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THE MECHANICAL PROPERTIES OF ANISOTROPIC POLYMERS

PROGRESS REPORT

A report of work carried out during the period 1st October, 1965 to 31st March, 1966.

INTRODUCTION

The work in this period can conveniently be split into two parts which are reported separately.

Part I is concerned with experimental work on the stress-strain properties of anisotropic polythene. This work was initiated as a first step in the collection of data on anisotropic polymers. The results provide a very useful, general idea of the properties of a polymer, together with their variation with anisotropy. The experience gained during this work has also been of use when considering apparatus design details for creep measurements.

Part II is concerned with the design of an apparatus for creep studies. The design considerations are discussed in Section 1; an outline of several design proposals being given in Section 2. The design project was started in the latter part of the period under review and therefore no comprehensive tests have yet been performed.

M. Darlington, B Sc., Grad.Inst.P.

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PART I

SOME MECHANICAL PROPERTIES OF ANISOTROPIC POLYETHYLENE

1. INTRODUCTION

The work described in this section is concerned with the stress-strain properties of polyethylene. These measurements provide a useful guide to many of the mechanical properties, such as initial modulus, tensile strength and elongation to break. They were intended to provide general background information on the polymer, before proceeding to specific techniques such as creep.

2. APPARATUS

The majority of the modulus measurements were performed on an Instron, model TT but a model TM Instron was used during the later experiments on ultimate properties. All experiments were carried out at room temperature (approximately 23°C) no attempt being made to provide further temperature stabilisation.

3. SAMPLE PREPARATION

A low-medium density polythene was used throughout the investigation. (ρ = 0.93 grams/ml.). Isotropic sheets of polythene were prepared from cube-cut granules by pressing between aluminium plates at 160°C. The sheets were kept at this temperature for about 20 minutes before being rapidly cooled by passing cold water through the press.

Anisotropic samples were obtained by selecting uniform isotropic sheets of approximately 6" by 3", and cold drawing them in a Denison machine. A grid, marked on each sheet prior to the drawing process, was used in the determination of the final draw ratio. No measurements were made until several weeks after the drawing process was performed.

Parallel sided specimens were used for the initial modulus measurements, the strips being 4 mm. wide and approximately 2.5 cms. long.

4. RESULTS

The isotropy of the original polythene sheets was tested by making initial modulus measurements on samples cut from various positions in several sheets. No systematic variation of the modulus with angle or position could be detected in the results. The mean value of the initial modulus of the isotropic sheets was 2.0×10^{9} dynes/cm^{2}.

The modulus quoted above is the secant modulus at a strain of 0.1% (calculated as increase in length divided by original length).

In all the stress-strain measurements, the extension of the specimen has been assumed to be equal to the movement of the cross-head. (After a correction had been applied to allow for deflection in the load cell). The validity of this assumption has been checked by determining the initial modulus (0.1% extension) for isotropic samples of varying length. No significant systematic variation of modulus with specimen length was detected. It was found, however, that the value obtained for the Initial modulus depended very much on the procedure employed for clamping the specimen in the jaw of the Instron. This behaviour has also been reported by Adams and Supnik (1956) and imposes a serious limitation on the absolute validity of the results obtained. The results may, however, be usefully employed for investigating the variation of modulus with anistropy.

The modulus at various extensions has been measured for two anisotropic sheets of draw ratio 3.9 and 4.3. For each sheet measurements were performed at three angles viz. 0° i.e. parallel to the draw direction, 90° to the draw direction and 45° to the draw direction. The results are given in tables 1 and 2. The results are summarised in table 3, where the effect of varying the crosshead extension rate on the measured value of the initial (0.1%) modulus may be clearly seen.

Preliminary investigations of the ultimate properties of polyethylene have been made on an anisotropic sample of draw ratio 3.8. Dumbell specimens were used for tests parallel to the draw direction, but the anisotropic sheet was not sufficiently wide for such specimens to be cut in the 90° or 45° directions. A parallel-sided specimen was therefore used for a test in the 90° direction. The results are summarised in table 4. The parallel-sided specimen was unsatisfactory as it broke in the grips after the completion of the necking stage. However, it serves to show the large difference in elongation-to-break that exists between the 0° and 90° directions. The 0° specimens showed no clear necking region during the extension process.

In order that a more detailed examination of ultimate properties could be made, a micro-tensile specimen cutter was obtained. (A.S.T.M. designation D.1708-59T), having an overall length of 1.5″ with a gauge length of 0.77″. This allowed specimens to be obtained at 0° and 90° to the draw direction. The cutter was found to be satisfactory and anisotropic sheets of draw ratio 1.07, 1.2 and 4.3 have been studied. The results obtained are summarised in Table 5, where they may be compared with the results obtained on isotropic specimens.

The Instron model TM was used for these measurements.

5. DISCUSSION

(a) Modulus Measurements

Despite the preliminary nature of the work so far, several definite conclusions may be formed:-

1) For draw ratios of 3.9 and 4.3

$$E_o > E_{90} > E_{45}$$

(where E_o is the initial modulus in a direction parallel to the draw direction, etc.)

2) For the draw ratio of 4.3, and all 3 angles, the initial modulus increases as the rate of extension increases.

