CoA Memo. No. 158

An Apparatus for the Measurement of Tensile Creep and Contraction Ratios in Small Non-Rigid Specimens.

(Shortened title - Creep in Small Non-Rigid Specimens)

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Abstract

An apparatus is described for precise measurement of creep properties in specimens with gauge lengths down to 1.2 cm. An extensometer has been developed which is supported independently of the specimen and exerts a load on the specimen of less than 5 grams. It can thus be used with small non-rigid specimens. The extensometer will detect strains down to 2×10^{-6}. The stability is excellent. An adaptation of the system which allows simultaneous measurement of tensile strain and lateral strain during creep is also described. The apparatus was designed for the measurement of anisotropy of creep properties in oriented thermoplastics and reference to such measurements is given. It is however entirely suitable for general application to small specimens.

1. Introduction.

Investigation of the creep behaviour of polymers is useful for both engineering and fundamental purposes. A relatively large quantity of creep data has now been collected for polymers in the isotropic state but very little has been published on the creep behaviour of anisotropic polymers, despite the fact that articles manufactured from polymers often contain material in the anisotropic state. A major reason for this would appear to be the difficulty of making precise strain measurements with the available anisotropic material.

The usual methods of preparing homogeneous anisotropic specimens from thermoplastic materials involve subjecting the sensibly isotropic material to large permanent deformation by hot or cold drawing techniques (See Raumann and Saunders, 1961). The deformations used may involve strains of several hundred per cent which, since they occur essentially at constant volume, involve large reductions in some dimensions. Most investigations to date have involved tensile drawing of sheet with strains as high as 500%, and consequent reduction in width and thickness by a factor greater than 2.

In studying anisotropy of creep properties say, in these materials it is necessary to cut samples at a variety of angles to the draw direction (which in this case is an axis of cylindrical symmetry in the material). The overall length of such samples is therefore limited in most cases to something less than ca. 5 cm. If drawing procedures are to be kept within normal laboratory facilities the thicknesses of the drawn specimens may well be only 1 mm. or less and width ca 5 cm. The resulting specimens, especially in "soft" polymers such as low density polyethylene, may well therefore be both small and lacking in rigidity, when compared with conventional tensile or creep specimens, and strain measurements present special difficulties.

In designing the apparatus the imposed conditions were therefore

(i) No part of the apparatus should impose a pre-load on the specimen of greater than 20 grams, this being estimated as a significant fraction of the lowest required creep load for certain anisotropic, low-density polyethylene specimens.

(ii) All moving parts to be stiction-free.

(iii) Strain must be measured by a suitable extensometer operating between points remote from the grips so that errors due to slippage in the grips etc. may be avoided. (See Adams and Supnick, 1956). This also allows the many advantages of dumbell specimens to be enjoyed. The extensometer must possess a lower limit of detection of strain of better than 10^{-5} with a gauge length no greater than 1.3 cm.

The nature of the specimens precludes all forms of extensometer which are supported by the specimen. In particular, size and weight will preclude the well-proven optical extensometers described by Dunn et al (1964). Bonded strain gauges are in principle possible, but present their own problems associated with bonding, calibration and stability. (See Findley, 1962).

The design and proof of a suitable extensometer is therefore a major portion of this work. The extensometer described below satisfies all the requirements mentioned above. The load on the specimen may in fact be reduced to less than 5 grams. The sensitivity is 2.5×10^{-6} cm. and minimum gauge length 1.2 cm. Stability is excellent. Further, the adaptation and use of this extensometer to the measurement of lateral contraction (thickness changes) during tensile creep is described.

2. The Extensometer.

2.1 General Principles.

The extensometer is based on a differential capacitor, linear displacement transducer, manufactured by Societe Genevoise Ltd. The transducer consists essentially of a moving shaft and a fixed body. The extensometer itself consists simply of two arms pivoted freely at their centres (Figure 1). On one end of each arm is a device for maintaining contact with the two gauge points on the specimen. These attachments are discussed in section 2.3. The opposite end of the bottom arm holds the body of the transducer whilst the moveable shaft rests against the lower surface of the upper arm. The relative movement of the gauge points is thus followed by the transducer; the simple translation of both gauge points by an equal amount in the same direction producing no change in 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 at the grips or general straining of the apparatus when the load is applied.

