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The time-dependent mechanical properties of fibre reinforced polymers

- by -

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Progress Report No. 3

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A report of work carried out during the period 1st October, 1968 to 30th March, 1969.

Contents

1. General Progress

In the six months from October, 1968 to March, 1969 the work has been divided into two main sections. The first of these has been the collection of tensile creep data both for the unreinforced resin and for the uni- and bi-directionally reinforced composites. The second section has been the continued quest for a successful lateral extensometer.

In Progress Report No. 2 it was reported that five creep machines were in production. These have now been installed and are all functioning satisfactorily. Longitudinal extensometers of the type described in Progress Report No. 2 have been manufactured for use on these rigs.

Comparisons have been made[2] between the experimental creep results of the composites described in this report and theoretical predictions based on the Elemental model.[3,4] Good agreement was shown to exist between the experiment and theory.

2. Lateral Extensometer

In Progress Report No. 2[1] two types of lateral extensometer were described. The first was mounted on the creep machine itself and measured the change of width of the specimen by means of the probes which were kept in contact with the surface of the specimen. This was unsuccessful as it also measured any nonparallelism of the sides of the specimen. An attempt to counteract this was made by the design of a second extensometer which, while its weight was carried by the creep machine, was attached to the specimen at fixed gauge points. This was more successful than the first but it was shown to be susceptible to very small sideways movements of the specimen relative to the machine.

To remove this error it became necessary to design an extensometer that was mounted directly on the specimen. Figure 1 shows the first attempt at solving this problem. It consists of two clamps, each with four point mounting, screwed into small aluminium pads that had been glued to the specimen. The transducer measures the relative movement of the two clamps. Tests showed that the presence of this extensometer did not affect the longitudinal creep compliance of specimens, and it was consequently hoped that this indicated that the axial stress distribution of the specimen had not been disturbed. Measurements of the creep contraction ratio using this extensometer were very consistent but unfortunately they were consistently smaller than expected. This is presumably due to a change in stress distribution caused by clamping a rigid body to a flexible specimen.

In view of these three attempts to produce a successful lateral extensometer the necessary qualifications for success would appear to be:-

i) Measurements must be taken at one place on the specimen.

ii) The extensometer must be mounted directly on the specimen.

iii) The method of mounting the extensometer on the specimen must not interfere with the axial stress pattern in the specimen.

The only apparent solution to this problem is to spring load an extensometer on to the specimen. A simple extensometer which operates on this principle has been built and is shown in Figure 2. Using this, some 100 second results have been obtained for the creep contraction of the MY 753 resin. These results, shown in Figure 6, can be seen to compare very well with those measured on this material by Darlington using his creep contraction measuring equipment.

3. Experimental Results

All creep results that have been reported in previous Progress Reports were considered to be preliminary but here the longitudinal creep measurements have all been made using fully developed apparatus. The creep contraction results that are included here are still only of a preliminary nature.

3.1 Unreinforced MY 753

To determine the stress-strain behaviour of the resin fully it is necessary to know:-

i) The variation of the creep compliance with time and stress.

ii) The variation of the creep contraction ratio with time and stress.

iii) The extent of inter-batch variation.

The first of these requires the measurement of longitudinal creep over a specified time period at several stress levels. As it is necessary to remove any effects due to inter-batch variations, the specimens to be tested must be produced from one sheet. The creep tests that have been performed were carried out on a set of five specimens at stresses up to 2.5×10^8 dynes/cm^2 for a duration of between 10^5 and 10^6 seconds. The individual stress levels were chosen such that the region of linearity of stress-strain behaviour should be clearly delineated. In Figure 3 the results of this series of creep tests are shown. At the lower stress levels, the compliances can be seen to be superimposed, indicating the linearity of the resin at these stresses. Above a stress of 6.4×10^7 dynes/cm^2 the curves begin to diverge as the resin becomes non-linear. The upper curve in Figure 6, which shows the 100 second stress-strain behaviour of the resin, shows the onset of non-linearity clearly. It is important that the creep tests on the composite materials are carried out at a stress level such that the resin is in the linear region. This stress level is equivalent to a strain at 100 seconds of not more than 0.2%. To ensure that even in the regions of stress concentrations no non-linearity is observed the 100 second strain is normally kept down to 0.1%.