3) At a given extension rate, and angles of 0° and 90°

$$E_{4.3} > E_{3.9}$$

but at 45°

$$E_{4.3} < E_{3.9}$$

(where $E_{4.3}$ is the initial modulus of the sample of draw ratio 4.3, etc.)

The actual shape of the stress-strain curve is also of interest, and an attempt has been made to obtain some general conclusions by determining the variation of the modulus with extension of the sample. Insufficient data are available at present for definite conclusions to be drawn, but it would appear that the modulus decreases as the extension rises, and at no time is Hooke's law obeyed (at least for extensions above 0.1%). The general shape of the curve for anisotropic specimens, cut at angles of 0° and 90°, would appear to be of approximately the same shape as the curves obtained for isotropic specimens. However for anisotropic specimens, cut at 45°, the decrease in the initial modulus appears to be of a slightly different form. It is not clear at present whether this is due in some way to the apparatus or whether it is a phenomenon connected with anisotropy.

The trend of the modulus results given in tables 1, 2 and 3 shows a general agreement with the results published by Raumann and Saunders (1961) on anisotropic polythene sheets.

(b) Ultimate Properties

From the results given in table 5 it will be seen that, as the draw ratio increases, the extension ratio decreases in the 0° direction (parallel to direction of drawing) but increases in the 90° direction. This is as would be expected for a normal anisotropic polymer sheet.

The opposite result is obtained for the results on tensile strength at break.

The results for the yield strength are also given in table 5. For the 0° direction the yield strength clearly increases with draw ratio, but the variation for the 90° direction is not clear from the results obtained so far. In connection with the yield strength, the general shape of the load-extension curve is of interest as it will be seen that, for a draw ratio of 4.3 the yield strength at 90° is much greater than the tensile strength at break. For all the other results the opposite behaviour is found. The general shapes of the load extension curves for draw ratios of 1.2 and 4.3 are given in figures 1 and 2 respectively.

6. FUTURE WORK

It is intended to investigate the stress-strain properties of anisotropic polythene for a range of draw ratios from one to approximately 4.5. At each draw ratio, stress-strain measurements will be made for angles of 0°, 45° and 90° to the draw direction. Several extension rates will be used at each angle. If possible, birefringence measurements will also be made.

Before such an extensive programme may be started, it is necessary to ensure the availability of a large supply of the polymer, and to determine a method of obtaining reproducible, isotropic sheets. Work in progress at present is concerned with this problem. It seems likely that the final choice of polymer will be I.C.I. alkathene, grade W.N.C. 18 or W.J.G.11. The polymer will be pressed between chromium plated, steel plates, covered with thin melanex film to prevent sticking of the polymer sheet to the plates.

PART II

The Creep Properties of Anisotropic Polymers

Section 1 Apparatus Design Considerations

1.1 INTRODUCTION

A knowledge of the creep behaviour of plastics is important for both engineering and fundamental reasons. Most plastics components are stressed in use and a knowledge of their behaviour under stress is therefore essential to the design engineer. The data obtained from constant straining rate experiments are often not adequate for plastics which exhibit non-linear deformation, probably over the entire range of strains. Furthermore, the very nature of such tests, where the polymer is forced to extend at a set rate, greatly increases the difficulties of interpretation of the polymer behaviour. The creep of plastics, where the specimens may react freely to an applied stress, is more easily interpreted on a fundamental basis. It is therefore considered that a useful contribution to the engineering knowledge and fundamental understanding of anisotropic polymers will be provided by a study of their creep properties.

This report is concerned with the design of an apparatus to obtain creep data on anisotropic polymers.

The basic requirements of such an apparatus are outlined in 1.2. 1.3, 1.4 and 1.5 are concerned with the considerations which determine the capabilities required of the apparatus: specimen size, creep loads and the creep rates expected. The final choice of a suitable apparatus should not be made without some consideration being given to the amount of experimental work to be carried out, and a typical programme for the investigation of a single polymer, is therefore outlined in 1.6. This is followed by a very brief survey of possible extensometer systems, which are probably the most important single part of any creep apparatus. Finally, in 1.8, a comparison is made between visual and automatic systems, and it is concluded that an automatic system, capable of simultaneous control of several creep rigs, is preferred for the type of investigation required.

1.2 BASIC REQUIREMENTS

An apparatus is required which will permit a wide range of polymers to be studied, including soft, low density polythenes (Young's Modulus about 10^9 dynes cms^{-2}) and hard plastics such as polymethyl methacrylate (Young's modulus about 4×10^{10} dynes cms^{-2}).

At present, strains in range 0.02 down to 0.001 are of interest, but the possibility of measuring larger (and perhaps smaller) strains would be an advantage. The measuring device should therefore be capable of detecting a strain of 10^{-5} or lower. For fundamental reasons, the early parts of the creep curve are of interest. For example, Turner (1964) has shown that, for certain low density polythenes, a change in slope occurs in the plot of log (strain) against log (time) at a time of approximately 200 seconds after the load is applied. It would therefore be desirable to commence creep measurements within 5 seconds of applying the load. The duration of an experiment may range from as little as 200 seconds up to several hours, or days, in some cases.

The range of polymers mentioned above requires the use of stresses in the range 10^6 to 10^{10} dynes.cms^{-2}. It is impossible to apply a stress instantaneously to a polymer, and an analysis (Turner, 1966) based on models has shown that meaningful readings can only be taken after a time equal to 10 times that required to apply the stress. If the initial part of the creep curve is to be studied, this requires that a system be designed to enable the load to be applied rapidly and in a reproducible manner. The loading system must also be designed to ensure axial loading of the specimen.

