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The Mechanical Properties of Anisotropic Polymers

Progress Report No. 3



A report of work carried out during the period
1st October, 1966 to 31st March, 1967.

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PART 1

General Developments

In the first year's progress report (Report No. 2, October, 1966) work on the stress-strain properties of anisotropic polyethylene sheets and the creep rupture properties of anisotropic polyvinyl chloride (P.V.C.) was described in some detail. It was indicated, however, that further measurements were required for the completion of both projects.

The variation of the creep rupture properties of heat-treated, as-received P.V.C. with temperature has now been studied at temperatures of 15, 20, 25 and 30°C. A few measurements at 25°C have also been made on an anisotropic sheet of draw ratio 1.3. (The previous measurements were carried out at room temperature, which varied from 17 to 21°C). The measurements are described in part II of this report. They complete the proposed study of anisotropic P.V.C. sheet.

The polyethylene study required the extension of the previously reported measurements to a sheet of high draw ratio (approximately 4.5) together with several subsidiary measurements. The necessary anisotropic sheets have been prepared and many specimens are ready for testing. The work has been delayed, however, while the experimental area is converted into a constant temperature laboratory. The conversion should be completed by the end of March, when it is hoped to carry out the necessary tests to complete the preliminary study of anisotropic polyethylene. This study will be extended to include creep properties, when the necessary creep rigs are ready.

The main projects during the period covered by this report have been concerned with the development of the creep apparatus and automatic timing control systems. A lever loading creep machine for use with loads of up to 4 kilograms and an extensometer for use with a wide range of plastics have been designed and built. Detailed descriptions of these items and the results of several trial experiments performed with them are given in part III of this report. A general purpose timer control system has been built. This will enable the automatic monitoring of up to nine transducers to be recorded by the print-out unit of a digital voltmeter. Consideration has also been given to the timing system for short-time creep tests. Details of the control systems are given in part IV of this report.

PART II

Creep Rupture Studies

1. Introduction

The creep rupture measurements on P.V.C., described in the previous progress report (Report No. 2, October 1966), were carried out in a room having no temperature control. The temperature during the majority of the tests varied in the range 17 - 21°C. In view of this variation, t and the fact that the mechanical properties of thermoplastics are usually very temperature dependent, it was considered necessary to repeat some of the measurements over a range of temperatures, in order to examine the behaviour. The measurements were carried out using the small, temperature controlled cabinet that was built around two of the creep rupture rigs during the previous six-month period. They are reported in the following section.

Attempts to obtain an anisotropic P.V.C. sheet of draw ratio 5.0 or higher have continued during the present period, but without success, although work published by Pinner (1965) indicated that such draw ratios might be possible. Even when a heated enclosure was used around the Denison jaws during the drawing process, a draw ratio of about 3.5 to 1 was found to be the practical limit. Confirmation of this limit has since been given by Vincent (1966). Apparently, very high draw ratios can only be obtained in carefully shaped samples of small area of cross section. Obviously such samples are of little use for anisotropy studies, where samples cut at various angles to the draw direction are required. It has therefore been decided not to continue with experiments with highly drawn P.V.C. sheet.

During earlier creep rupture work on P.V.C. it was found that most specimens suffered a large irreversible deformation sometime during their life time. This large deformation occurred over a time relatively short compared with the time to fracture and might, from an engineering viewpoint, be regarded as failure, even though fracture had not occurred. The extended specimen was obviously considerably strengthened, as it held the applied load for some time, despite having a greatly reduced area of cross section. The time to fracture, t_2 , would therefore appear to be related to the structure of the extended state, while the 'time-to-extension', t_1 , was more characteristic of the prepared specimen. The apparatus described in the previous report did not allow measurement of t_1 , but only of the fracture time, t_2 . Modifications are therefore being made to enable t_1 to be measured, as well as t_2 . These modifications are described in section 3.

2. Temperature Dependence of the Creep Rupture Properties of Polyvinyl Chloride

Most of the measurements were performed on heat-treated, as-received sheet (i.e. the isotropic state), but some measurements were also made on an anisotropic sheet of draw ratio 1.3. The method of preparation of the isotropic and anisotropic specimens was identical to that described in the previous progress report. The apparatus was also essentially the same as

that used previously. The microswitches, however, have been relocated and the timing instruments improved. This has greatly increased the general reliability of the apparatus. A general view of the apparatus is given in fig. 2.1. The constant temperature cabinet enclosing the first two machines may be seen in the foreground. The cabinet enabled the temperature to be stabilised to $\pm 0.2^\circ\text{C}$. Temperatures of 15, 20, 25 and 30°C were used in the present study. The variation of applied stress with the log of the time to fracture for isotropic P.V.C. at each of the above temperatures is shown in fig. 2.2. The stress is taken as the applied load divided by the original area of cross section (i.e. the nominal stress). The behaviour at 15, 20 and 25°C appears to be linear, but at 30°C a shift appears to occur between two, more or less linear parts of the curve. The results demonstrate the temperature sensitivity of the creep rupture properties; an increase in temperature of 20°C to 25°C causing a decrease in life time from 10.5 to 1.2 hours, at a stress of 6,500 p.s.i.

The results for the anisotropic P.V.C. specimens, at a temperature of 25°C , are given in table 2.1. For comparison, the life times, at the same stress, for the anisotropic specimens tested at $17 - 21^\circ\text{C}$ are also listed. (Taken from previous report). Again it will be seen that an increase in temperature of approximately 5°C lowers the time to fracture by about an order of magnitude in all cases.

The above experiments complete the study of the mechanical properties of anisotropic P.V.C. sheet.

3. A Method of Recording the Extension-Time Behaviour Prior to Creep Rupture

In section 2.1 it was indicated that the variation of the extension of the specimen with time (before fracture) ought to be determined, in addition to the time to fracture. Since fracture times up to 100 hours are studied, an automatic recording system is desirable. Extensions of 0.1 to 0.5 inches were observed in the creep rupture work, but because of the non uniform cross section of the specimens these figures cannot be converted to strain. A measure of the total separation of the grips was therefore taken to be adequate for determining the time at which the rapid extension occurs.

Linear displacement, resistance transducers, manufactured by Ether Ltd; have been chosen for this application. They have a resolution limit of 0.001 inch, and a full range displacement of 0.5 or 1.0 inch. In operation, a D.C. voltage is connected across the internal slide wire; a measure of the displacement being given by the voltage between one end of the slide wire and the sliding contact.

