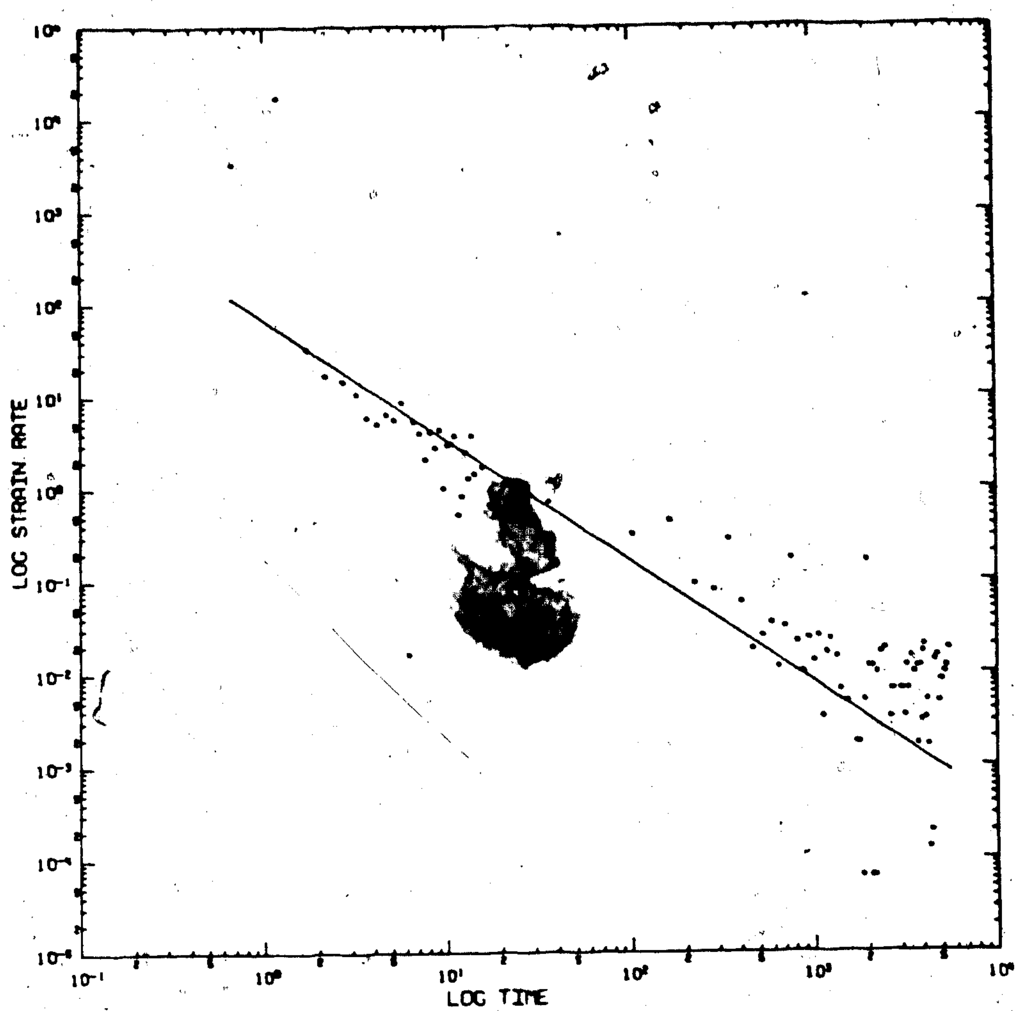
Axial Stress = 6.38 MPa

Figure B.1 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test U9-9#11



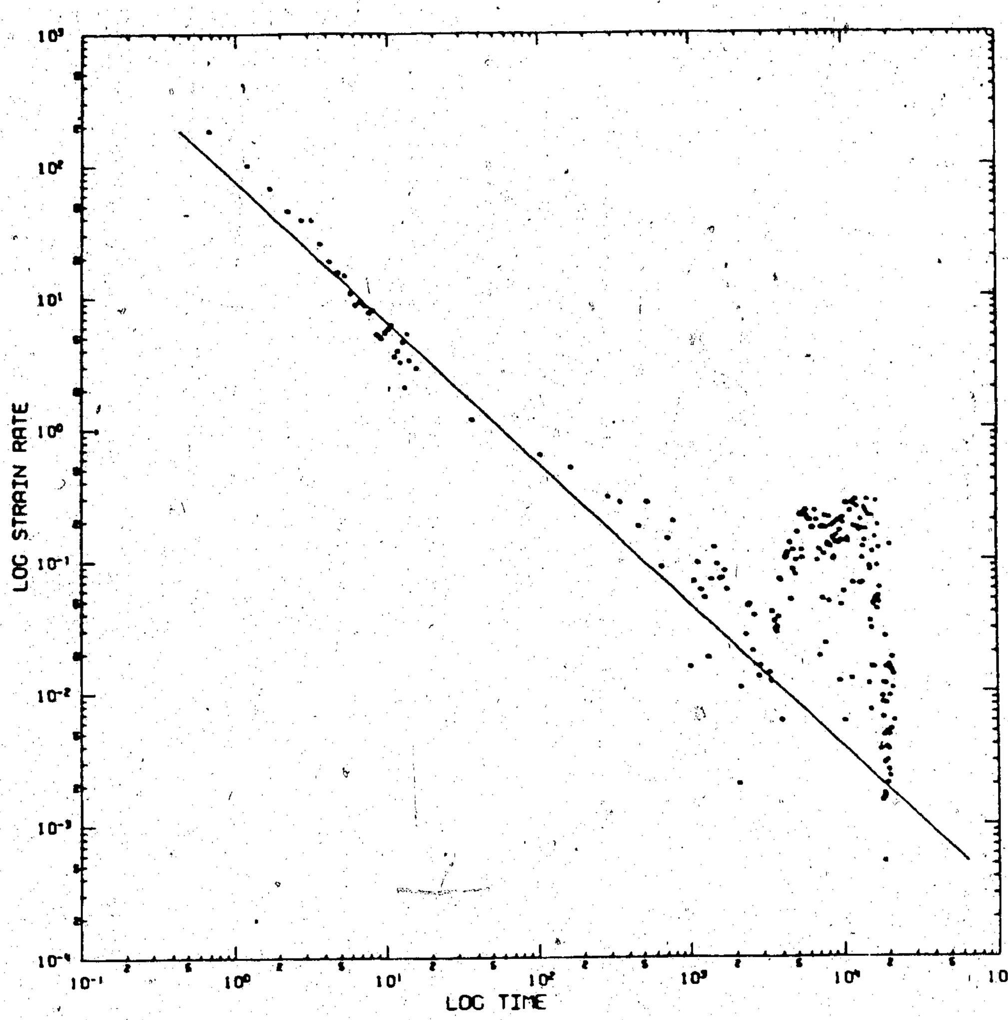
Axial Stress = 6.38 MPa

