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DEPARTMENT OF MATERIALS

The time-dependent mechanical properties of fibre reinforced polymers

- by -

M. Dootson, B.Sc.(Eng.)

Progress Report No. 4

A Report of work carried out during the period 1st April to 30th September, 1969

Contents

1. General Progress

The six months from April to September 1969 have been spent mainly in consolidating the work of the previous eighteen months.

Firstly, due to major servicing problems, it became necessary to redesign the resin impregnating head of the filament winding machine. By the removal of all moving parts from the vicinity of the resin, these servicing problems have been completely overcome. Using the redesigned machine many sheets of high quality glass reinforced epoxy resin have been produced.

A sophisticated version of the spring mounted lateral extensometer described in Progress Report No. 3 has been designed and tested. Six of these have now been produced and are now in service yielding satisfactory results.

The majority of the period has been spent in setting up the tensile creep testing machines. This has been necessitated by the discovery that errors of up to 10% in creep compliance have been obtained through mis-alignments of the loading linkages of the order of .01 inch.

All the apparatus is now functioning correctly and more creep results for uni- and bi-directionally reinforced specimens are being obtained. Included in these current creep results are not only values for creep compliances but also for the creep contraction of these specimens.

2. Apparatus development

2.1 Lateral extensometer

In Progress Report No. 3 it was suggested that the optimum form of lateral extensometer was such that it could be mounted onto the specimen by spring pressure. A simple model of an extensometer of this type was tested and shown to work satisfactorily.

Figure 1 shows the sophisticated version of this simple model that has been designed, tested and brought into general use. The general principle of operation of the extensometer is shown in Figure 1a. The extensometer is held onto the specimen by the two spring loaded plungers. The spring pressure can be adjusted such that the extensometer will not slip on the specimen and none of the points of contact of the extensometer on the specimen are depressed into the surface. The transducer remains in contact with the surface of the specimen during contraction, and measures the magnitude of this phenomenon. In order to ensure that the transducer is in contact with the centre of the specimen and that the extensometer is unable to twist on the specimen, a specimen centralising device has been included on the extensometer. This is shown in Figure 1b. It consists simply of two plates, each with three protuberances on the surface, mounted on a left and right hand threaded rod passing through the base plate of the extensometer. The threaded rod is rotated until the protuberances are all lightly in contact with the surface of the specimen. In this position the specimen is centralised in the extensometer.

This form of extensometer appears to cause no form of stress concentration in the specimen as test results have been of the correct magnitude. Also the output from the transducer appears to follow the movement of the specimen very well with little or no evidence of any stick-slip.

2.2 Filament widning machine

The original filament winding machine, described in Progress Report No. 1, has worked satisfactorily and has produced good quality laminates. Cleaning the resin impregnating head after each winding, however, was found to be a very dirty job. On some occasions when the resin gelled before the winding was finished, due to a build up of exotherm, it was found necessary to remake any moving parts that had been submersed in resin. These were clearly unsatisfactory occurences and in consequence a new resin impregnating head, of the design shown in Figure 2, has been made. This has no moving parts submersed in the resin and is thus much easier to clean and service.

The only changes that have been made from the original machine have been with the impregnating head. A light aluminium structure, connected to the driving thread, supports the impregnating head above the mandrel. The head consists of an inverted bottomless polythene bottle, which contains the resin, onto which is screwed an adjustable nozzle. This nozzle produces a rectangular orifice $^1/_8$ inch long which can be adjusted to any width between 0 and 0.04 inch. In Figure 2b, section 4.4 shows a cross-section through the centre of the nozzle. Two $^1/_8$ inch thick mild steel plates, shaped to give a tapering hole, can be seen. The right hand plate is fixed in position while the one on the left can be adjusted to vary the gap between the plates. The left hand plate has a slot cut through it from the bottom edge to a hole near the top. This leaves a thin piece of metal at the top edge which acts in a similar manner to a hinge. By screwing a set screw with a conical end into this slot, in the position marked by the left hand solid spot, the gap between the two plates is decreased. To open the gap again a second conically ended set screw is screwed into the conical hole, marked by the right hand solid spot, after the first has been unscrewed. To ensure that the adjustable plate does not stick in position it slides between two thin P.T.F.E. gaskets.