A digital voltmeter with print-out unit has been obtained for the automatic recording of tensile creep data. This voltmeter will also be used, with the above mentioned transducers, for the automatic recording of sample extension during creep rupture experiments. A timing control

system, described in part IV, will enable multiple experiments to be automatically monitored. It will also be possible to use the voltmeter for creep rupture studies, while it is in use for creep studies.

A diagram of the transducer and the method of attaching it to the creep rupture apparatus is given in fig. 2.3. A light, rigid rod, 6, is attached to the upper grip, 2, of the apparatus. A magnet, 8, is attached to the free end of the rod. The transducer, 9, is rigidly held to the lower grip holder, 5. A small platform is attached to the upper end of the movable transducer shaft, and this platform is attracted to the magnet. Thus, as the specimen extends, the transducer shaft is pulled out of the transducer body, this movement being converted to a voltage variation. On fracture of the specimen the magnetic joint breaks, so preventing any damage to the transducer.

It is hoped to describe measurements made with this system in the next report.

PART III

An Apparatus for the Study of the Tensile Creep of Anisotropic Polymers

1. Introduction

An apparatus for the study of the tensile creep of polymers may be conveniently split into two separate units: a loading assembly and a device for measuring the extension of the sample (i.e. an extensometer). The design considerations for both parts were discussed in detail in progress report No. 1 (1966). The requirements were most severe in the case of the softer polymers such as low density polyethylene. It was hoped that, for the rigid thermoplastics, a loading system based on the existing creep rupture apparatus would be satisfactory. However, it was realised that a new loading apparatus would be required for work on the softer polymers. Accordingly a new loading system has been built which should be suitable for the study of the softer polymers at all strain levels, and for the more rigid polymers at very low strain levels (i.e. less than 0.5%). The new loading assembly is described in section 2.

An extensometer has been built which should be suitable for the study of the majority of polymers. Details of this extensometer are given in section 3. For convenience, the problem of attaching the extensometer to the specimen is discussed separately in section 4.

Preliminary trials with a P.V.C. specimen were carried out with the extensometer attached to one of the creep rupture rigs. Reproducible creep curves, for creep times of several minutes, were obtained and the extensions indicated by the extensometer were checked to $\pm 15\%$ with the aid of a cathetometer, for a strain of about 1%. A certain amount of zero drift occurred during the above tests. It is thought that this may have been due to temperature changes. If the creep rupture rigs are found to be suitable loading assemblies for the rigid thermoplastics at moderate and high strains (i.e. 0.5% and above), it will avoid the construction of more complicated load and guide assemblies, such as that described in section 2. Tests on the creep rupture rigs, using a standardised P.V.C. specimen, will therefore be made as soon as the new constant temperature laboratory is ready.

Trials with the loading system and extensometer, described in sections 2 and 3 respectively, are described in detail in section 5.

2. A Lever Loading Apparatus

This apparatus has been constructed for tensile creep studies on the softer plastics over the range of strains from 0.05% to approximately 10%. It is also suitable for use with the more rigid plastics, for strains up to about 0.3%. A photograph of the apparatus is given in fig. 3.1 and a simple diagrammatic representation in fig. 3.2.

The general design follows that developed by Turner at I.C.I. (See Dunn, Mills and Turner, 1964). The load is applied via the 2:1 load lever which is pivoted in ball bearings having very low friction. The chain rests on curved lever ends so that the load line does not alter as the lever arm rotates. It is of great importance that the load is applied axially to the specimen, and several design features have been included to ensure this. The sliding guide bar, which can move freely through the fixed guide block (see fig. 3.2), ensures that the load is applied in a fixed reproducible direction (nominally vertical). This assembly, and the universal joint between the guide bar and link rod, help to prevent any transverse or torsional forces reaching the specimen. However these features are completely wasted unless the specimen grips are accurately made and located so that the centres are accurately sited on the load line of the apparatus. The specimen itself must also be accurately machined so that the centres of the locating holes lie on the central axis of the gauge length position. The specimen clamps must be perfectly shaped, and positioned on the specimen, as any deviation from symmetry in the arrangement will cause the specimen to bend as the load is applied.

The specimen clamps and the hooks are cone-shaped to assist in the exact siting of the specimen axis along the load line of the apparatus. Initially, simple flat-faced cones at each end of the specimen were held together by a nut and bolt assembly which passed through holes in the cones and the specimen. However, with this arrangement it was found to be difficult to get the cones sited symmetrically, and frequently, slight bending of the specimen was observed when a load was applied. The original cones have now been replaced by interlocking cone assemblies which ensure that the cones are attached symmetrically to the specimen. The new assembly design is shown in fig. 3.3. The cones are held together by a nut and bolt.

Trials with this apparatus are reported in section 5.

3. The Extensometer

The design considerations, for an extensometer for the measurement of small strains occurring during the tensile creep of anisotropic polymer specimens, have been given in detail in progress report No. 1 (1966). The basic details of the extensometer finally built may be seen in fig. 3.4, where it is shown mounted on the loading rig described in the previous section. Detailed drawings of the extensometer parts are given in figs. 3.5 and 3.6. These drawings will be discussed at the end of this section.

The extensometer is based on a differential capacitor, linear displacement transducer, manufactured by Societie Genevoise Ltd. (Sogenique System). It consists of only two basic parts: an interpolating head and a reference shaft which passes through it to form the differential capacitor.

Basically the extensometer consists of two arms pivoted freely at their

centres. One end of each arm is forked to enable it to rest against pins set in the gimbals which are attached to the specimen. (See section 4). The other end of the bottom arm holds the transducer, the moveable shaft of which rests against a ground and polished plate, let into the upper arm. The relative movement of the gimbals is thus recorded by the transducer. Any movement which represents the simple translation of both gimbals by an equal amount in the same direction will obviously not alter the transducer reading. The device can therefore be used to record the extension of the original sample gauge length, and the results will not be affected by slippage in the grips or general straining of the apparatus when the load is applied.