Figure B.2 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test U9-9#21



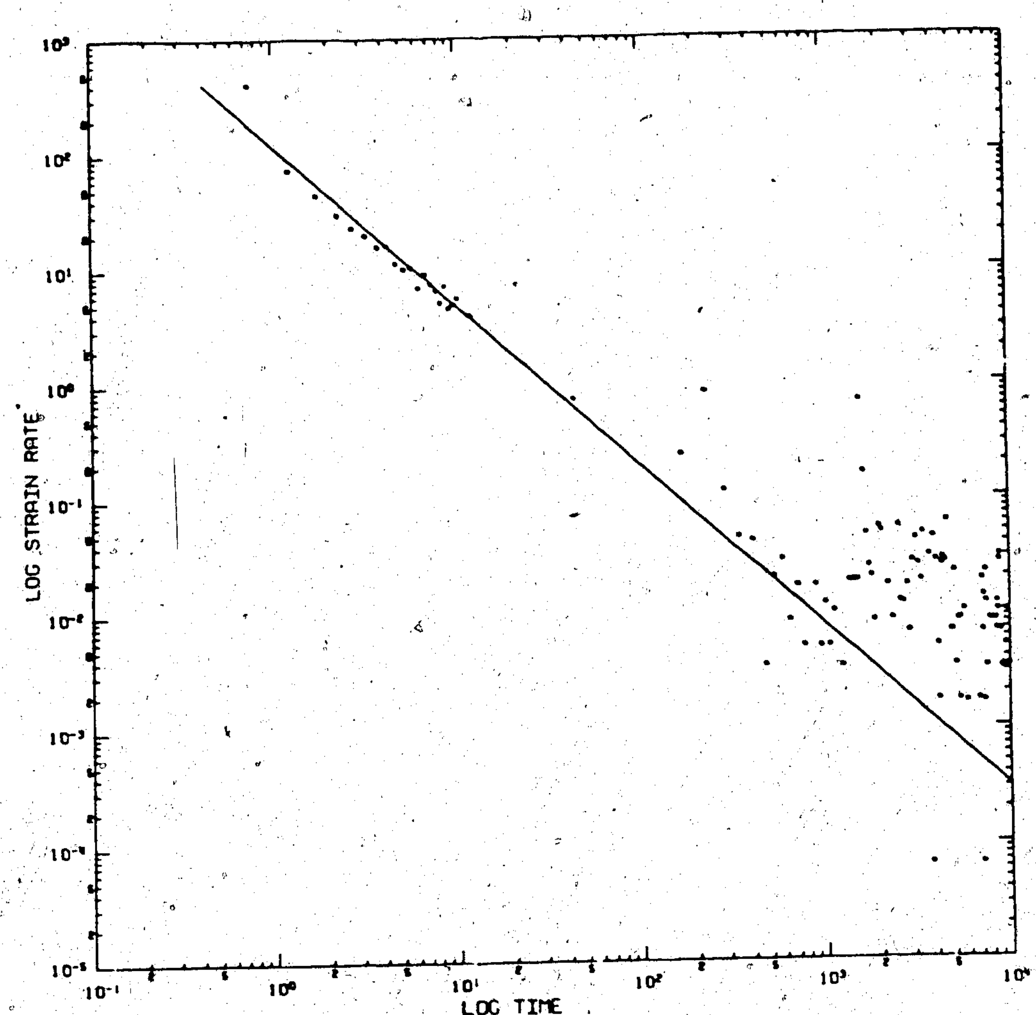
Axial Stress = 7.18 MPa

Figure B.3 Logarithm plot of strain rate (micro-strain/min.) vs time (min) Test U10-9#2