The mechanical properties of most polymers tend to be very temperature dependent. It would therefore be desirable to perform the creep experiments in some form of constant temperature enclosure.

1.3 SAMPLE PREPARATION

This varies according to the polymer to be studied. Low density polythene has been considered in detail and will be discussed below. For many of the harder plastics the preparation is less involved.

Isotropic sheets of low density polythene may be formed by pressing cube-cut granules between steel plates at 160°C. The sheets so formed are 24 cms by 24 cms. and usually 0.2 cm. thick. Due to imperfections near the edges of the sheet, the central 18 cm. square portion only is generally used; two smaller sheets 16 cms. long and 6 cms. wide being cut from each isotropic sheet. The smaller sheets are cold drawn in a Denison tensile testing machine to various lengths (i.e. draw ratios) depending on the amount of anisotropy required. For a draw ratio of 4:1 the anisotropic sheets are approximately 3 cms. wide, which places a severe limit on the length of the specimens cut from the sheet at angles of 45° and 90° to the draw direction. For a draw ratio of 1.2:1 this critical dimension increases to 5.4 cms. However, the length of the specimens cut from the sheet will be limited in this case by the size of regions of uniform draw ratio. The width of the anisotropic sheets could be increased by starting with a wider isotropic sheet, but care must be taken not to restrict the contraction of the sample in the directions at 90° to the draw direction, or the form of the anisotropy will be altered. This is not so important when necking occurs (draw ratio > 3.5) and it may be possible to get a 4 cm. wide strip by starting with an isotropic sheet 8 cms. wide and an initial grip separation of ten to twelve cms. The initial separation is controlled by the maximum permissible extension of the Denison jaws. For smaller draw ratios (< 1.5) necking does not occur, and the initial ratio of the strip length to width should not be reduced below 2:1 or the specimen contraction will be restricted. However, the initial specimen length (grip separation) is not restricted in this case by the maximum movement of the Denison jaws and a longer sample could be employed. The upper limit is set by the original size of the pressed sheets.

It is rather more difficult to draw any conclusions about the samples obtained for intermediate draw ratios (i.e. 1.5 to 3.5). Such ratios are usually only obtained in the region of the 'neck' itself and hence uniform regions of anisotropy may be very limited in area. Trials will have to be performed to ascertain the optimum values for original specimen size and rate of extension of the sheet.

It may be concluded from the above discussion that the maximum length of anisotropic specimens for creep studies will probably be in the range 3.5 to 5.0 cms., depending on the draw ratio. Allowing for room to grip the specimens it would appear that the sensitivity of the creep apparatus must be high enough to deal with gauge lengths of the order of 2 cms.

1.4 CREEP LOADS

The magnitude of the creep load depends on the polymer, the strain required and the specimen cross-sectional area (at a given temperature).

For an isotropic, low density polythene specimen having a width of 0.4 cms. and a thickness of 0.2 cms. (standard thickness of the isotropic sheets produced at present) the cross-sectional area will be 0.08 cms^2. Assuming a tensile creep modulus of 2×10^9 dyns.cms^{-2}, a strain of 0.002 will require a load of approximately 300 grams. For an anisotropic specimen of draw ratio 4:1 the area of cross-section will be reduced by the drawing process to 0.04 cms^2, and the creep modulus will depend on the orientation in the sheet. A table of values, estimated from constant straining rate experiments is given below:-

Angle	Modulus	Load for strain of 0.002
0°	3.3×10^9	250 grams.
90°	2.6×10^9	200 grams.
45°	0.82×10^9	50 grams.

(Moduli in dynes cms^{-2}).

It will be seen that under certain conditions, loads as low as 50 grams may be employed. The loading system must therefore be frictionless or large errors may be introduced. A direct loading system might be indicated by this requirement. However, axial loading restrictions may introduce difficulties and further consideration must be given to this problem.

It will also be seen from the above table that any system designed to measure the strain must have a negligible loading effect on the specimen: a requirement which is seldom satisfied in practice with existing extensometers (apart from the use of a cathetometer).

The required load, for the same strain, could be raised by increasing the cross-sectional area of the specimen: in particular, its thickness. However, a doubling of thickness of the isotropic sheets only results in raising the minimum load from 50 to 100 grams in the above example. This is still rather small and means that, if a standard isotropic sheet is to be used throughout the work, the specimens of low draw ratio will be of the order of 0.4 cm. thick. This is undesirable with short samples of the softer polymers owing to grip difficulties etc.

This problem will be given further consideration, but at present it appears that a frictionless load system, capable of handling loads as small as 50 grams, must be designed.

For the more rigid polymers the loads may be considerably higher (ten kilograms or more) and a lever loading system will be necessary. Friction in the loading system and extensometer loading must still be kept low, but are not as critical as in the case of the softer polymers.

1.5 CREEP (EXTENSION) RATES

The creep rate has its highest value directly after the load is applied; the rate decreasing with time (for small strains). In general the initial creep rate for the softer polymers will be higher than that of the rigid polymers. The true creep rates to be expected during tests on anisotropic samples are difficult to estimate owing to the lack of suitable published information. However, some idea may be obtained from published results on isotropic specimens. (Turner, 1964/65).