The weight of the transducer (approximately 60 grams) can be counter-balanced if required, but, with the arrangement shown in fig. 3.4, the weight of the transducer does not measurably affect the specimen gauge length, and counterbalancing is not therefore necessary. In fact the weight of the transducer helps to maintain a firm contact between the forked extensometer arm and the lower gimbal pins. The external spring on the transducer shaft pushes the shaft against the upper transducer arm, and so helps to maintain firm contact between these two parts, and between the forked end of the upper arm and the upper gimbal pins. This spring pressure does affect the specimen gauge length; causing a contraction which increases with the strength of the spring. A load of approximately 100 grams above the static load compresses the spring 0.1 inch; for strains of 0.1% and 2% this represents a load of 1 gram and 20 grams respectively. The static load is that load which is required to hold the shaft in a suitable position at the start of an experiment. It may be of the order of 20 grams. These extensional and static loads may be neglected when working with rigid thermoplastics, where the loads required to produce a 0.1% strain will be approximately 1,000 grams. For polythene, however, when the creep load may be as little as 100 grams, it would be desirable to reduce the combined extensional and static loads to less than 10 grams. It may be possible to achieve this by removing the transducer's external restoring spring, and using magnetic coupling between the transducer shaft and the upper extensometer arm. A weak, internal transducer spring should provide sufficient pressure to maintain contact between the upper extensometer arm and gimbal pins. Preliminary trials with such an arrangement have been carried out, using a rigid P.V.C. specimen (I.C.I. standardised P.V.C. - see later). The results obtained showed an error of about 10% when compared with the I.C.I. data, whereas results obtained with the external spring in position showed an average error of 5% or less. The results are considered hopeful, however, and attempts to reduce the error are in progress.

The movement of the transducer shaft is measured by an electronic control unit, as supplied by the transducer manufacturers. With this unit, the limit of resolution corresponds to a shaft movement of 10^{-6} inch. The normal limit of use is however 10^{-5} inch. The maximum possible absolute error between any two readings, which is inherent in the detection system, is

6×10^{-5} inch. In practise, the error will normally be less than this. The full measuring range of the transducer is 0.1 inch. Each transducer is supplied with its own calibration unit so that when it is connected to the control unit, the instrument reads true displacement directly in inches. This avoids difficult calibration experiments. By means of junction boxes and a selector unit, several transducers can be monitored on one control unit.

The extensometer arms must be able to pivot freely at their centres and it is essential that the pivot mechanism is not slack, or sideways and torsional movements may be superimposed on the required pure rotational movement. When extensions of the order of 10^{-4} inch are being studied even the slightest degree of slack in the pivots may introduce error into the measurement. In view of these requirements, the possibility of using cross spring pivots has been investigated. The principles of such pivots have been given in an N.P.L. publication (1956). Also Geary (1954) has given an account of these pivots together with a bibliographical survey of their uses. The characteristics of the type of cross spring pivot used in the present investigation have been given by Nichols and Wunsch (1951). Details of the cross spring pivot system are given in fig. 3.5. A cross spring pivot may be seen on the lower extensometer arm in fig. 3.4. The pivots have been found to be satisfactory in use. They combine freedom of pure rotation with a high degree of resistance to sideways and torsional forces. They are however rather more complicated to construct than conventional pivot systems. Accordingly a pivot system employing needle bearings has been constructed and tested for comparison purposes. Detailed drawings of the bearing bracket and modified extensometer arm are given in fig. 3.6. A needle bearing pivot may be seen in position on the upper extensometer arm in fig. 3.4. The construction of this pivot system was found to be simpler than that of the cross spring pivot system, and with careful adjustment it appears to operate satisfactorily.

It is now intended to construct several new extensometers; some employing needle bearings and others employing cross spring pivots. This will enable further trials and comparisons to be made. Several improvements are to be incorporated into the new designs on the basis of experience gained so far. The new designs are as given in figs. 3.5 and 3.6. These may be compared with the original extensometer shown in fig. 3.4. It will be seen that the new extensometer arms are bulkier in design and that the back plate (identical for both new designs) has a grooved guide for the brackets which support the extensometer arms. The former modification is intended to reduce the arm flexibility, while the latter will assist in the correct positioning of the brackets during gauge length adjustments.

The new set of extensometers should be ready for creep studies in the near future.

4. Attachment of the Extensometer to the Specimen

The method of attaching the extensometer to the specimen is of great importance. The gauge length must remain constant and accurately defined throughout the creep test; especially when specimens having a gauge length of only 0.5 inch are being tested. The attaching devices must not constrain or deflect the specimen in any way, and must not introduce end corrections of any type, as this would remove one of the main advantages of a gauge-length extensometer over a jaw-separation extensometer. This problem has been considered in detail by Mills and Turner (1965). For rigid plastics, having a thickness and width of not less than 0.1 inch, they found a gimbal ring attachment to be suitable. Two of these devices have therefore been built and tested in these laboratories, and found to be satisfactory for work on rigid plastics such as unplasticised P.V.C. and polycarbonate. Details of the gimbals may be inferred from fig. 3.7. They are shown, in position on a specimen, in fig. 3.4. The inner rectangular ring is made of aluminium, while the outer ring is made of brass. The latter has been lightened by drillings. The approximate weight of each gimbal is 12 grams. The conical ends of the specimen contacting pins locate into small cone-shaped holes in the specimen. These holes define the specimen gauge length. They are cut in the specimen using a carefully constructed jig and cutting tool.

For work with polythene specimens of thickness in the range 0.03 to 0.07 inch the gimbals are obviously not satisfactory. Experiments are in progress on a new method of attachment. Details of a device which it is thought may be suitable are given in fig. 3.8. The pins which are rigidly held in wide steel strips are pushed into the polyethylene by the spring of the steel strips. The normal forked end of the extensometer is replaced by a brass block which holds the steel strips. One possible disadvantage of this system is that as the arm rotates (specimen extending) the pins are pulled sideways to a small extent. It is not certain at present if this will affect the results obtained.

5. Apparatus Trials

All the trials performed so far have been on rigid P.V.C. specimens, using the extensometer and gimbal attachments described in section 3 and 4 respectively. Initially a creep rupture apparatus was used for applying the load to the specimen. The results obtained are mentioned briefly in section 1. These trials will be continued when the new constant temperature laboratory is ready.

The critical trials of the extensometer have been made on the more sophisticated loading rig described in section 2. The general arrangement of the apparatus for these trials is shown in fig. 3.4. For these trials a method of producing accurately known extensions under normal experimental conditions was required. This was accomplished by using specimens cut from a sheet of P.V.C. supplied by the Research department of the Plastics division

of I.C.I. Ltd. The 100 second isochronous stress-strain curve, for strains from 0.1 to 2%, for the sheet was also supplied; the result being guaranteed to be reproducible to within 2%. The curve was obtained, using the apparatus and procedures given by Turner (1964-1965), with specimens having a gauge length of 8 cms.