In Figure 3, the continuous line shows the creep compliance in the linear region. This line was calculated as being the best fit of the low stress data by the ICT 1905 computer using a linear regression technique. The discontinuous retardation time spectrum associated with this linear region creep compliance is shown in Figure 4.

Due to inexactitudes in the weighing of the two components of the resin during manufacture of specimens, a certain amount of variation in the properties of the resin occurs. This is obviously minimised by taking care at all stages of manufacture, but some variations still occur. Figure 5 shows a typical set of low stress compliances for samples cut from different sheets of MY 753 resin. The variation in properties is in the order of ± 5%. This variation is sufficiently large to make it necessary to manufacture a control specimen of resin with each batch of composite material produced rather than use an average description of the resin.

To complete the description of the resin, creep contraction results are required. As the lateral extensometer is not yet fully reliable, these results were obtained by Darlington using his creep contraction extensometers. The 100 second results that he obtained are shown in Figure 6 in conjunction with the associated values of the longitudinal strain. From these results the creep contraction ratio at 100 seconds has been calculated to be 0.388. In the development of the spring loaded lateral extensometer, results were obtained for the 100 second creep contraction of the MY 753. These are compared with Darlington's results in Figure 6 and, while only of a preliminary nature, agree very well with the accurately obtained values.

3.2 Uni-directionally reinforced MY 753

Figures 7, 8, 9 show a selection of creep data obtained for uni-directionally reinforced MY 753. In order that the properties of the resin remained linear, these tests were conducted such that the 100 second strain was of the order of 0.1%. The results have been grouped according to volume fraction to give a picture of the variation of the creep compliance with angle unclouded by other variations.

In Progress Report No. 2 the variation of the 100 second creep compliance of this system was predicted and compared with experimental results. Here again the same trend of results with angle is obtained with higher compliances obtained at 60° to the fibre axis than at 90°. All three figures show the same trend but the most descriptive is Figure 7. It can be seen that at low angles to the fibre axis there is very little creep while at higher angles the time dependent extension is a considerable proportion of the whole.

A comparison between these results and theoretical predictions based on the Elemental model has been made[2] and the agreement was shown to be good, apart from what was described as an apparent error in the measurement of the volume fraction of the fibres. It has since been shown that in fact no errors are introduced from this source. The upper curve in Figure 5 corresponds with the low stress curve in Figure 3 and was in fact used to describe the resin properties for the purposes of the theoretical predictions. This is some 5% above the mean value of the four curves in Figure 5 and would in fact account for part of the observed discrepancy between the theoretical and experimental results for the composite.

3.3 Bidirectionally reinforced MY753

Figure 10 shows the creep compliance results of the only bidirectional samples that have been tested to date. These have approximately the same number of fibres in each of two orthogonal directions. One of the samples was cut at 0° to one of the orthogonal directions and the other at 45°. The general shape of the creep curves is much the same as those for the unidirectional specimens. Here however, as predicted, there is a larger creep compliance in the 0° direction, and the 45° sample behaves in the same manner as a unidirection sample cut at this angle. 45° is, in this bidirectional case, the angle at which maximum compliance and creep rate are obtained.

Comparison between these results and theoretical predictions again show a good agreement, with the same magnitude of discrepancy as for the unidirectional case.

4. Theoretical Dsicussion

In section 3.2 it is described how there is a small discrepancy between the experimental and theoretical results for the creep compliance. This is only partly due to the variation in the properties of the resin and always results in a predicted compliance that is greater than the actual measurements.