Sample	Strain at Times after Load Applied of:-					
	5 secs.	10 secs.	15 secs.	20 secs.	30 secs.	100 secs.
Low density polythene	0.0070	0.0076	0.0081	0.0084	0.0088	0.01
	(0)	(0.0006)	(0.0005)	(0.0003)	(0.0004)	(0.0012)
	0.016	0.0178	0.0186	0.0194	0.0204	0.0237
	(0)	(0.0018)	(0.0008)	(0.0008)	(0.001)	(0.0033)
Unplasticised PVC	0.0033	0.00353	0.00358			0.00360
	(0)	(0.00023)	(0.00005)			
	0.00680	0.00695	0.0070			0.0071
	(0)	(0.00015)	(0.00005)			

(Numbers in brackets give change of strain in each time interval).

It is anticipated that many polymers will exhibit creep behaviour somewhere between the two cases given above. For polythene it will be seen that the strain increases from zero to 0.016 during the five seconds after the load is applied, but a change of only 0.001 in 10 seconds occurs after the first 20 seconds of the test.

For PVC, the large initial creep extension has finished within 3 seconds of the application of the load, and a change in the strain of less than 0.0001 is observed in the time interval from 5 to 15 seconds.

1.6 PROPOSED EXPERIMENTAL PROGRAMME

This section has been included in order to demonstrate the magnitude of the task of a full investigation into the creep behaviour of an anisotropic polymer.

Previous work on constant straining rate tests of anisotropic polymers suggests that a minimum of 6 draw ratios must be studied if a complete picture of the effect of varying the anisotropy is to be obtained. If the isotropic state is included this means that seven basic samples must be tested. For each sample, specimens cut at 0°, 45° and 90° to the draw direction are required. At each angle it is of interest to study the effect of at least 3 different loads. This represents a minimum of 63 creep runs. In order to test the reproducibility of the results, the above runs must be repeated, representing a total of 126 runs. But it has been shown that the mechanical properties of polymers are very dependent on their thermal history and a complete picture can only be obtained by varying the method of preparation of the isotropic sheets. It will be seen from the above, brief description, that the examination of a single polymer may involve about 200 creep runs. (In fact the number could easily rise to 600 if any of the results show poor reproducibility). A few of these runs may only last for 20 minutes, but many will continue for several hours. The minimum time necessary to examine a single polymer will therefore be of the order of 5 weeks of continuous experimental work, assuming that about 6 creep rigs are available.

1.7 BASIC METHODS OF CREEP MEASUREMENT

(a) Cathetometers

The use of a cathetometer to measure the distance between two marks on the specimen, or simply to follow the movement of the lower specimen clamp, probably represents the simplest, most direct method for creep studies. Unfortunately, even when used by a skilled observer, the minimum error in the cathetometer readings is of the order of 0.001 cm. Procedures can be devised for following the movement of the lower clamp during the latter part of the initial rapid creep extension (approximately 50 seconds after load applied) but such procedures are bound to result in a slight loss of accuracy. Furthermore, if actual gauge length readings are required, measurements frequently cannot be made for some time after the application of the load. This method has the advantages of applying no load to the sample and of measuring any reasonable value of strain (100% would not be excessive).

(b) Simple Optical Lever Extensometers

A typical extensometer in this class has been described by Mills and Turner (1965). They are reasonably simple to construct and operate and have a lower limit of detection of about 0.0005 cms. They have the advantage of measuring the gauge length extension without loading the specimen to any great extent, the latter condition being achieved by the use of counterbalances. The system however is still in the visual class which reduces the accuracy of readings taken during the period directly after loading. The necessity of using a lamp and scale system limits the range of strains which may be measured (usually up to 4%).

(c) Lamb Type Extensometer

This represents the class of extensometer which is attached direct to the sample. It is capable of detecting an extension of 0.00005 cms with a gauge length of 5 cms. The disadvantage of this type of extensometer is that it imposes a load on the specimen. By careful choice of construction materials this load may be reduced to an acceptable level for work on the rigid plastics, but is still too large for satisfactory operation with the softer polymers such as polythene and polypropylene. In its usual form the extensometer is used with a lamp and scale measuring system, which limits the upper value of the strain to 2%.

A modification to this type of extensometer has been described by Mills and Turner (1965) which allows it to be used in an electronic measuring system. A very small linear variable differential transformer was actually mounted on the extensometer, so increasing its overall weight. The sensitivity of the system was similar to that of the visual system but problems were encountered with long-term stability.

(d) Photoelectric Cells

These have been incorporated in extensometer systems where continuous recording was desired. A typical design has been given by Scherr and Palm (1963). The system accuracy was comparable with that from a cathetometer, and in general photoelectric methods have been superseded by superior electronic devices.

(e) Bonded Wire Resistance Strain Gauges

These have been rejected for use with plastic materials, for reasons outlined by Findley (1962).

(f) Clip-on Strain Gauge Extensometers

These have been described by Jackson and McMillan (1963). They can be used, in conjunction with automatic recording systems, to cover the complete creep curve from several seconds onwards. Commercially available models can detect a movement of 0.00005 cm with a gauge length of 2.5 cms. The maximum measurable strain for these specifications is 10%, but other models are available for larger gauge lengths or greater maximum strains. The main disadvantages of such extensometers are (i) they form a non-axial load on the sample (actually weight is about 40 gram), (ii) they have a resistance to extension of about 40 gram at maximum strain and (iii) the minimum gauge length permissible at present appears to be 2.5 cms.