In the present trials, creep strains in the range 0.05 to 0.25% were employed, the upper limit being fixed by the design limit of the loading rig (which was designed primarily for use with polythene). The experimental procedure, after setting up the apparatus, was as follows: the reading on the control unit, with no load on the sample, was noted. A load of 1 kilogram was placed on the scale pan (i.e. 2 kilograms applied to the specimen) and the new reading noted on the control unit, after 100 seconds. The load was then removed and the specimen left load free for 400 seconds. The zero was again noted, and a load of $1\frac{1}{2}$ kilograms placed on the scale pan. This procedure was repeated up to a load of 4 kilograms. These results enabled a plot of the applied stress against strain at 100 seconds to be drawn. This could be compared directly with the plot provided by I.C.I. For convenience, log-log graph paper is used. Altogether, three separate specimens were tested in this manner, the procedure being repeated several times for each specimen. Some typical results are shown in fig. 3.9, where they may be compared with the I.C.I. curve. It will be seen that nearly all the results lie between the I.C.I. line and a line shifted 10% to the right of it, (i.e. towards larger strains for a given stress). The I.C.I. data were obtained at 20°C. The present data were obtained at a temperature which varied in the range 19 to 22°C. The agreement between the two sets of results is considered satisfactory. Work is continuing with the aim of improving the reproducibility of the results, and possibly getting closer agreement with the I.C.I. data.

During the above trials some zero drift was noted. That this drift was not caused by the electronic control system was proved by using a separate control transducer, held rigidly in an aluminium block. The transducer reading did not vary by more than 3×10^{-5} over a period of 14 days, and part of this variation could be attributed to temperature variations. The zero drift during the tests may well have been caused by daily temperature changes. It is intended to repeat the above tests when the new constant temperature laboratory is ready.

Some 'stiction' was noticed during the early trials with the extensometer, probably caused simply by the very small displacements involved in these experiments. It has been overcome by using a vibrator, positioned so as to tap the upper extensometer arm bracket, very lightly, at a frequency of 50 c/s.

PART IV

Automatic Control Systems for Creep and Creep Rupture Studies

1. Creep Control Systems

If isochronous stress-strain curves are required, the procedure given in section 5 (part III) is used. Only 1 reading per creep test is taken, usually 100 seconds after the load is applied. As the creep rate is usually low by this time, the reading may be obtained manually by the operator with very little error. As the nature of the tests requires the constant attendance of the operator, there seems little advantage in using automatic control. This form of test therefore requires no additional apparatus.

However, the method of use of the transducer measuring unit is relatively slow, and if the creep rate is high, it is impossible to follow the creep extension manually. A modified transducer measuring unit has therefore been obtained, which gives a D.C. output which is directly proportional to the displacement of the transducer from an initial balance position. This voltage may be recorded by a pen-recorder or a voltmeter, or both, if required. At present a digital voltmeter is thought to be the most useful, single recording instrument for the creep studies. However, for full automation, and for overnight runs, a method of recording the voltmeter readings is essential. A digital voltmeter with integral print-out unit has therefore been chosen. (Weyfringe, Type 4P). The reading and printing of a voltage may be controlled manually or by an external triggering signal. Thus by feeding pulses into the voltmeter at known time intervals, a record of the variation of extension with time may be obtained automatically.

Automatic timing systems are being constructed for this purpose. It is intended to use a programme controller manufactured by K.A. Schmersal and Co. (West Germany) for the short term creep and recovery experiments. (i.e. tests of up to 5 minutes duration). The pulse times can be adjusted to suit particular requirements. In particular it will enable pulses at equal intervals on a log time scale to be obtained. This is the best time scale for creep studies. This same programme controller can also be used to give pulses on a log scale for a period of up to 5 hours by using a separate (interchangeable) motor. It therefore forms a very useful general timer-controller.

During short term creep tests, only one specimen at a time can be tested, although other specimens may be mounted in other rigs ready for testing. However during long term creep tests, when readings may only be taken at intervals of an hour or more, per rig, it will be possible to carry out many creep tests simultaneously using the one transducer measuring unit.

A modified form of the control unit described in the following section

may be used for this purpose. As well as the normal timing pulses, a new method of selecting each transducer in the junction box in turn will be needed.

2. Creep Rupture Systems

The transducers for creep rupture studies, and their method of use, were described in section 3(part II) of this report. A control circuit has been designed which will select a transducer, connect it to the digital voltmeter and then send a pulse to the voltmeter to read the voltage and print it. Up to nine transducers can be monitored simultaneously by this method. At a signal from the master clock a selector system is set in operation which selects each transducer and then pulses the voltmeter. At the end of the cycle it re-sets itself and waits for the next timing signal from the master clock. The master clock gives out timing signals which are approximately equally spaced on a log scale, for the first hour; followed by a pulse every half hour or hour as required.

The unit has been built except for the inclusion of a commercial auto resetting timer which has not yet been delivered. Full details of the system will therefore be delayed until the next report.

References

Report No. 1 - March, 1966. The Mechanical Properties of Anisotropic Polymers. Progress Report No. 1 to the Ministry of Aviation. CoA Memo. No. 104.

Report No. 2 - October, 1966. The Mechanical Properties of Anisotropic Polymers. Progress Report No. 2 to the Ministry of Aviation. CoA Memo. No. 115.

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Dunn, C.M.R., Mills, W.H., and Turner, S. (1964). British Plastics, July.

Geary, P.J. (1954). B.S.I.R.A. Research Report M.18.

Mills, W.H., and Turner, S. (1965). Paper 23. Symposium on Developments in Materials Testing Machine Design. Manchester. September.
(Published by Inst. Mech. Eng. London).

Nickols, L.W., and Wunsch, H.L. (1951). Engineering, 172, 473, October.

N.P.L. (1956). Notes on Applied Science, No. 15, H.M.S.O.

Pinner, S.H. (1965). Plastics, May, p. 82.

Turner, S. (1964-1965). Series of articles in British Plastics.

Vincent, (1966). Private Communication.

Table 2.1 A Comparison of the Creep Rupture Properties of Anisotropic P.V.C. Specimens at 25°C and Room Temperature (17-21°C).
Draw Ratio = 1.3.