On a careful search through the foundations of the theoretical model a possible source of this error has been found. In Hashin's[5] original paper in which he discusses the elastic constants of a unidirectional composite in which the fibres are randomly distributed, it appears that the random distribution that he proposes is of a specific type. This is such that each fibre is surrounded by a cylinder of resin, the diameter of which bears a constant ratio to the diameter of the fibre. In order that there shall be no voids in the composite it is therefore necessary that the diameter of the fibres is graded down to an infinitesimal size. This model type of random distribution is not the same as that found in real composites where the fibre diameter is constant and the distribution random in a general sense. In a later paper[6] when discussing the possible limits within which the properties of a unidirectional composite, composed of two cylindrical phases of arbitrary phase geometry, must lie, Hashin shows that his specific random case corresponds with the upper bound of compliance for these composites. Any variation from Hashin's random case must therefore produce a lower compliance.

References

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5. Hashin, Z. The elastic moduli of fiber-reinforced materials. J. Appl. Mechs., Trans. A.S.M.E., 31, 223. June, 1964.

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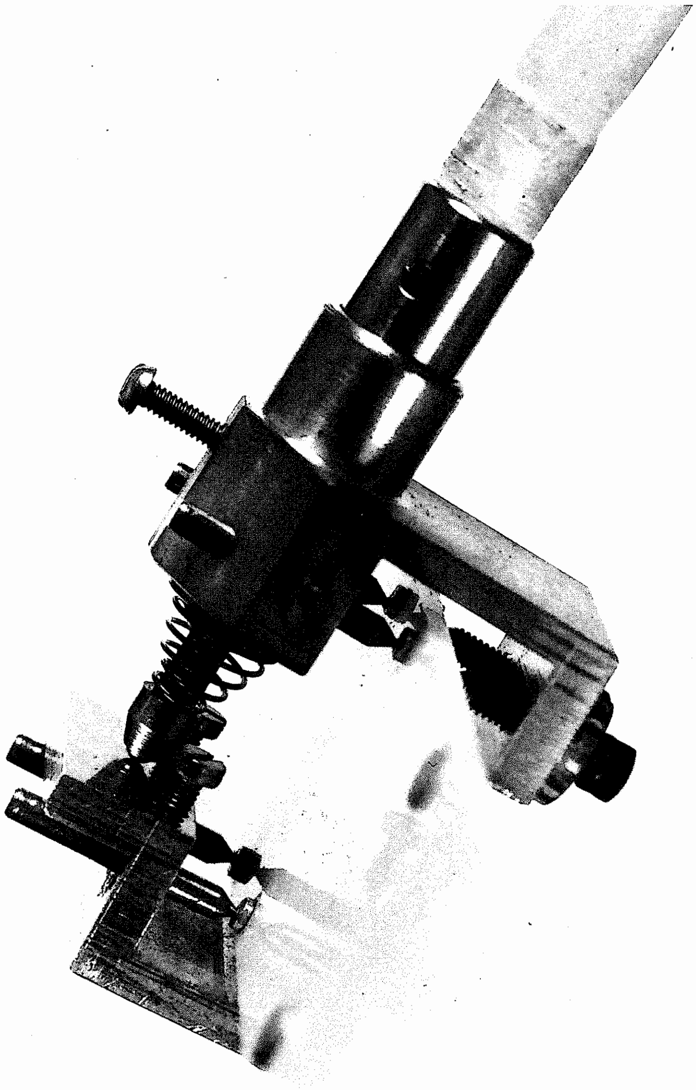