(g) Electronic Displacement Transducers

These are usually of the differential transformer (e.g. Gossick, 1954), variable inductive or differential capacitor (e.g. Kinloch and Waters, 1960) types. Some of these devices have been designed to measure displacements, but may be incorporated in extensometer systems to give accurate, automatic recording of gauge length or sample grip movement. Certain types are very small and light and could possibly be attached direct to the sample. Unfortunately they are usually less sensitive, less stable and of more limited movement than their large counterparts. The latter may weigh as little as 40 grams, but counterbalancing is still preferred when using this type.

(h) Moiré Fringe Systems

Measuring systems based on Moiré fringes have been used for some time for accurate linear measurement. The adaptation of such a system to the creep extension of polymers would appear however to be more difficult than the use of electronic displacement transducers, with regard to weight and rigidity.

1.8 DISCUSSION

The sample preparation details outlined in section 1.3, indicate that the anisotropic specimens for creep tests will have a gauge length of approximately 3 cms. In some cases this may in fact be reduced to as little as 2 cms. Some examples of published creep data given in section 5 show that for some polymers, changes of as little as 0.0001 in 100 seconds may be expected. For most work however the measurement of a strain of 10^{-3} to 1% will be adequate. For a gauge length of 3 cms this requires that an extension of 0.00003 cms ($\simeq 10^{-5}$ inches) be detectable. If creep extensions are to be measured during the first 100 seconds of a test, this will require readings of an extension in the range 0.001 to 0.05 cms during the time that the creep rate is at its highest.

The use of cathetometers to measure creep strains is largely confined to long term tests (i.e. from 10 minutes to 1 year after application of load) on isotropic polymers where sufficient specimens are available to compensate partly for the poor accuracy, or where large gauge lengths may be used. Neither of these requirements can be met when working with anisotropic samples, where the method of preparation limits the specimen size and restricts the number of specimens available for reproducibility tests.

The use of the Lamb type extensometers would appear at first to be a useful compromise between the cheaper, inaccurate cathetometer methods and the more accurate, but also more expensive, automatic methods. It has however several limitations. It is difficult to construct an extensometer of this type for use with a 5 cm. gauge length, and the extensometer weight limits its usefulness with certain of the softer polymers, Also, varying the gauge length requires a new extensometer to be built. The optical lever method is slightly less sensitive than the Lamb extensometer, but does not suffer from the above disadvantages. It does however suffer from the fundamental disadvantage of a visual system: its use requires the presence of an operator. It has therefore been restricted mainly to the study of creep from a few seconds to a day or longer, where, after the initial period, the interval between readings may extend to many hours.

For a programme of the type proposed in section 1.6, the use of the optical lever system, with six creep rigs, would require the operator to be in continual attendance throughout the day for a period of five weeks; the entire time being spent on the collection of data for a single polymer. This is obviously unsatisfactory and supports the suggestion that an automatic system is desired. Such a system would allow creep tests to be performed overnight, without the attendance of an operator, resulting in a considerable saving in operator time and allowing data to be analysed during the course of the investigation. For maximum efficiency the system should be easy to set up and control, and should preferably have superior sensitivity and response time compared with the visual system.

The proposed design of such a system is given in a later section. It should possess all the above qualities and present a negligible load to the specimen. These qualities will be maintained over the entire range of polymers mentioned in section 1.2, and the extensometer system will be easily adaptable for use during constant straining rate experiments. No known extensometer can offer this versatility. It is suggested that, initially, six creep rigs will be built, but the nature of the system is such that twelve rigs could be controlled at very little extra cost.

The requirement of axial loading of the creep specimens must be emphasised. However great care must be taken to ensure that any devices associated with the requirements for axial loading, or with the loading device itself, do not pre-load the specimen or introduce friction, or the versatility of the extensometer system will be reduced.

Section 2. Proposed Designs and Preliminary Tests

2.1 INTRODUCTION

Details are given in this chapter of proposed designs for various parts of a creep apparatus. The extensometer and specimen loading system are considered separately. Finally, the results of some preliminary tests of the transducer and extensometer system are given.

2.2 THE EXTENSOMETER SYSTEM

After detailed consideration, it was decided to develop an extensometer based on a differential capacitor linear displacement transducer, manufactured by Societie Genevoise Ltd. (Sogenique system). A single transducer had a mass of 40 grams and therefore required counterbalancing.

The design of a gauge length extensometer employing two independent transducers would be relatively easy. However, in certain applications (e.g. working involving rapid extensions) the use of two transducers would be a great disadvantage as the two signals would need to be measured simultaneously on separate control units, or else switched alternately into one control unit. The cost per extensometer would also be increased. An attempt has therefore been made to design an extensometer which requires only one transducer to perform true gauge length measurements. (The use of one transducer to measure overall sample extension is a much easier problem).

Details of an extensometer, which has been built in order to evaluate the proposed system, are given in fig. 2.1. Variation of the gauge length may be achieved by making one of the lever arm pivots movable, and including a facility to allow the transducer to be moved in its holder.

A block diagram of the control unit for 6 transducers is given in fig. 2.2.