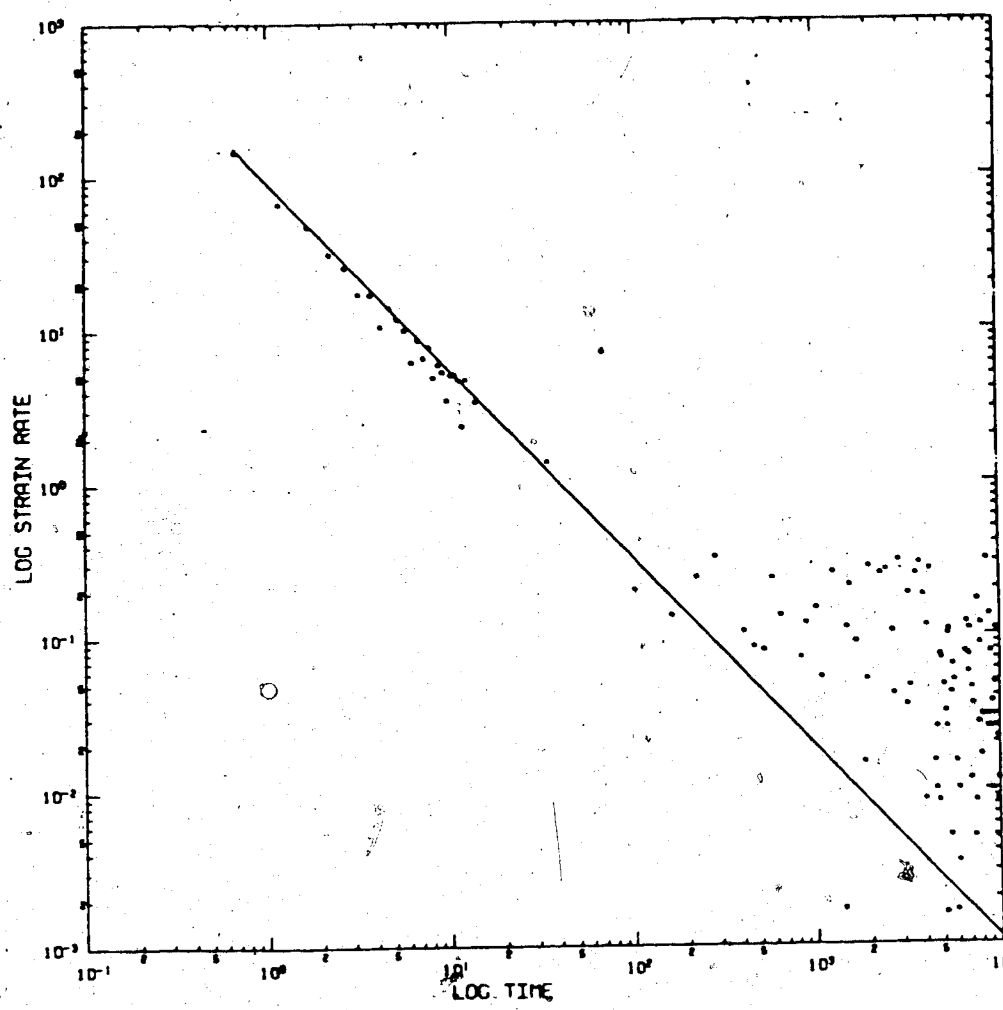
Axial Stress = 4.78 MPa

Figure B.4 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test S9-9#7