FIGURE 1. Direct mounted lateral extensometer

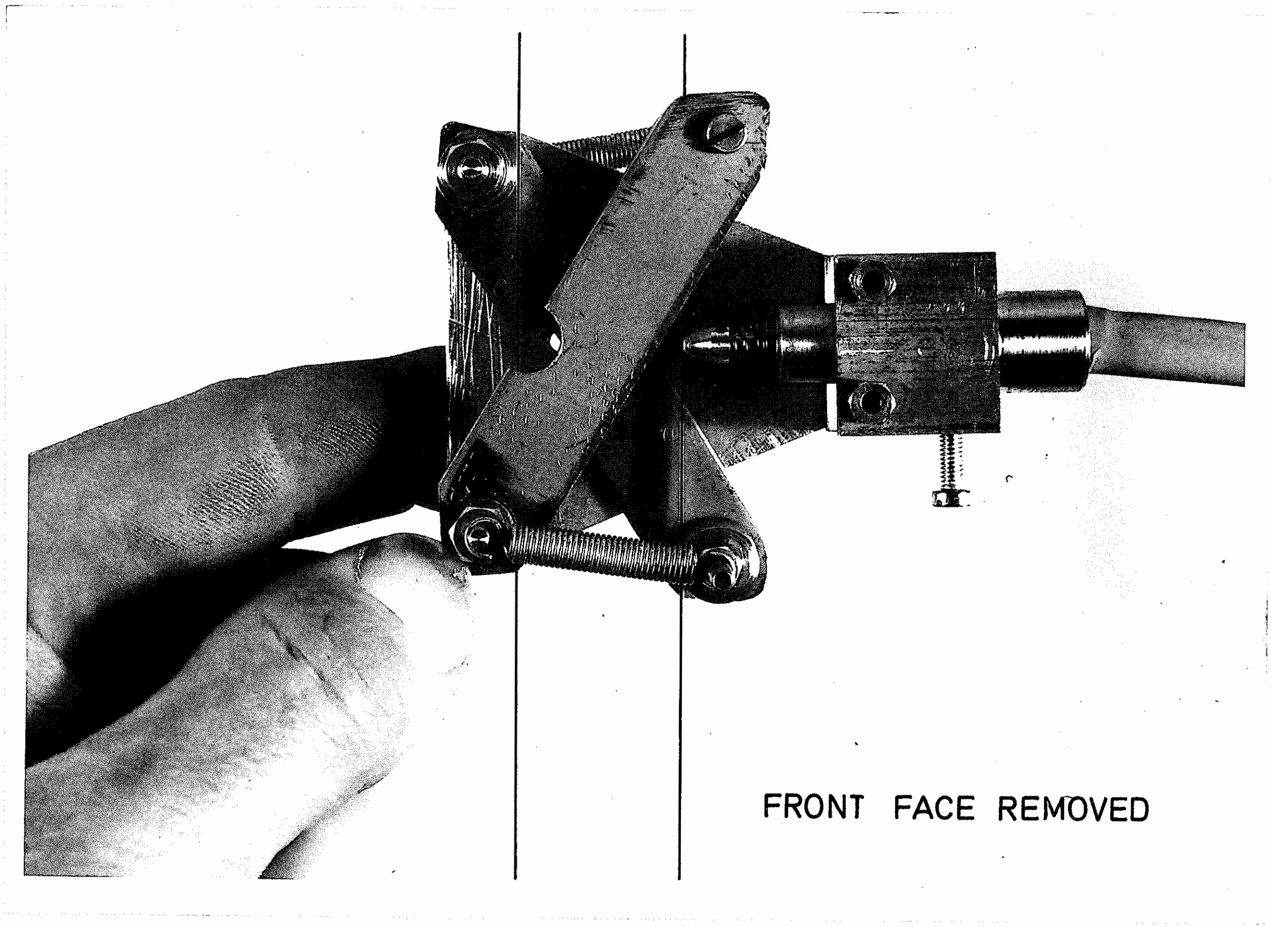

FIGURE 2. Spring loaded lateral extensometer

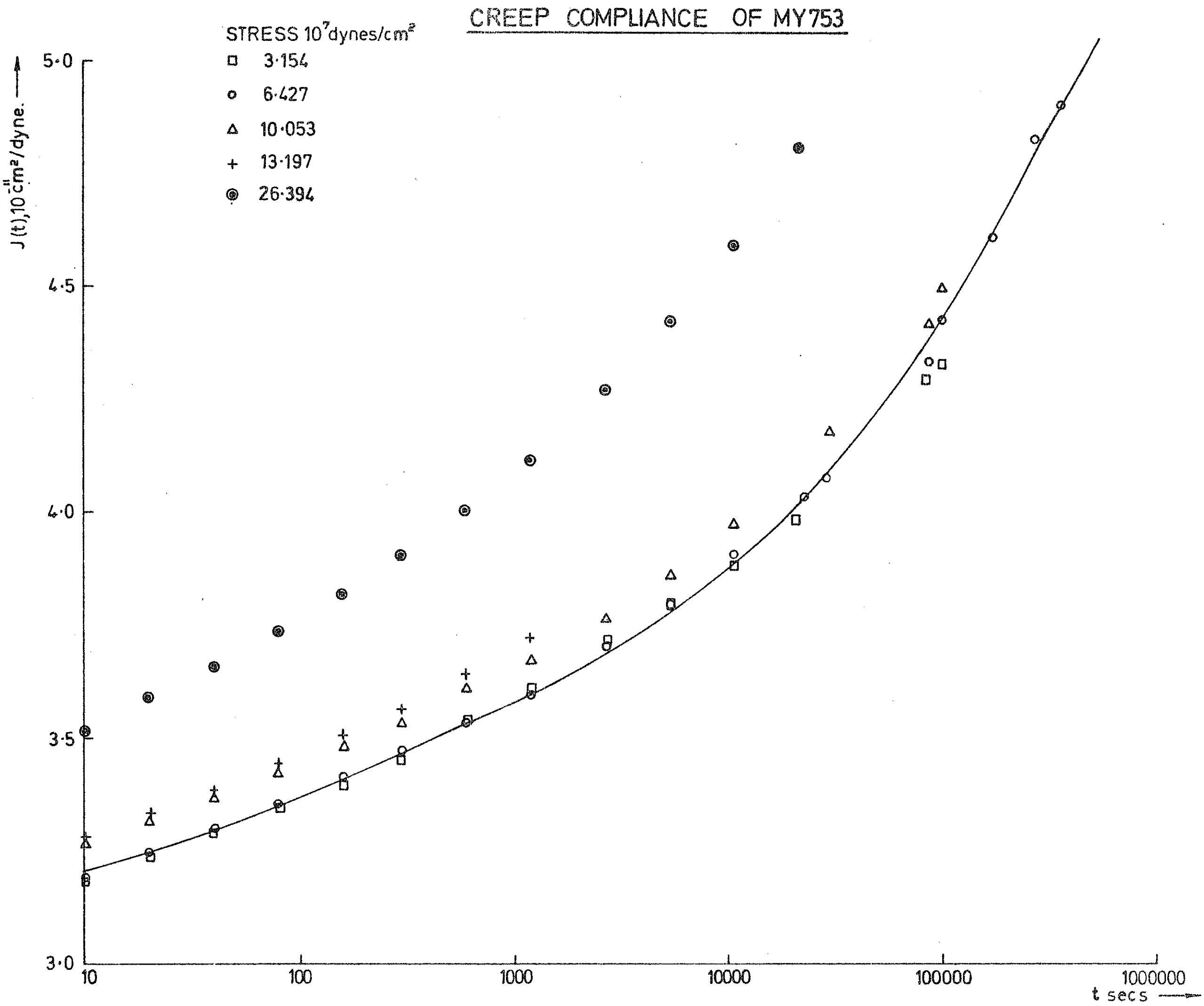
CREEP COMPLIANCE OF MY753
STRESS 10^7 dynes/cm^2
3·154
6·427
10·053
13·197
26·394
J(t), 10^{-11} cm^2/dyne.
5·0
4·5
4·0
3·5
3·0
10
100
1000
10000
100000
1000000
t secs