2.3 THE LOADING SYSTEM

The magnitudes of the loads required for soft polymers are such that they could easily be applied by direct loading. However, if specimen pre-loading is to be avoided a balanced lever-loading system would seem preferable. A suitable design is under consideration at present. A lever-loading system is essential for the more rigid polymers.

A method of applying the load in a reproducible manner using reversable motors is also under consideration at present.

2.4 PRELIMINARY TEST RESULTS

The stability of a Sogenique transducer and control unit has been tested over a 7 day period by clamping the transducer in an aluminium block and monitoring the temperature of the block and the output of the transducer. The block was not temperature stabilised; thus allowing the temperature to cycle over a range of about 5°C every 24 hours. At one arbitrarily chosen temperature (18.5°C) the variation in the transducer reading was less than 0.00002″ over the 7 day period. In a single 24 hour period, the variation was as low as 0.000005″. The stability of the basic transducer system would therefore appear to be adequate.

Preliminary tests of an extensometer of the type shown in fig. 2.1 have indicated that the use of knife edge pivots is not entirely satisfactory owing to the stiffness of the transducer cables. It has therefore been decided to replace these simple pivots with cross-spring pivots, and a new extensometer incorporating two cross-spring pivots is being made at present.

TABLE 1. RESULTS ON ANISOTROPIC POLYETHYLENE SHEET

DRAW RATIO = 3.9

Angle	Crosshead (1) Rate	Variation of Modulus(2) with Extension		
		0.1%	0.2%	0.5%
0°	0.01 (2.6 cms)	3.52 x 10^9 (0.092%) (3)	3.51 x 10^9	3.33 x 10^9
	0.01 (2.2 cms)	3.57 x 10^9 (0.0905%)	3.53 x 10^9	
90°	0.01 (2.55 cms)	2.72 x 10^9 (0.093)	2.69 x 10^9	2.60 x 10^9
	0.01 (2.32 cms)	2.94 x 10^9 (0.092%)		
45°	0.01 (2.2 cms)	0.84 x 10^9 (0.0975%)	0.78 x 10^9	0.69 x 10^9

(1) Crosshead rate given in ins./min.
(Figure in brackets is initial separation of grips)

(2) Modulus given in dynes/cm^2.

(3) Figure in brackets is true % ext.^{n} (0.1% is nominal value). 0.2% and 0.5% values are exact.

TABLE 2. RESULTS ON ANISOTROPIC POLYETHYLENE SHEET

DRAW RATIO = 4.3

Angle	Crosshead Rate (ins./min.)	Variation of Modulus with Extension (1)		
		0.1%	0.2%	0.5%
0° (2) (2.35 cms)	0.01	3.86×10^9 (0.091%)		
0° (2.3 cms)	0.002	3.82 (0.0905%)		
	0.01	3.97 (0.090%)		
	0.1	4.6 (0.089%)		
90° (2.15 cms)	0.002	3.02 (0.092%)		
	0.01	3.2 (0.092%)		
90°	0.002	3.05 (0.093%)		
(2.58 cms)	0.01	3.32 (0.0925%)		
	0.1	3.94 (0.091%)		
45° (2.5 cms)	0.01	0.82 (0.0985%)	0.79	
45°	0.002	0.78×10^9 (0.098%)	0.735×10^9	0.695×10^9
(2.6 cms)	0.01	0.83 (0.098%)	0.79	0.735
	0.05	0.92 (0.098%)	0.84	0.775
	0.1	1.1 (0.0975%)	1.03	0.895

(1) Modulus given in dynes/cm^2.

(2) Figure in brackets (column 1) is initial separation of grips.

TABLE 3. SUMMARY OF RESULTS FOR VARIATION OF INITIAL MODULUS WITH ANGLE IN ANISOTROPIC POLYETHYLENE SHEETS.

Draw Ratio	Crosshead Rate (ins./min.)	(1) Initial Modulus (Dynes/Cm^2)		
		0°	90°	45°
3.9	0.01	3.54×10^9	2.83×10^9	0.84×10^9
4.3	0.002	3.82	3.03	0.78
	0.01	3.91	3.26	0.82_5
	0.05			0.92
	0.10	4.6	3.94	1.1

(1) Measured at extension of 0.1%.

TABLE 4. ULTIMATE PROPERTIES OF AN ANISOTROPIC POLYETHYLENE SHEET

(DRAW RATIO = 3.8) (TENTATIVE DATA)

Angle	Sample Description (4)	Initial Separation of grips	Cross-head Rate	Extension at Break	Extension Ratio (3)	Yield Strength	Tensile Strength at Break
0°	DUMBELL (1.0" gauge length)	4.2 cms (1.65")	0.5"/min (50%/min)	1.216" (122%) (2)	2.216		7.9x10^{3} p.s.i.
0°	DUMBELL (1 0" gauge length)	4.6 cms. (1.81")	0.5"/min (50%/min)	1.23" (123%)	2.23		8.1x10^{3} p.s.i.
90°	parallel sided (3 cms long, 0.4 cm. wide)	2.65 cms (1.04")	0.5"/min (48%/min)	> 7.75" (>745%) (1)	> 8.46	1.2x10^{3} p.s.i.	>0.69x10^{3} p.s.i.

(1) Specimen necked, then broke in grips.

(2) Calculated as increase in length/original length.

(3) Calculated as final length/original length

(4) Thickness of all samples = 0.037 "(0.094 cms.)