Angle To Draw Direction	Stress (p.s.i.)	Lifetime (Hours)	
		25°C	17-21°C
90°	6,500	0.27	3.8
90°	6,500	0.34	3.8
90°	6,850	0.086	0.7
60°	6,600	0.48	8.5
60°	6,790	0.258	3.0
45°	7,000	0.393	5.8

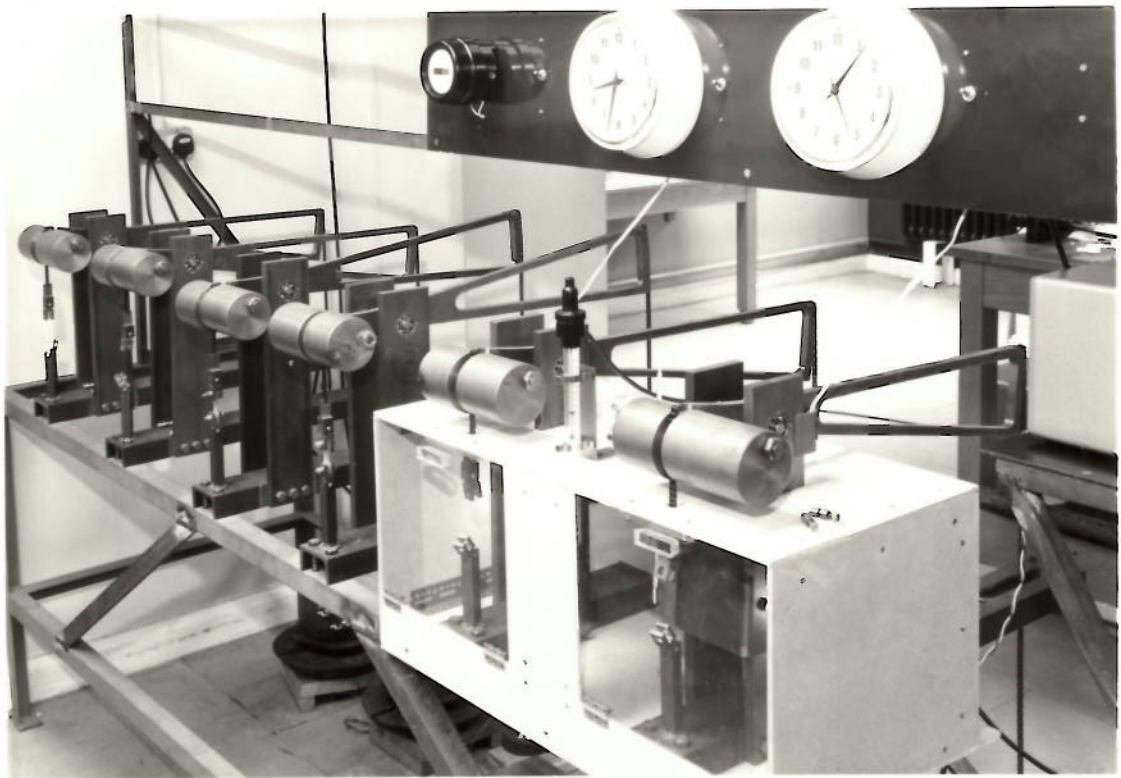


FIG. 2.1 THE CREEP RUPTURE APPARATUS

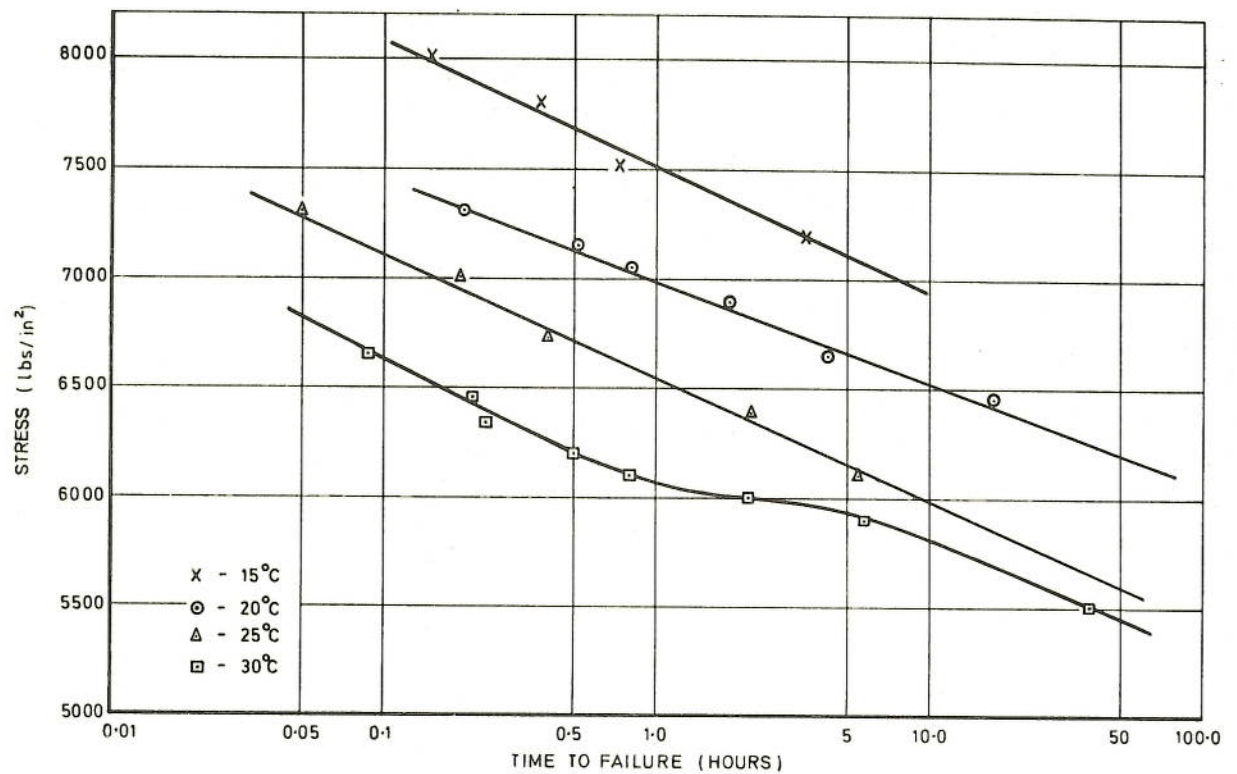


FIG.2.2. VARIATION OF FAILURE TIME WITH APPLIED STRESS FOR ISOTROPIC PVC SHEET

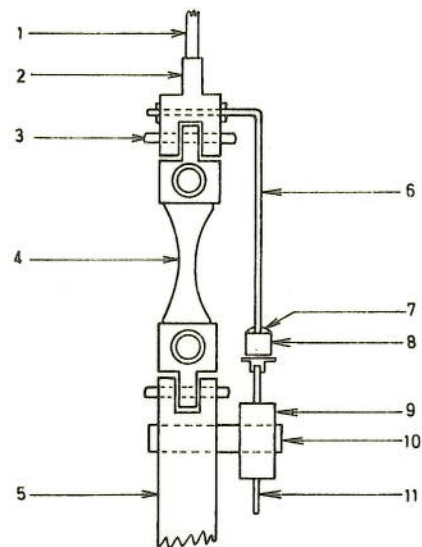


FIG.2.3. THE EXTENSOMETER AND MOUNTING FOR CREEP RUPTURE STUDIES