FIG 3

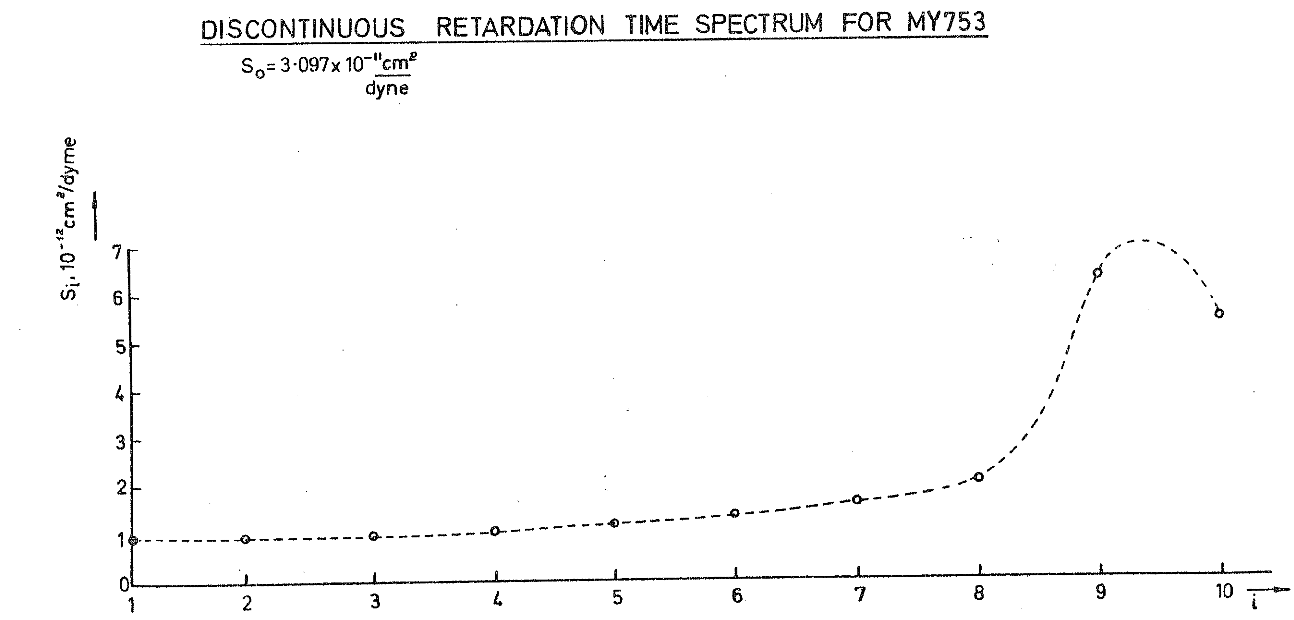
DISCONTINUOUS RETARDATION TIME SPECTRUM FOR MY753
$S_o = 3{\cdot}097 \times 10^{-11} \frac{cm^2}{dyne}$
S_i, 10^{-12} cm^2/dyme
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
8
9
10
i

FIG 4

FIGURE 5 CREEP COMPLIANCE OF MY 753 AT LOW STRESSES.