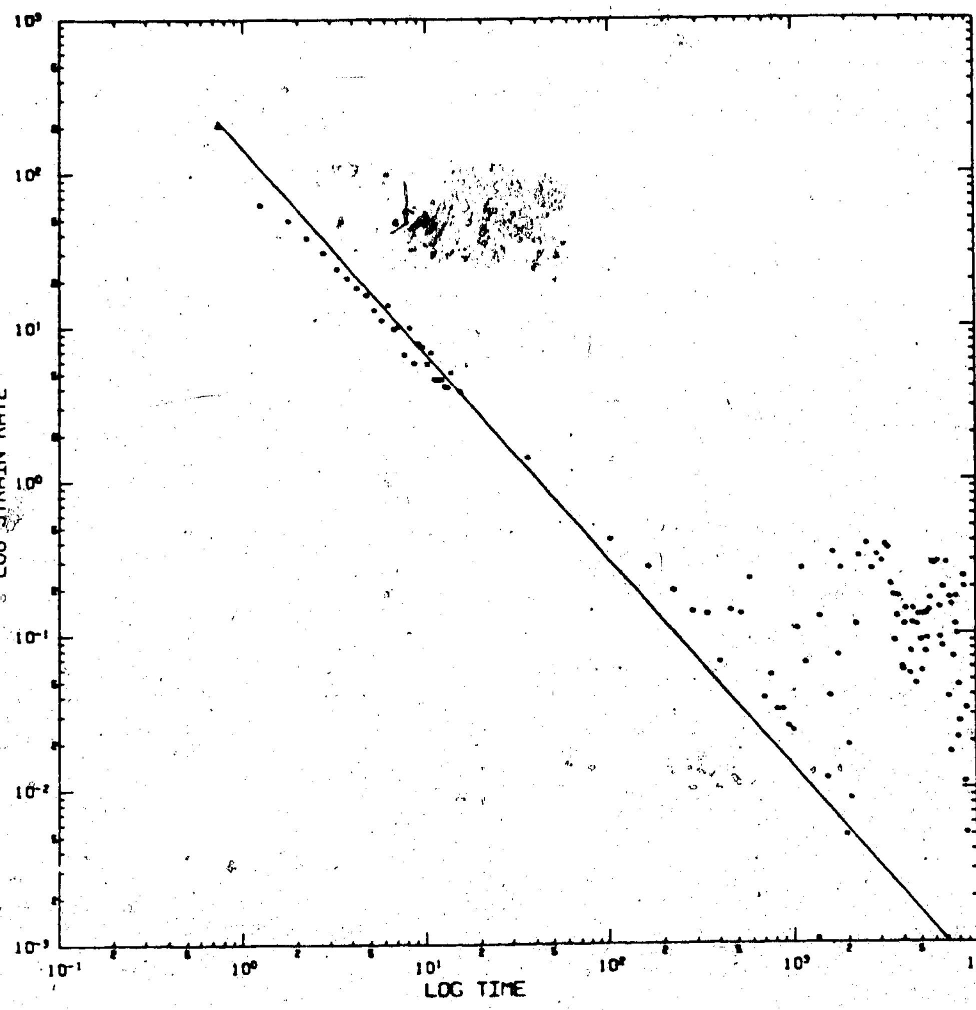
Axial Stress = 3.99 MPa

Figure B.5 Logarithm plot of strain rate (micro-strain/min) vs time (min), Test S9-9#15