1. FLEXIBLE CHAIN; 2. UPPER SPECIMEN GRIP ASSEMBLY;
 3. FLEXIBLE COUPLING; 4. SPECIMEN; 5. LOWER GRIP HOLDER;
 6. LIGHT ROD; 7. ARLDITE JOINT; 8. MAGNET; 9. TRANSDUCER
 BODY; 10. RIGID TRANSDUCER HOLDER; 11. TRANSDUCER SHAFT.



FIG. 3.1 THE LEVER LOADING APPARATUS FOR SPECIMEN LOADS UP TO 10 KILOGRAMS

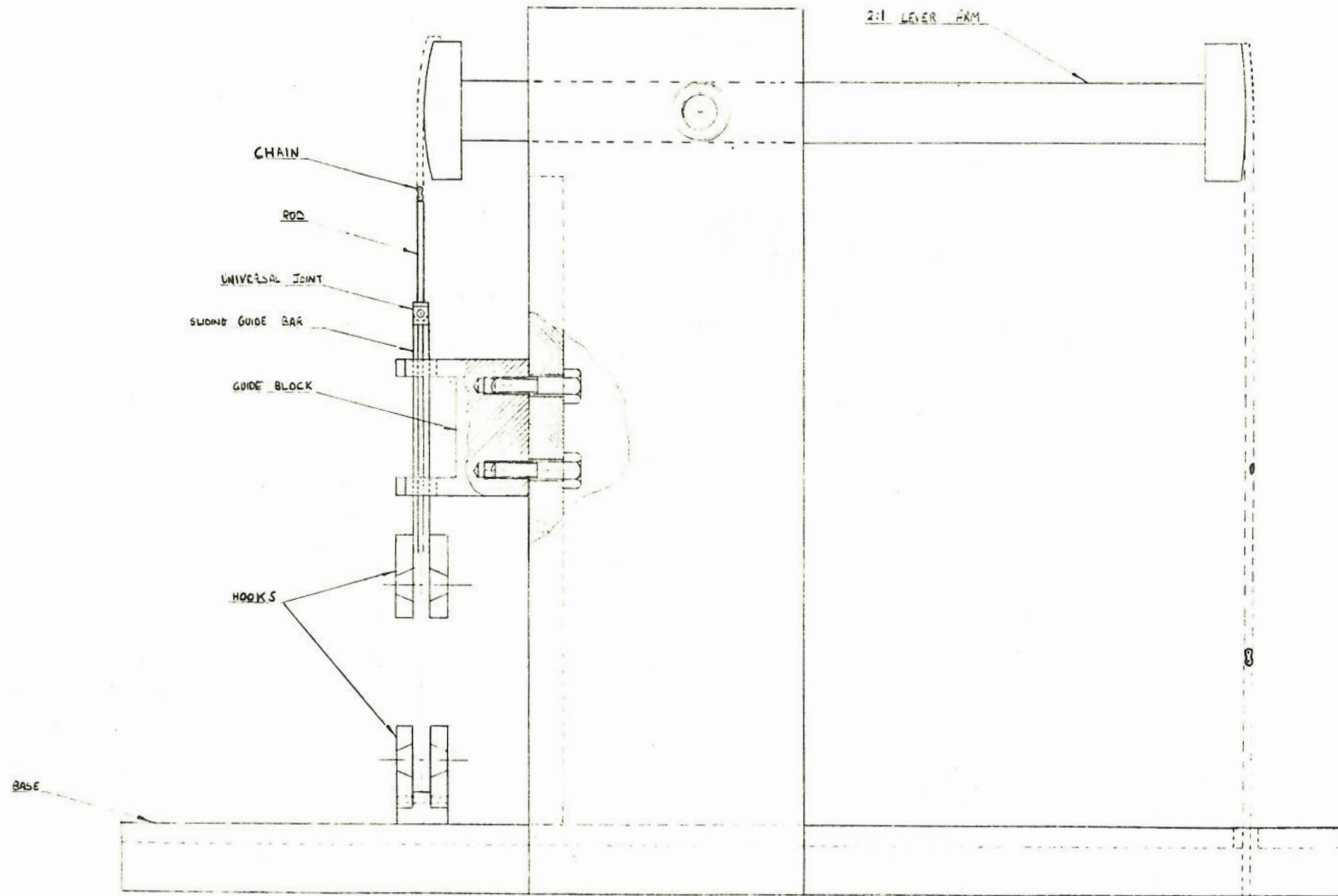


FIG. 3.2. DIAGRAMMATIC REPRESENTATION OF THE
LEVER LOADING CREEP RIG

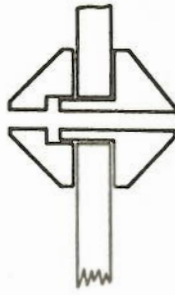


FIG.3.3. THE NEW CONE - SHAPED CLAMPS IN
POSITION ON A SPECIMEN (SIDE VIEW)