It has been found that accurate control of the quantity of resin passing through the nozzle can be obtained. A better quality of laminate is produced using this new system than previously. This is probably due to the relative lack of air entrainment in the resin which in turn is due to the lack of moving parts.

3. Epxerimental Results

Because of the drive to get all apparatus working correctly by this time, only a few experimental results have been obtained.

Firstly, the results shown in Figure 3 for a set of unidirectionally reinforced specimens were obtained before the lateral extensometers were completed. These values of creep compliance follow the familiar pattern for unidirectional specimens that has already been shown. The 0° results show very little time dependence while the high angle results creep markedly. The 75° results are again higher than the 90°. No comparison has yet been made between these experimental results and theoretical predictions.

Figure 4 shows some creep compliance results for a set of bidirectionally reinforced specimens with v_f = .48, x = .39, y = .61. Again, these results were obtained before the lateral extensometers were completed and so there are no values of the creep contraction ratio for these specimens. Also at the time of these tests the creep apparatus had not been accurately aligned and some errors are possible in the magnitude of the compliances.

The first results that have been obtained with all the apparatus in correct working order are shown in Figures 5 and 6. These figures show the creep compliances and creep contraction ratios for samples cut at various angles from the bidirectionally reinforced sheet B2. This has an average volume fraction of glass of 0.51 and contains 66% of this glass in the surface layers in the x-direction and the remaining 34% of glass in the central layer in the y-direction. The usual bi-directional trend can be seen with the samples in the x and y directions having low compliances and samples at intermediate angles having higher compliances and larger time dependence. The creep contraction ratios in Figure 6 are of particular interest as they are the first that have been obtained on this contract. Two main points of interest should be noted from this Figure. Firstly that the ratios are small at 0° and 90° (in the order of 0.1) and larger at intermediate angles (up to 0.45) and secondly that while the ratios increase with time at intermediate angles, they appear to decrease at 0° and 90°. In the case of the 0° results not only was η_{12} found to decrease with time but also was the contraction strain, ϵ_{12}. This seems a most unusual occurence and it will be of interest to see whether this can be predicted from theoretical considerations. To show the variation of the compliance and contraction ratio with angle for these specimens, Figure 7 and 8 show these functions, taken at 100 seconds, plotted against angle.

4. Remarks

4.1 Packing order

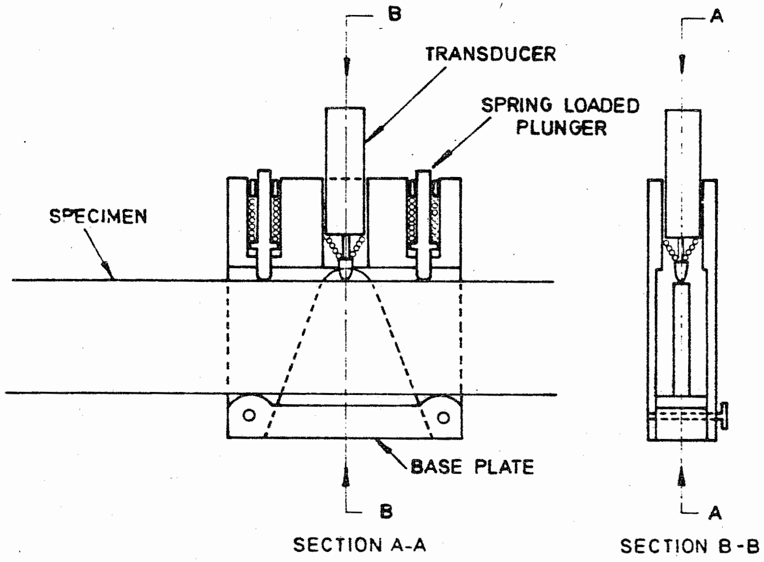
Theoretical predictions for the mechanical properties of fibre reinforced plastics, other than uni-directionally reinforced, yield bounds rather than an exact solution. These bounds represent uniform strain and uniform stress assumptions.

It is possible that, depending on the packing order of the layers of a multi-directional laminate, the mechanical properties may vary within these extremes. In order to check whether this thought is of any consequence, a batch of laminates has been produced in which pairs of laminates have the same values of x and y and similar values of v_f with the only difference being in the packing order. Tests on specimens cut from these laminates should produce valuable information on the effects, if any, of packing order on creep compliance and creep contraction ratio.