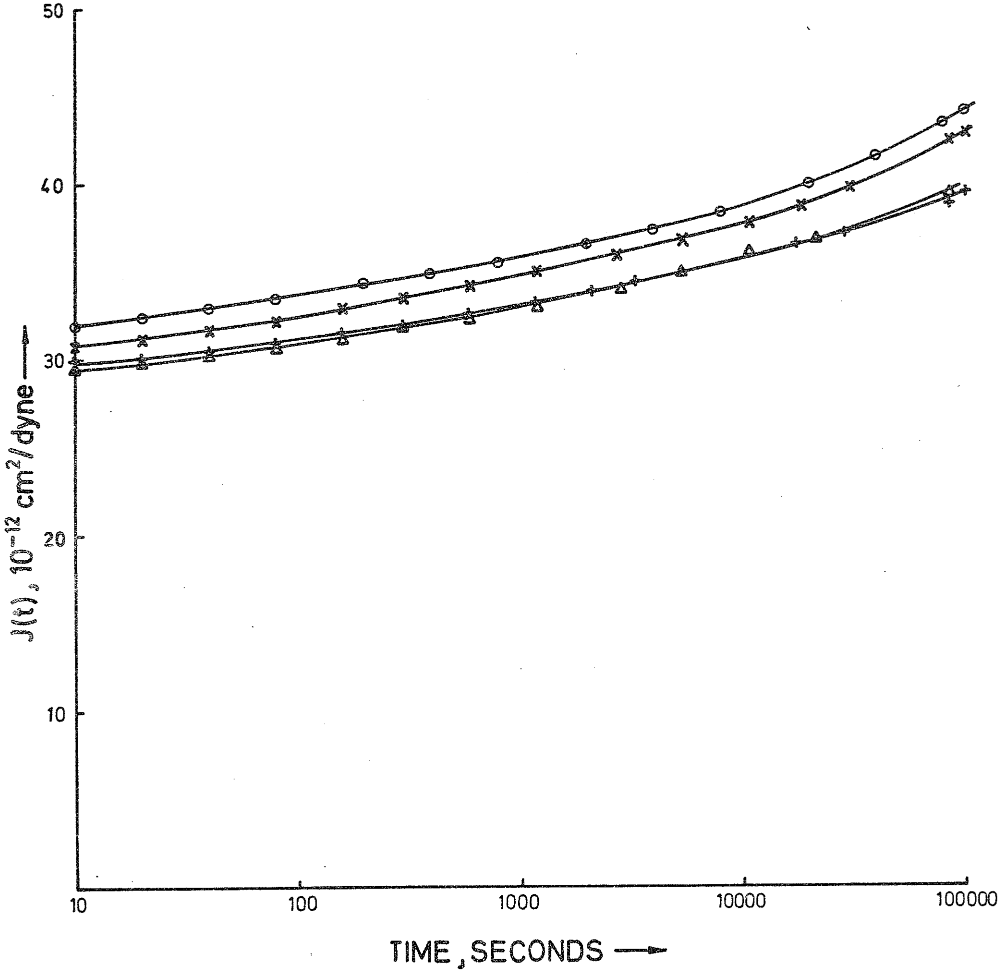

FIGURE 6 LONGITUDINAL AND LATERAL 100 SECOND STRAINS OF MY 753

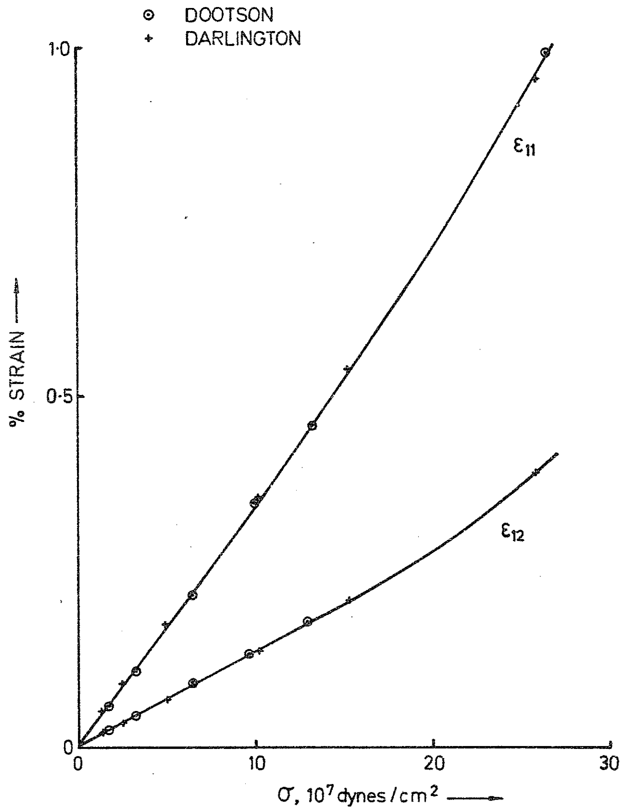

FIGURE 7 TENSILE CREEP COMPLIANCE OF UNIDIRECTIONALLY REINFORCED MY 753
$V_f = 0{\cdot}37 \pm {\cdot}01$

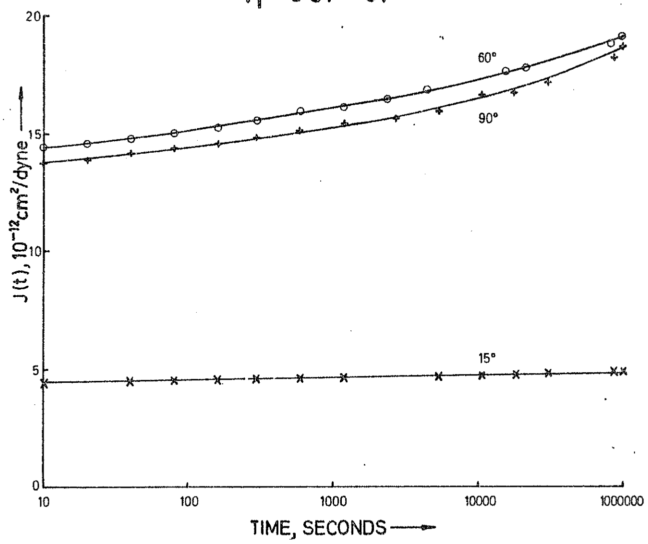

FIGURE 8 TENSILE CREEP COMPLIANCE OF UNIDIRECTIONALLY REINFORCED MY 753