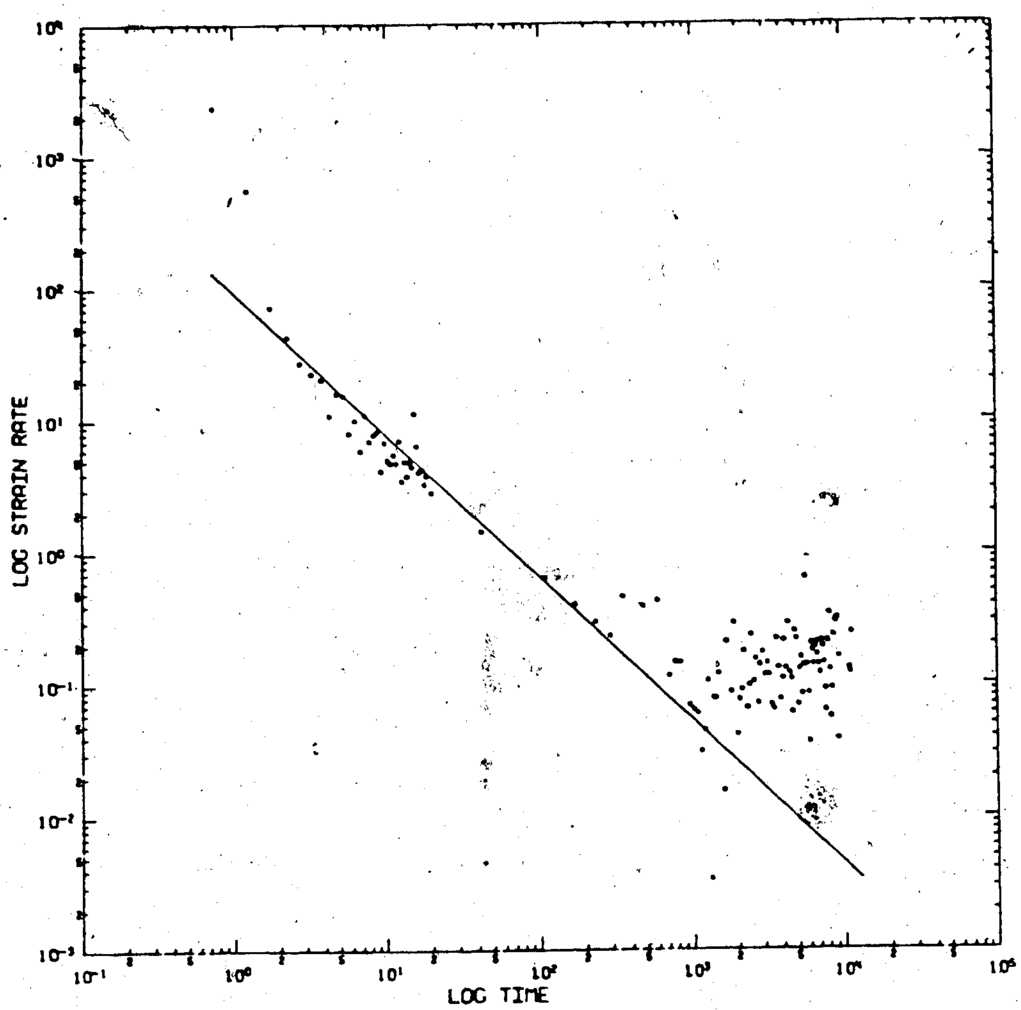
Axial Stress = 3.99 MPa

Figure B.6 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test S9-9#17



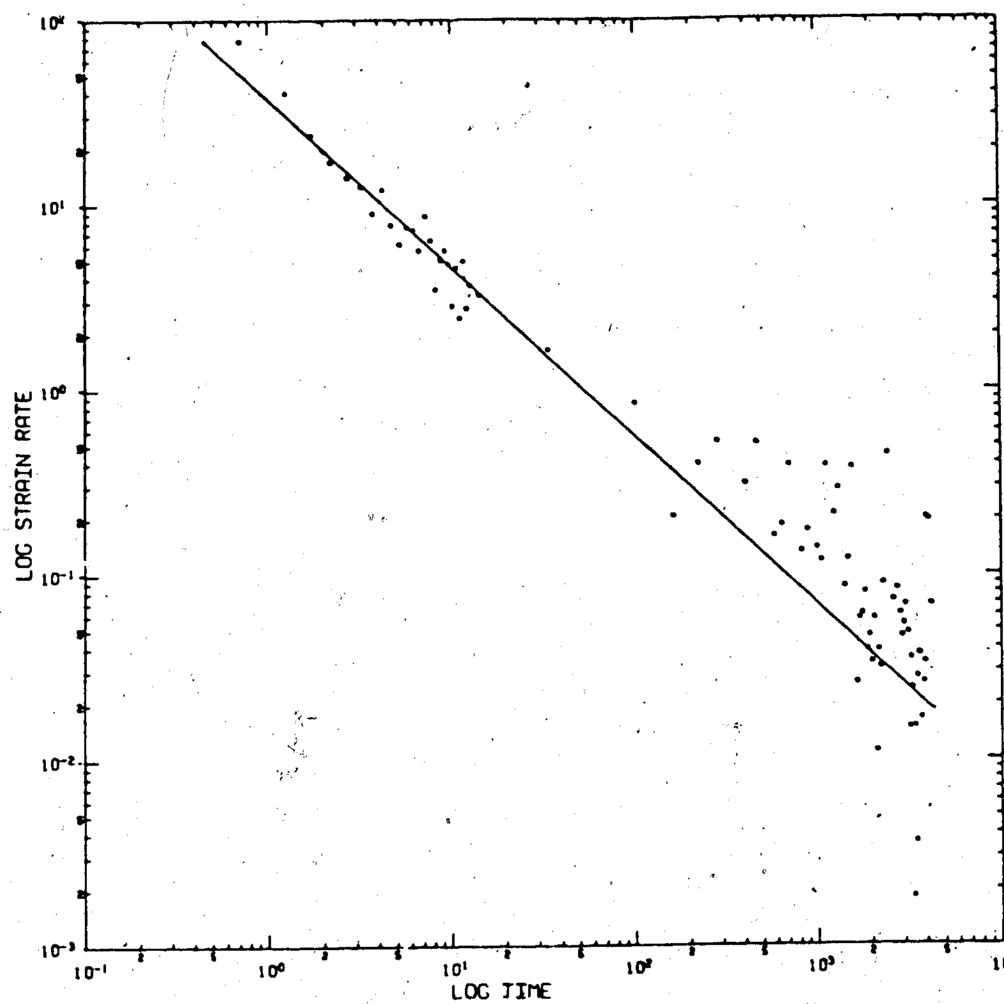
Axial Stress = 3.99 MPa

Figure B.7 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test S10-9#2