TABLE 5. ULTIMATE PROPERTIES OF ANISOTROPIC POLYETHYLENE SHEETS
(MICRO-TENSILE SPECIMENS) (1).

Draw Ratio	Angle	Extension at Break	Tensile Strength at Break	Extension Ratio at Break	Yield Strength (2)
Isotropic		5.4″	2.6×10^3 p.s.i (1.8×10^8)	8.0	1.6×10^3 p.s.i (1.1×10^8)
1.07	0°	5.0″	2.7×10^3 p.s.i. (1.9×10^8)	7.5	1.7×10^3 p.s.i. (1.2×10^8)
	90°	5.6″	2.5×10^3 p.s.i. (1.7×10^8)	8.3	$1.4_5 \times 10^3$ p.s.i. (1.0×10^8)
1.2	0°	4.5″	3.2×10^3 p.s.i. (2.2×10^8)	6.8	1.9×10^3 p.s.i. (1.3×10^8)
	90°	6.5″	2.4×10^3 p.s.i. (1.65×10^8)	9.4	1.25×10^3 p.s.i. (0.86×10^8)
4.3	0°	0.52″	8.3×10^3 p.s.i. (5.7×10^8)	1.7	8.1×10^3 p.s.i. (0.56×10^8)
	45°				0.92×10^3 p.s.i. ($0.63_5 \times 10^8$)
	90°	9.52″	1.1×10^3 p.s.i. (0.76×10^8)	13.3	1.6×10^3 p.s.i. (1.1×10^8)

(1) All tests carried out at a crosshead separation rate of 0.5 inches/min. (65% per minute).

(2) Values in brackets are in dynes/cm^2.

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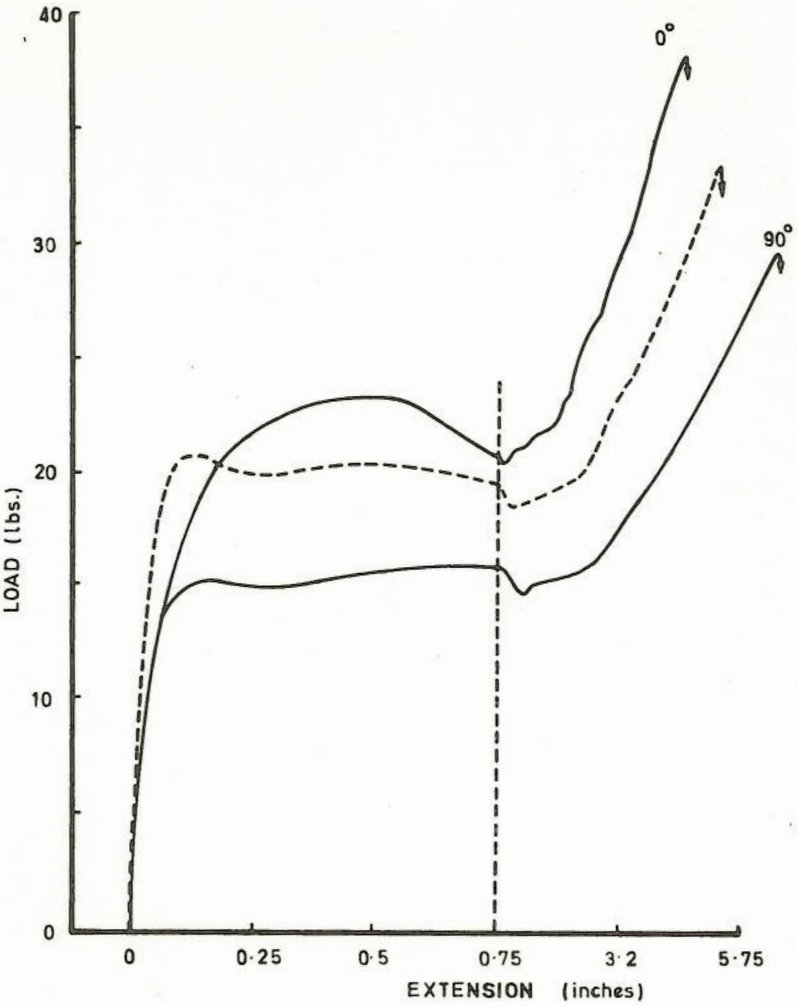


Fig. 1. ANISOTROPIC POLYTHENE SAMPLE (DRAW RATIO 1·2)
(--- ISOTROPIC SAMPLE)