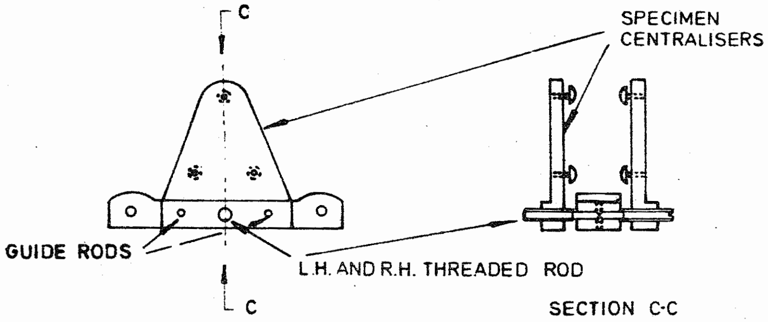
4.2 Future programme

During the next six months it is hoped to produce sufficient creep data for glass reinforced plastics to enable some conclusive comparisons to be made between theoretical predictions and actual behaviour for these materials. It would be interesting to follow these tests with a further selection using a different ratio for the moduli between the phases. If a different technology is required to manufacture these materials it would be useful to study this in the near future.

FIGURE 1

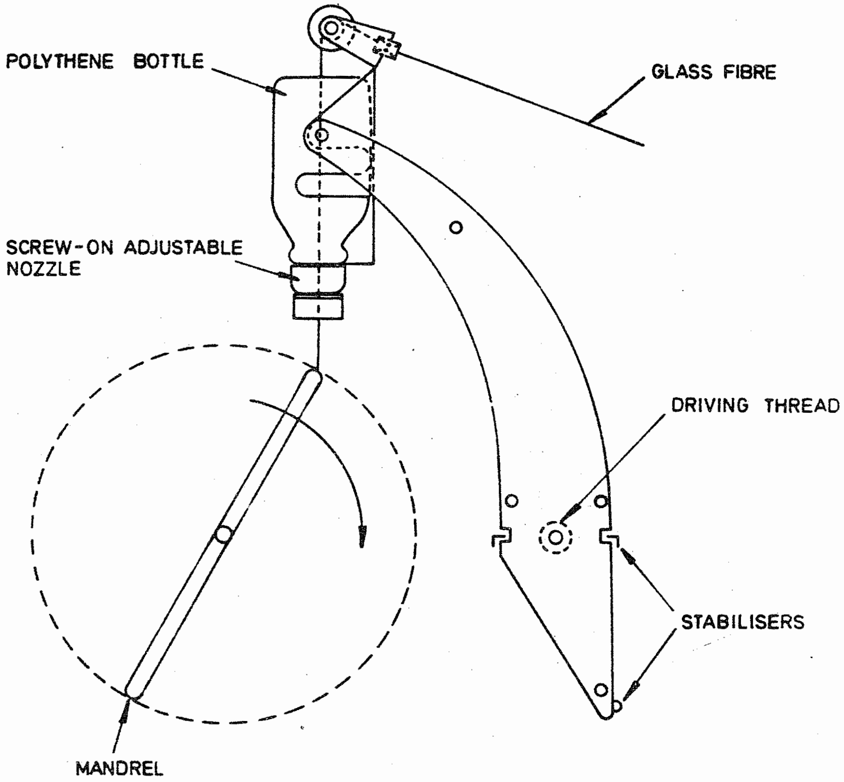


a) LATERAL EXTENSOMETER



b) SPECIMEN CENTRALISING DEVICE.

FIGURE. 2



a) MODIFIED RESIN IMPREGNATING HEAD

b) SCREW-ON ADJUSTABLE NOZZLE

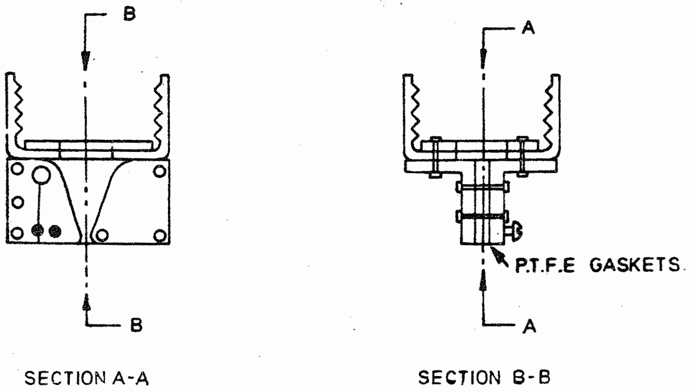


FIGURE 3 VARIATION OF CREEP COMPLIANCE WITH TIME. V_f = ·51, X = 1, Y = 0.