$V_f = 0{\cdot}43 \pm {\cdot}01$

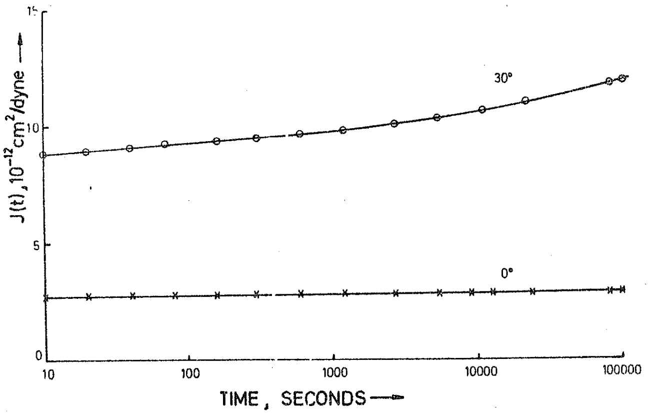

FIGURE 9 TENSILE CREEP COMPLIANCE OF UNIDIRECTIONALLY REINFORCED MY753
$V_f = 0{\cdot}50 \pm {\cdot}02$

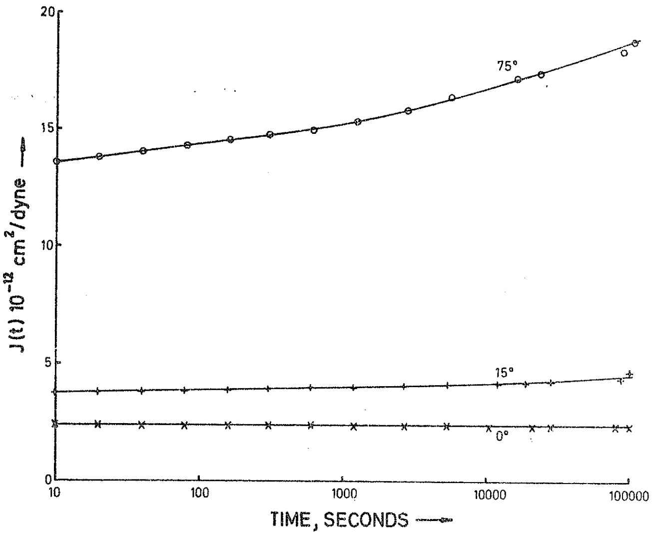

FIGURE 10 TENSILE CREEP COMPLIANCE OF BIDIRECTIONALLY REINFORCED MY 753
$V_f = 0{\cdot}45 \pm {\cdot}03$, $X = {\cdot}515$, $Y = {\cdot}485$