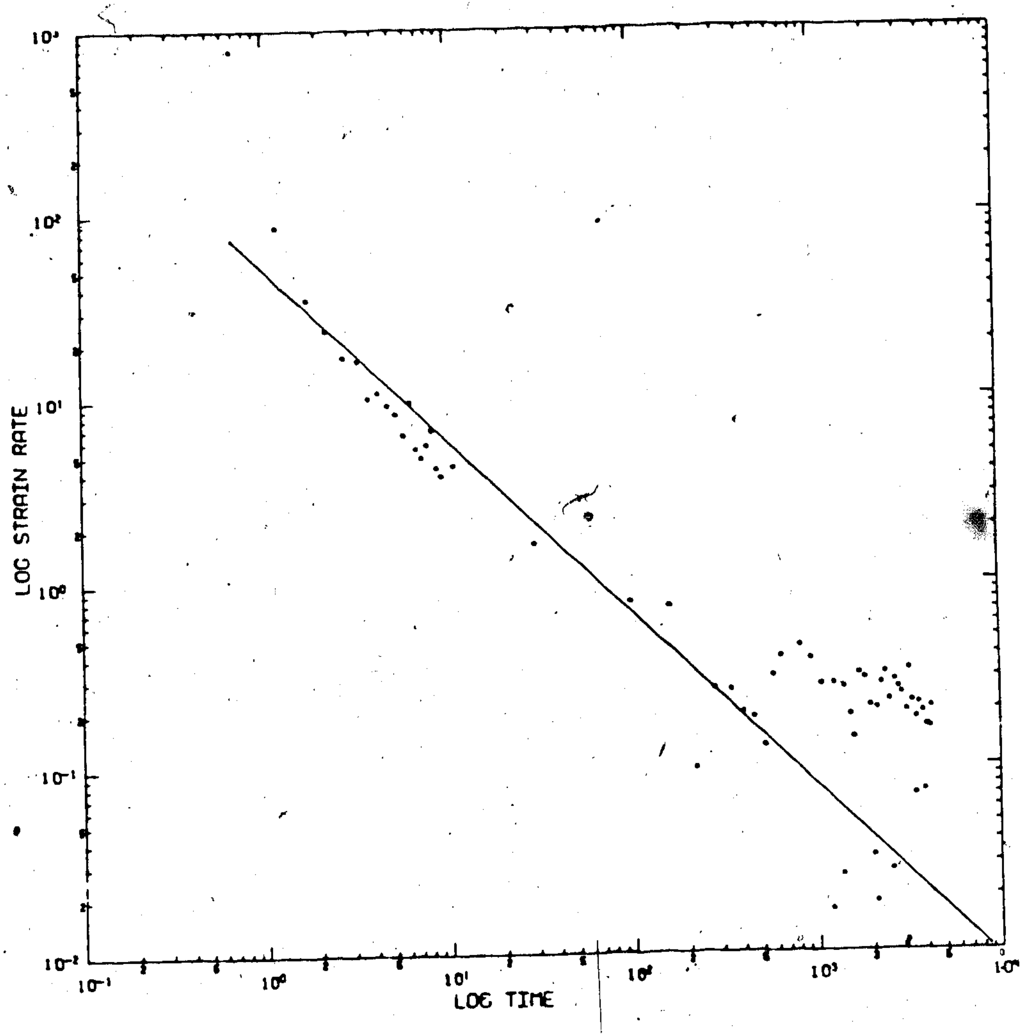
Axial Stress = 2.39 MPa

Figure B.8 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test UT6F2



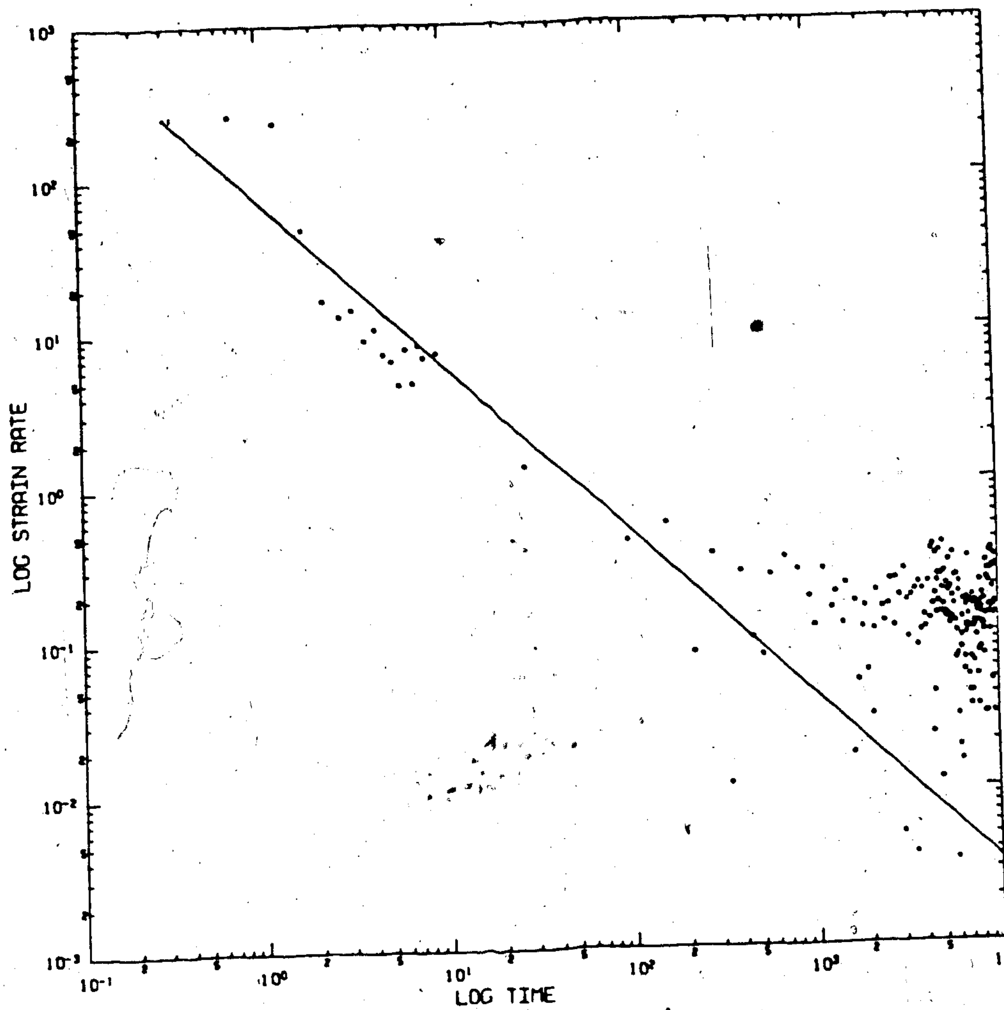
Axial Stress = 2.39 MPa

Figure B.9 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test UT6D