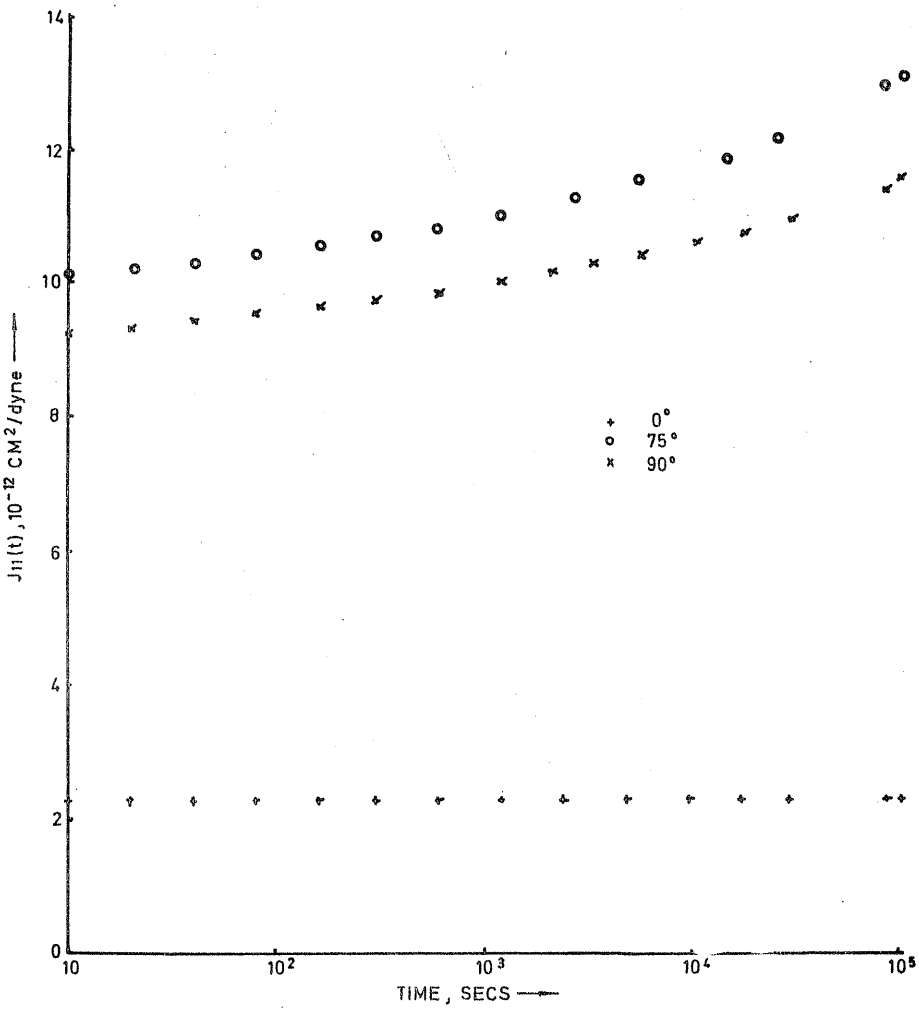


FIGURE 4
VARIATION OF CREEP COMPLIANCE WITH TIME. V_f = ·48, X = ·39, Y = ·61

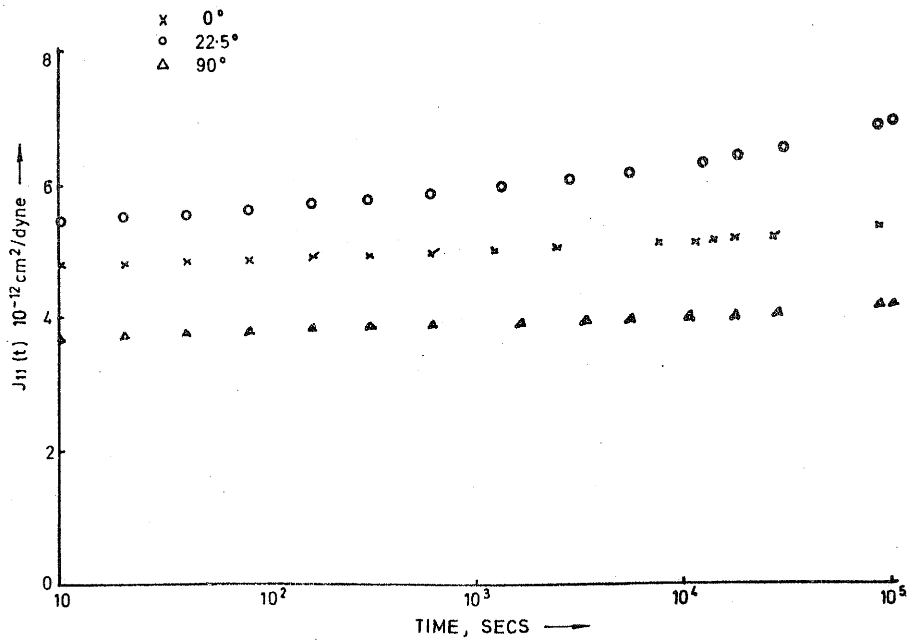


FIGURE 5 VARIATION OF CREEP COMPLIANCE WITH