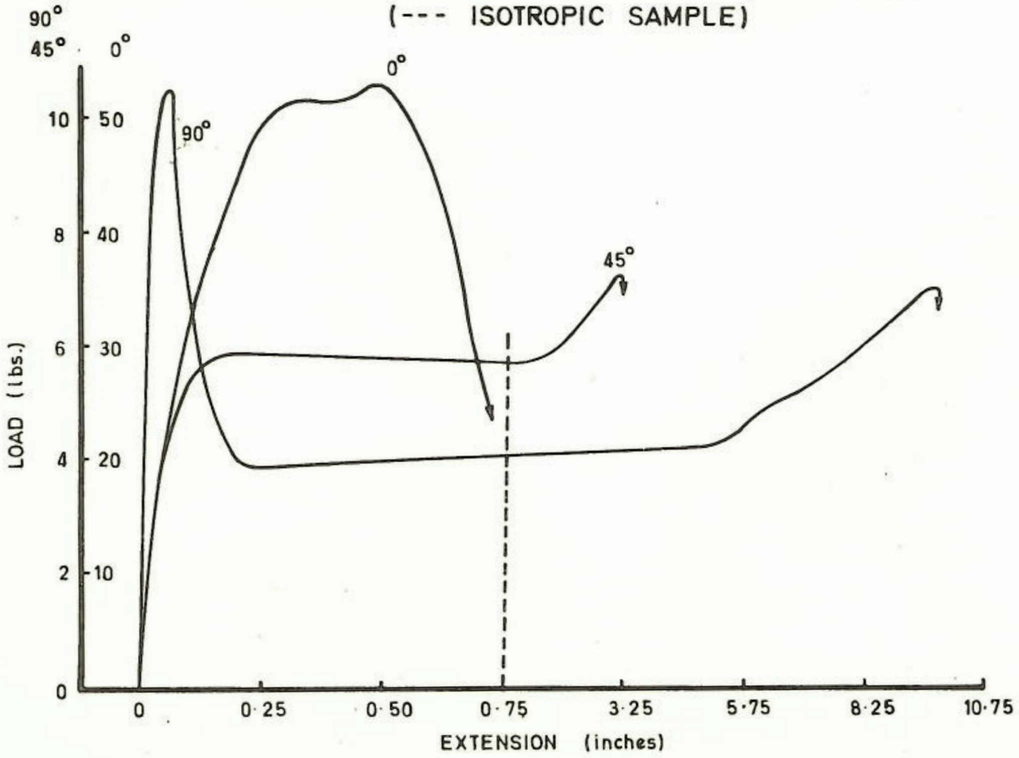
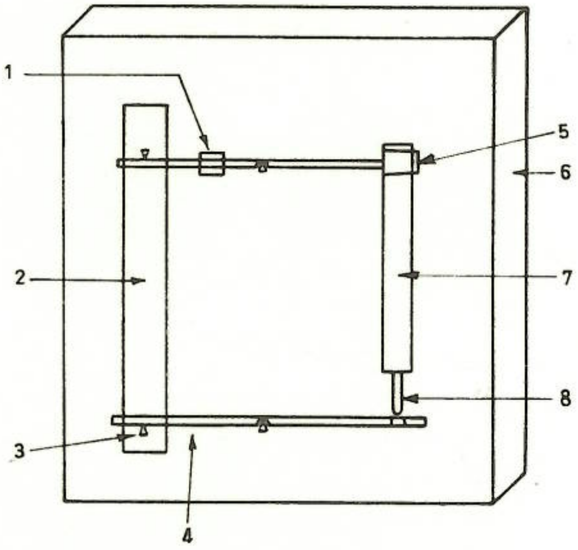


Fig. 2. ANISOTROPIC POLYTHENE SAMPLE (DRAW RATIO 4·3)



1. TRANSDUCER COUNTERBALANCE. 2. SPECIMEN. 3. SPECIMEN PINS. 4. RIGID LEVER. 5. TRANSDUCER HOLDER. 6. BRASS PLATE. 7. TRANSDUCER BODY. 8. MOVEABLE SHAFT.

Fig 2·1 SINGLE TRANSDUCER EXTENSOMETER.

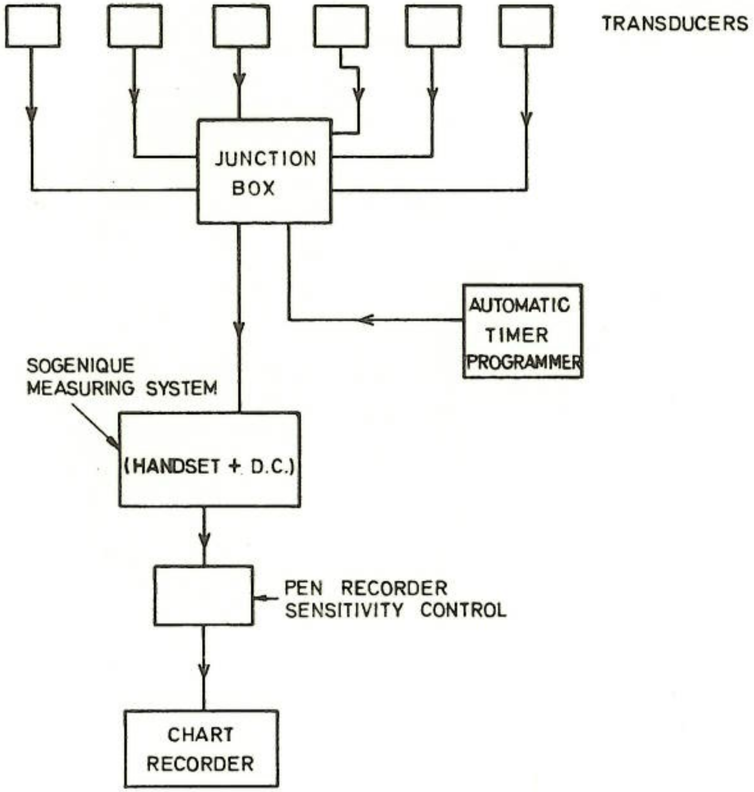


Fig 2·2 CONTROL SYSTEM