2.2 Construction Details.

The general construction may be inferred from figures 1 and 2. The overall dimensions are not critical and may be adjusted to suit individual requirements. However, for convenience, the system described here has been set up with the distance from the gauge point to the extensometer arm pivot equal to the distance from the pivot to the transducer centre line. The extensometer arms are made from high-carbon steel; the back plate, bearing brackets and transducer holder being of brass. The region of the underside of the upper extensometer arm where the shaft of the transducer makes contact is ground flat and lapped with diamond paste. The ball end of the transducer shaft is also lapped. The hardened silver steel pivot shafts, with ground, cone-shaped, ends (1, figure 2) are a tight fit in the extensometer arms. These shafts rotate in solid pivot bearings, 3, located in the bearing brackets, 4. The back bearing is pushed against the brass plug, 2, by screwing the Allan screw, 9, against the back of the front bearing (shaft in position). The bearings are adjusted until there is just no perceptible slack. The lower extensometer arm can be positioned directly under the upper arm by adjusting the positions of the brass plugs, 2.

The bearing brackets are held to the rigid back plate by single screws through the slotted holes. A grooved guide in the back-plate allows the brackets to be moved to any required separation on the back-plate without upsetting the alignment of the system. The present design enables a gauge length anywhere in the range 1.2 to 3.0 cm. to be used, but other ranges are obviously equally possible.

The mass of the transducer is approximately 40 grams but the extensometer design allows this to be counterbalanced for work on softer polymers. The spring on the transducer shaft pushes the shaft against the upper extensometer arm, so maintaining firm contact between these two parts. This arrangement however, also produces an undesirable downward force on the specimen at the upper gauge point. The spring pressure is therefore countered by adding an adjustable brass counter-weight to the upper extensometer arm. This increases the effective pre-load at the lower gauge point and necessitates the use of a counter-balance on the lower arm to offset the combined effect of the brass counter-weight and the transducer mass. A spring of the required properties is used as there is insufficient space for the size of balance weight required. The spring is connected between the lower arm and an extension screw on the back-plate. The brass weight and the spring are adjusted until both arms lie reasonably horizontal, no specimen being attached during this exercise. The load required to separate the gauge points is always less than 10 grams and the alteration of load due to the transducer spring during a creep test has been found to be negligible when compared with the applied tensile creep load.

2.3 Attachment of the Extensometer to the Specimen.

The method used for attaching the extensometer to the specimen is of great importance and it is therefore varied to suit the nature and size of the test specimen. The holes drilled in the extensometer arms allow the various attachments to be fitted as required. The attaching devices must not constrain or deflect the specimen in any way and mustnot introduce end effects of any type, as this would remove one of the main advantages of a gauge length extensometer over a device for measuring grip separation. This problem has been considered in detail by Mills and Turner (1965). For rigid plastics, having a thickness and width of not less than 0.25 cm., they found a form of gimbal ring attachment, with forked extensometer ends, to be suitable. Several of these devices have been tested in this laboratory and found to be satisfactory under the conditions stated above, despite the reduced gauge length. The mass of each gimbal was 12 grams. Full construction details have been given by Mills and Turner.

The above authors also describe an attachment for use with low modulus materials such as low-density polythene. However, their method would appear to be unsuitable for use on small gauge lengths. Details of a suitable attachment are seen in figures 2 and 4. The dimensions are not critical provided that the device has sufficient stiffness to resist the small bending and twisting movements that represent an alteration of gauge length. The "gripping" points (6, figure 2) must obviously be exactly opposite one-another and care must be taken when assembling the device, to ensure that the points lie on the centre line of a mounted specimen. After mounting a specimen the Allan screws (5, figure 2) are adjusted until their points just penetrate the specimen surface. Although this new device is theoretically inferior to the gimbal method, because of the rigid extensometer-specimen link, it has been found to be satisfactory in use, providing that care is taken in the initial alignment of the system.

3. The Loading Machine.

The requirements for a tensile loading machine have been discussed in detail by Findley (1962) and Dunn et al (1964). As the general design of the present loading machine is based on that given by the latter, only the main points and major differences will be indicated. Details of the machine built for studies on materials such as polythene are given in figure 3. The slide guide assembly and universal joint are used to ensure that the load is applied axially to the specimen without any transverse or torsional forces. The chain rests on curved lever ends so that the load line does not alter as the lever arm rotates. The specimen hooks (see figure 4) are accurately made and located with their centres exactly on the load line of the apparatus. The specimen clamps and the specimen itself must also be accurately machined. The hooks and clamps for this apparatus are cone-shaped to assist in the correct location of the specimen. The cones themselves are interlocking to ensure that they are attached symmetrically to the specimen. The 2:1 loading lever is pivoted on hardened knife edge bearings instead of ball races as the latter were found to be prone to stiction troubles during creep tests under very low loads (i.e. below 300 grams). A platform, driven by a reversible electric motor at a speed of 0.3 cm/sec., is used for smooth application and removal of the weights constituting the creep load. This has been found to give satisfactory, reproducible loading behaviour on this creep machine.

A stronger version of the above creep machine has been built for use with rigid thermoplastics. However, in contrast, it has been found unnecessary to include a slide-guide assembly, providing the specimens are accurately machined. This has been confirmed in a detailed study elsewhere (S. Turner, 1968, private communication).