TIME. V_f = ·51, X = ·66, Y = ·34

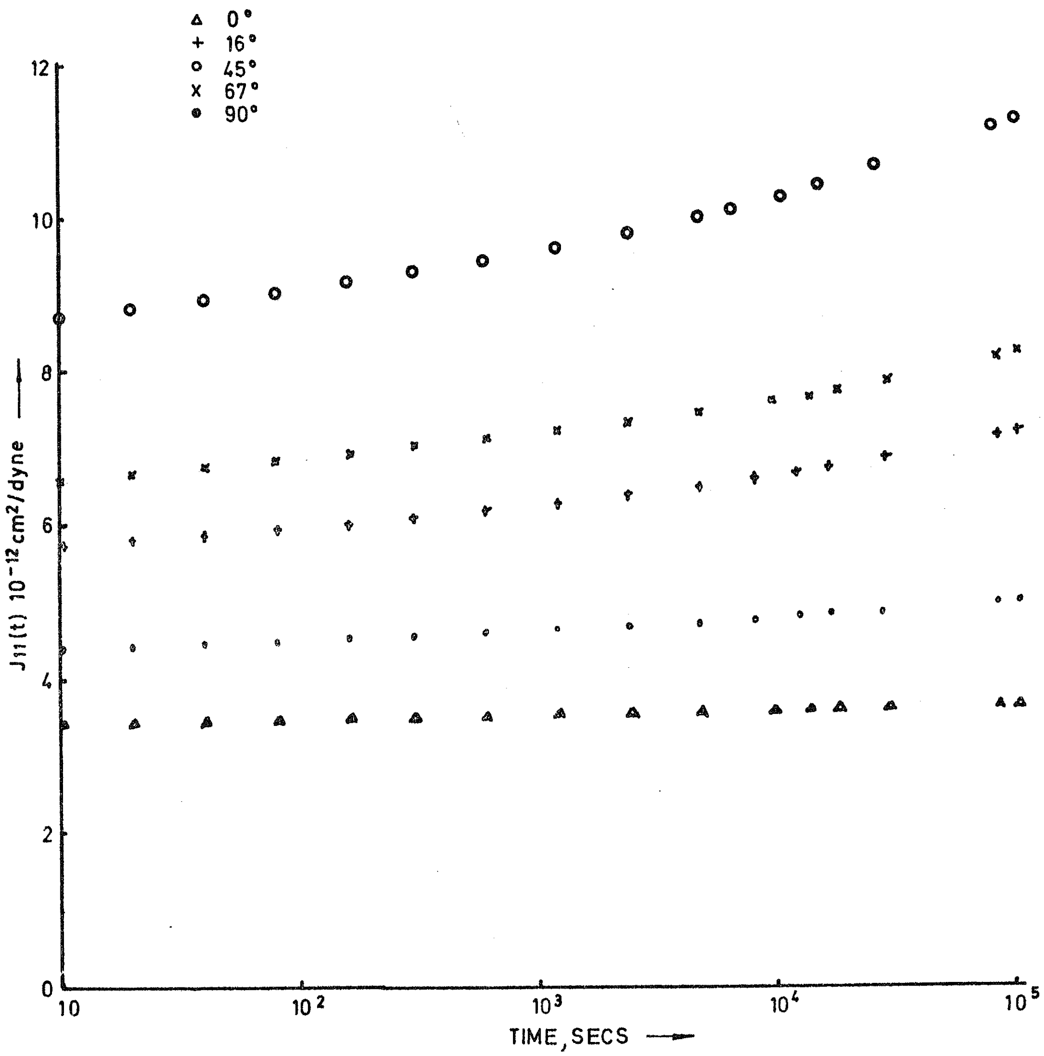


FIGURE 6 VARIATION OF CREEP CONTRACTION RATIO WITH TIME V_f = ·51, X = ·66, Y = ·34

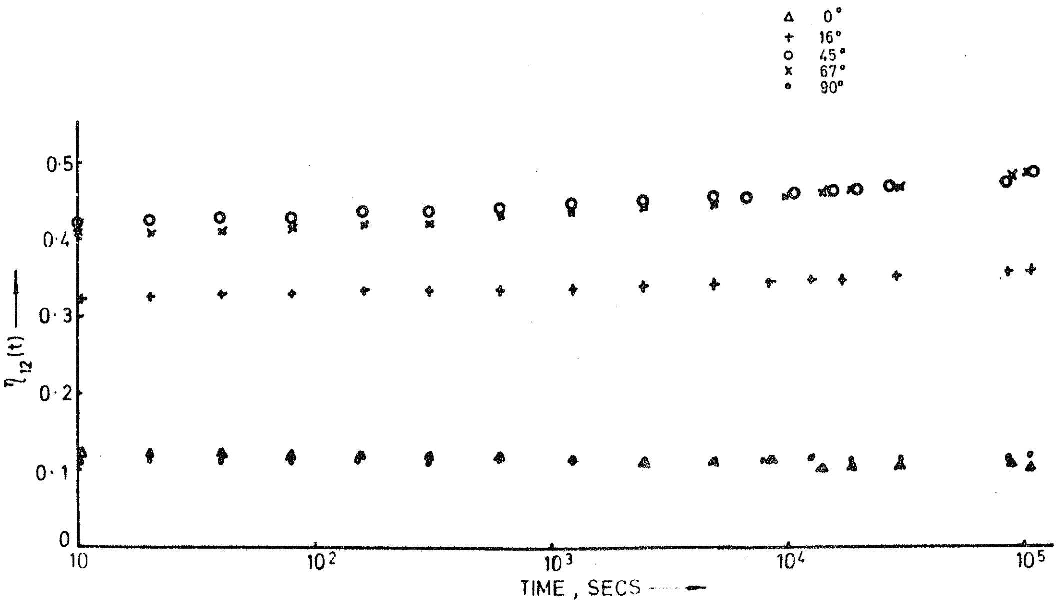


FIGURE 7

VARIATION OF 100 SEC CREEP COMPLIANCE WITH ANGLE V_f =·51, X=·66, Y=·34

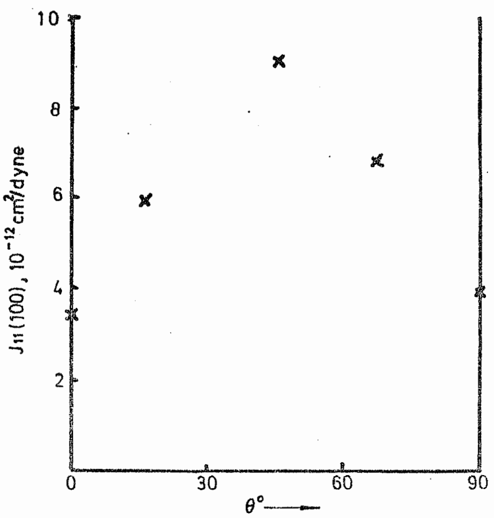


FIGURE 8

VARIATION OF 100 SECOND CREEP CONTRACTION RATIO WITH ANGLE V_f = ·51, X=·66, Y=·34