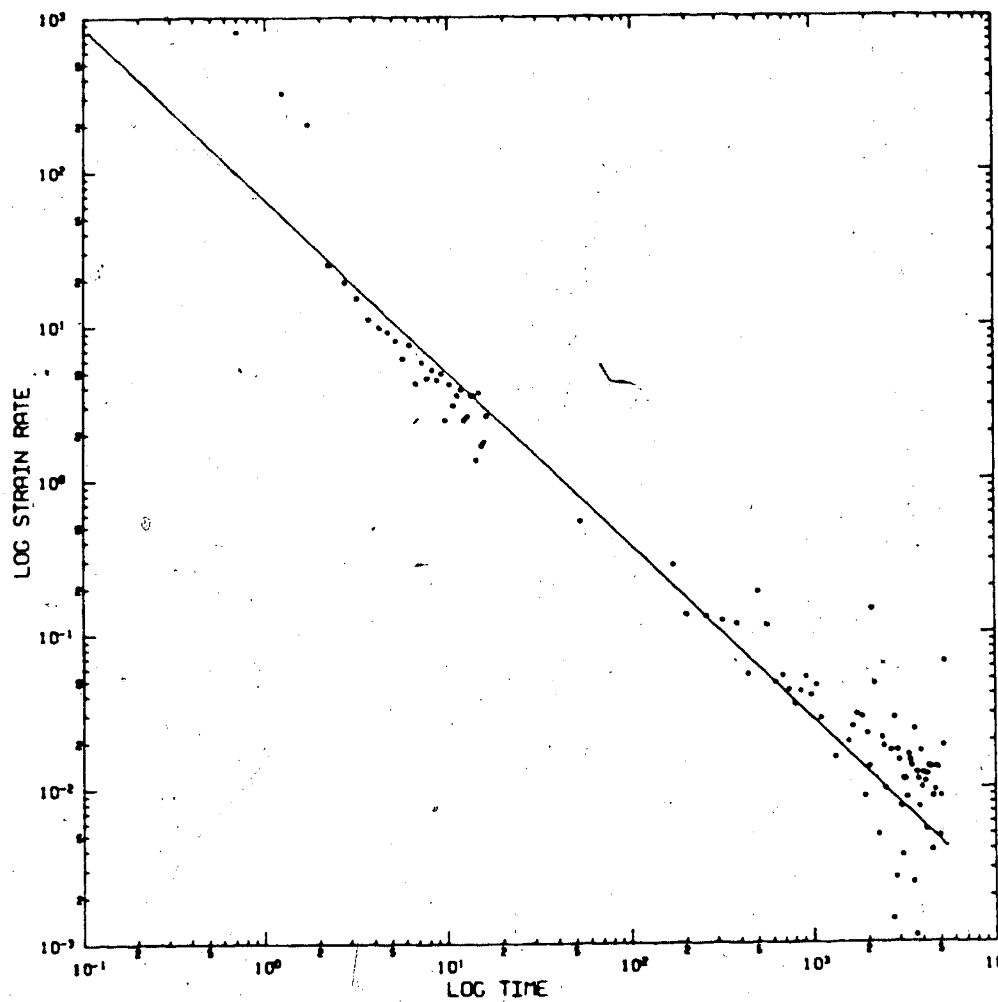
Axial Stress = 2.39 MPa

Figure B.10 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test UT6D2



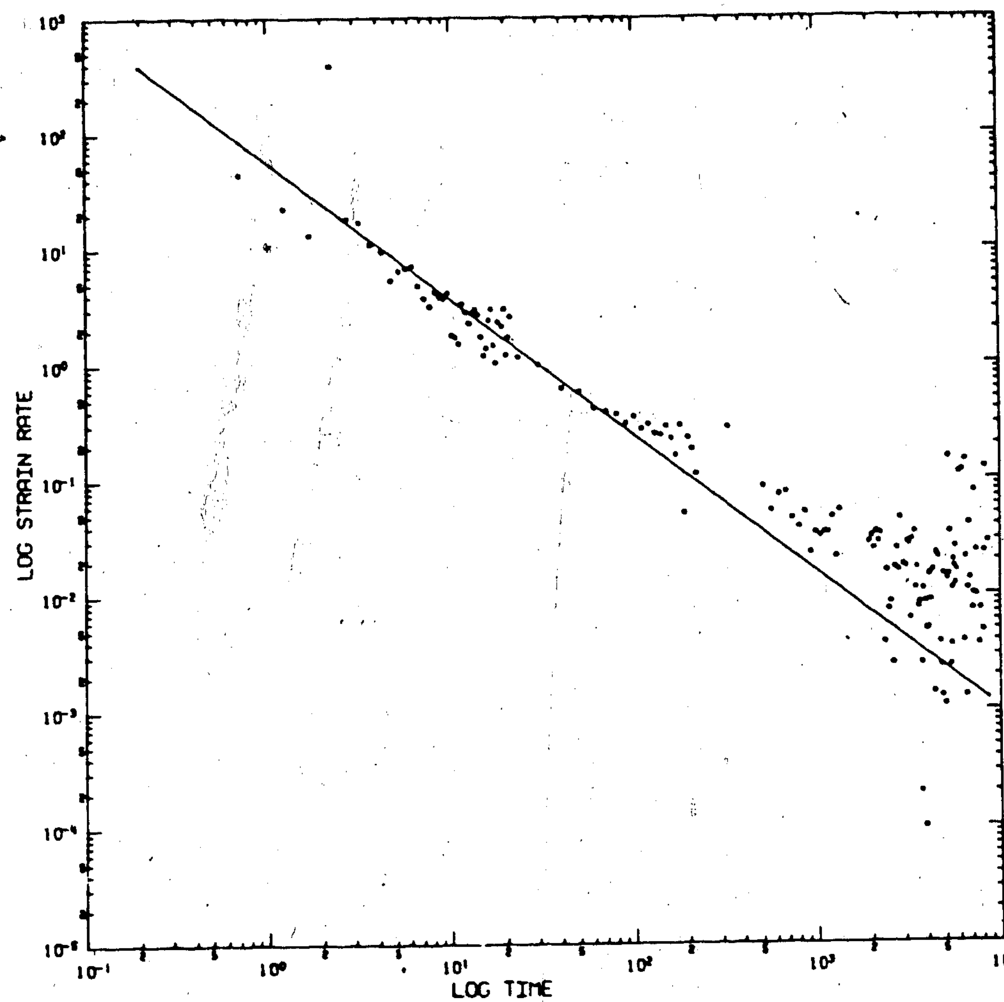
Axial Stress = 2.92 MPa

Figure B.11 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test UT6D3



Axial Stress = 1.86 MPa

Figure B.12 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test CT6A



Axial Stress = 2.66 MPa

Figure B.13 Logarithm plot of strain rate (micro-strain/min) vs time (min) Test CT6A3