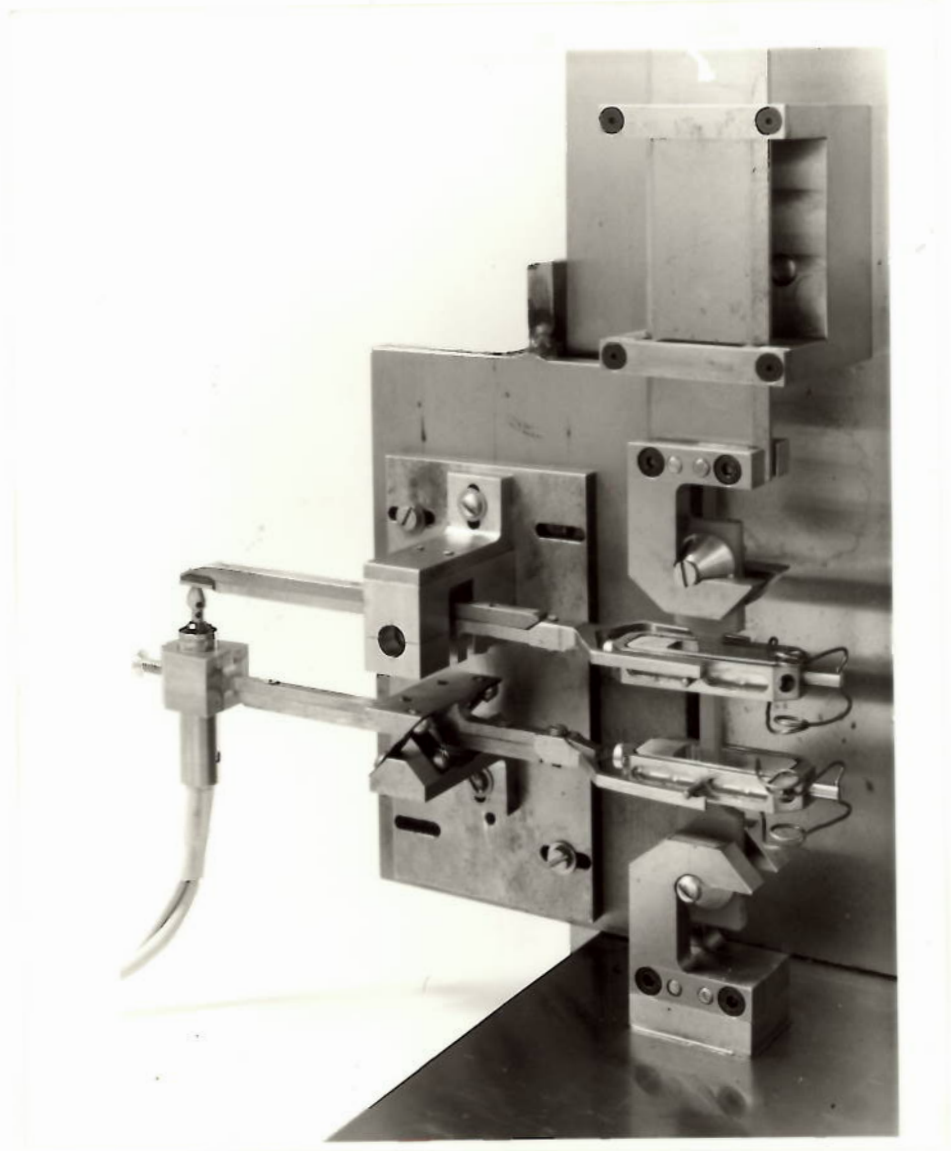
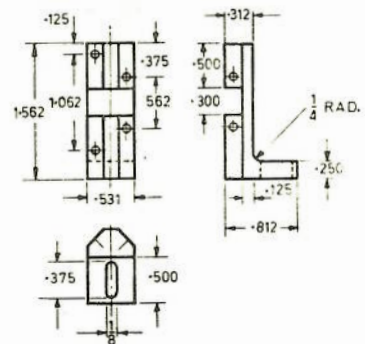
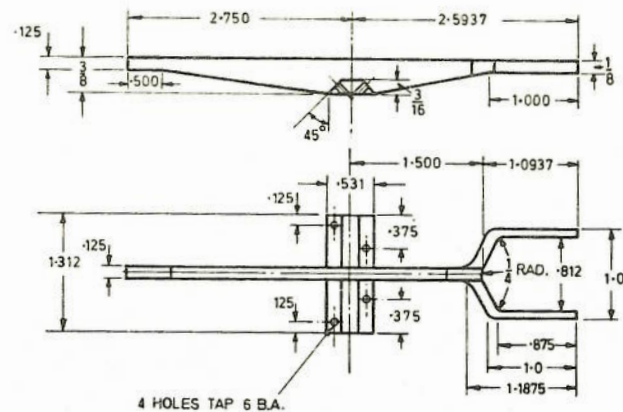


FIG. 3.4 THE EXTENSOMETER AND GIMBAL RINGS



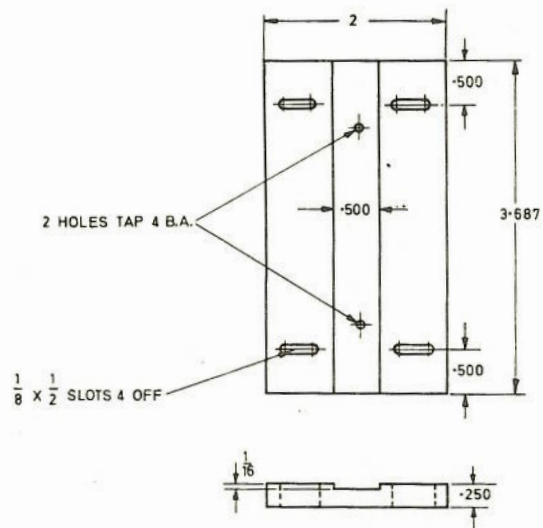
MATERIAL - BRASS

BRACKET



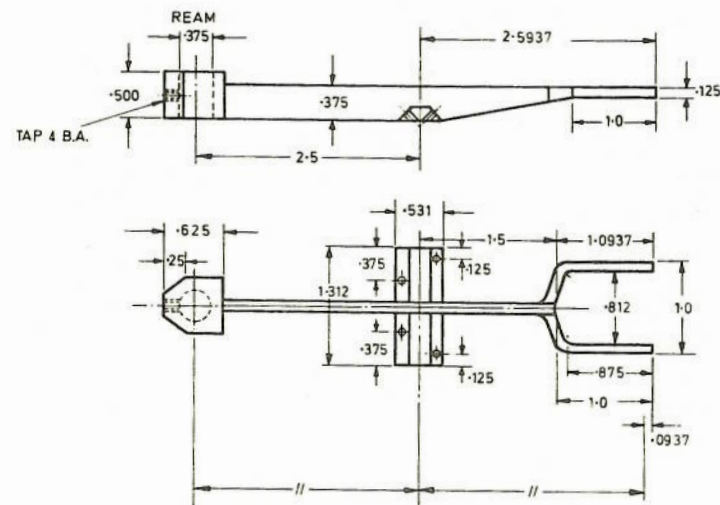
MATERIAL - GAUGE PLATE

EXTENSOMETER ARMS



MATERIAL - BRASS

BACK PLATE 1-1



MATERIAL - GAUGE PLATE

EXTENSOMETER ARMS

FIG. 3.5. THE CROSS SPRING PIVOT EXTENSOMETER

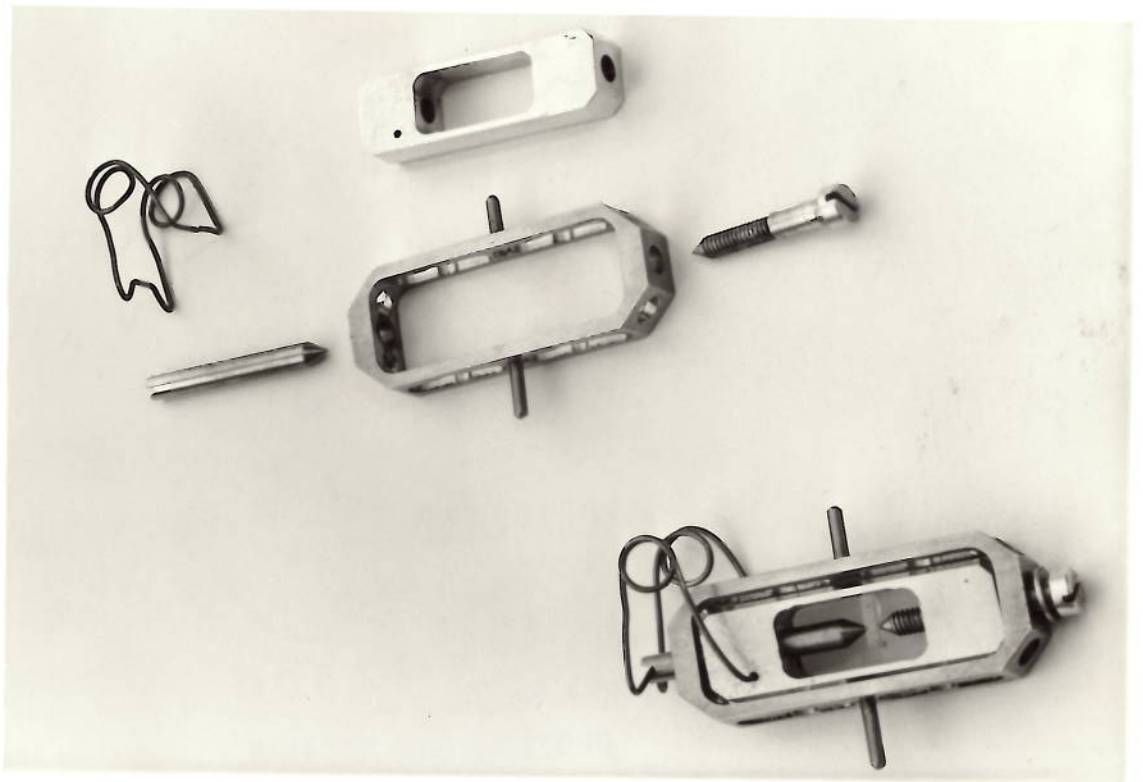


FIG. 3.7 THE GIMBAL RINGS

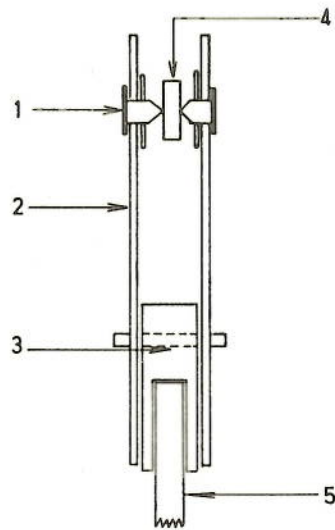


FIG. 3.8. A POSSIBLE METHOD OF ATTACHING THE EXTENSOMETER TO A POLYETHYLENE SPECIMEN (PLAN VIEW)

1. PIN; 2. SPRING STEEL STRIP; 3. BRASS BLOCK;
4. SPECIMEN; 5. EXTENSOMETER ARM.

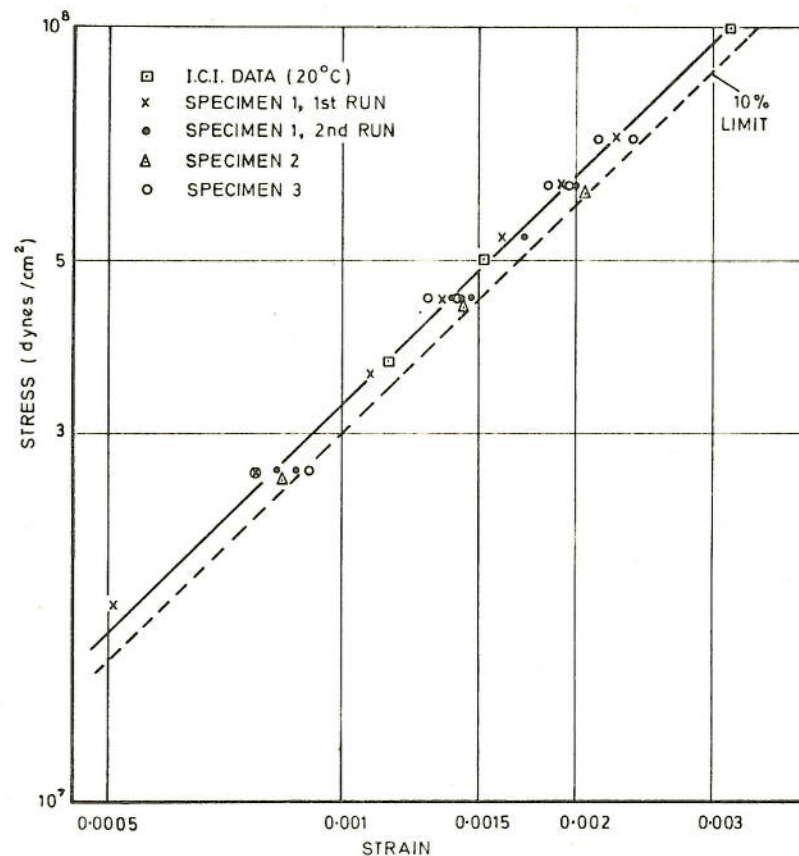


FIG. 3.9. A 100 SECOND ISOCHRONOUS STRESS-STRAIN CURVE OBTAINED WITH I.C.I. STANDARD P.V.C. SPECIMENS (TEMP. 19-22°C)