4. Measuring Technique.

The movement of the transducer shaft is measured by an electronic control unit, as supplied by the tranducer manufacturers. With this unit, the limit of resolution corresponds to a shaft movement of 2.5×10^{-6} cm. Each transducer is compensated in such a way that the control unit will read the displacement directly in inches for any transducer connected to it. The digital display of the control unit is used when the instrument is balanced by hand. However, for the early part of a creep test an out-of-balance D.C. signal from the control unit is used. This is fed into a digital voltmeter with an integral print-out device. The D.C. output signal is adjusted to give 10 volts for any required decade (i.e. for 10^{-4} inch to 0.1 inch). Automatic timers are used to trigger the voltmeter to read, and print, the D.C. voltage (i.e. the transducer shaft displacement from an initial zero setting) at known times after application of the load.

In order to make full use of the available sensitivity certain precautions have to be taken. The importance of good apparatus alignment and perfectly shaped specimens has already been mentioned. Other precautions are concerned with friction in the apparatus. For instance the slide-guide assembly is highly polished and treated with Rocol anti-scuffing powder, while a vibrator (figure 3) is used to eliminate slip-stick effects in the extensometers themselves.

5. Performance.

In order to establish that the results obtained in using the apparatus were reproducible and free from absolute errors, trials were carried out using specimens machined from materials characterised by I.C.I. Initially the tests were of the 100 second isochronous stress-strain type (see Turner, 1963), the extensometer being used on both loading machines mentioned in section 3. Over the strain range 0.0005 to 0.05 the inter-specimen reproducibility was better than $\pm$ 4% for five P.V.C. specimens and for five polypropylene specimens. The mean of the results for each material did not deviate from the data supplied by more than 5% over the entire strain range. Measurements have also been made for strains as low as 0.00001. However, at this low strain the scatter in results reached $\pm$ 15%. A gauge length of 2.0 cm. was used in all the trials.

The stability of the electronic control unit has been monitored for a period of 6 months using a transducer held firmly in an aluminium block. During the entire test (at constant temperature) the transducer reading did not drift by more than 2×10^{-5} cm. The overall stability of a complete creep rig has been checked by carrying out a creep and recovery test for a period of 38 days. No zero drift could be detected.

The creep apparatus has been used for a detailed study of the creep behaviour of highly anisotropic, low-density polyethylene. A gauge length of 1.25 cm. was used and modulus values as low as 6.0×10^8 dynes/cm^2 were encountered. (See Darlington and Saunders, 1968). The apparatus was found to be simple to operate and reliable in use providing the precautions outlined above were taken.

6. Additional Applications of the Extensometer.

With very little modification, the extensometer described above has been used to measure the lateral contraction of a specimen during tensile creep. It has been used simultaneously with a normal tensile extensometer on a specimen with a gauge length of only 1.25 cm. For this purpose the normal tensile attachments on the extensometer arms are replaced by rigid feelers as shown in figure 4. Brass contact pieces are fitted to the ends of the feelers. These contact pieces are slightly rounded and highly polished, to minimise friction effects as the specimen extends. They rest lightly against the specimen sides; the pressure exerted on the specimen being controlled by the spring on the shaft of the transducer which pushes the shaft against the "upper" extensometer arm. The general arrangement may be inferred from figures 3 and 4.

Exhaustive tests have shown that the presence of the contraction device does not affect the value obtained for the tensile modulus. However the scatter in the contraction results between specimens is greater than would be expected from sensitivity considerations. The scatter is reduced if extreme care is taken, at all stages, to ensure that the extensometers do not upset the alignment of, or bend, the mounted specimen. As the specimen extends during a creep test there is a slight translational movement of the specimen through the brass contact pieces of the contraction extensometer. However, subsidiary tests have shown that this does not appear to affect the results providing the specimen surface is visually satisfactory.

Up to the present time the simultaneous measurement of longitudinal extension and lateral contraction has only been used for comparative studies of creep contraction ratios. In particular, the large variation of creep contraction ratio with angle for highly anisotropic, low-density polyethylene, has been studied in some detail. (See Darlington and Saunders, 1968). The results were extremely promising. A new device for the measurement of lateral contraction (limited to gauge lengths greater than 2.0 cm.) has been built to assist in improving the absolute validity and reproducibility of the contraction device described here.

Although designed primarily for use with creep machines, the extensometers described in this paper should also be suitable for use with constant extension rate machines.

Acknowledgements

Grateful acknowledgement is made to Mr. S. Turner and Miss D. Thomas of I.C.I. Plastics, Ltd., for providing several characterised samples and for many helpful discussions during the development of the apparatus. This work was supported by a grant from the Ministry of Technology.

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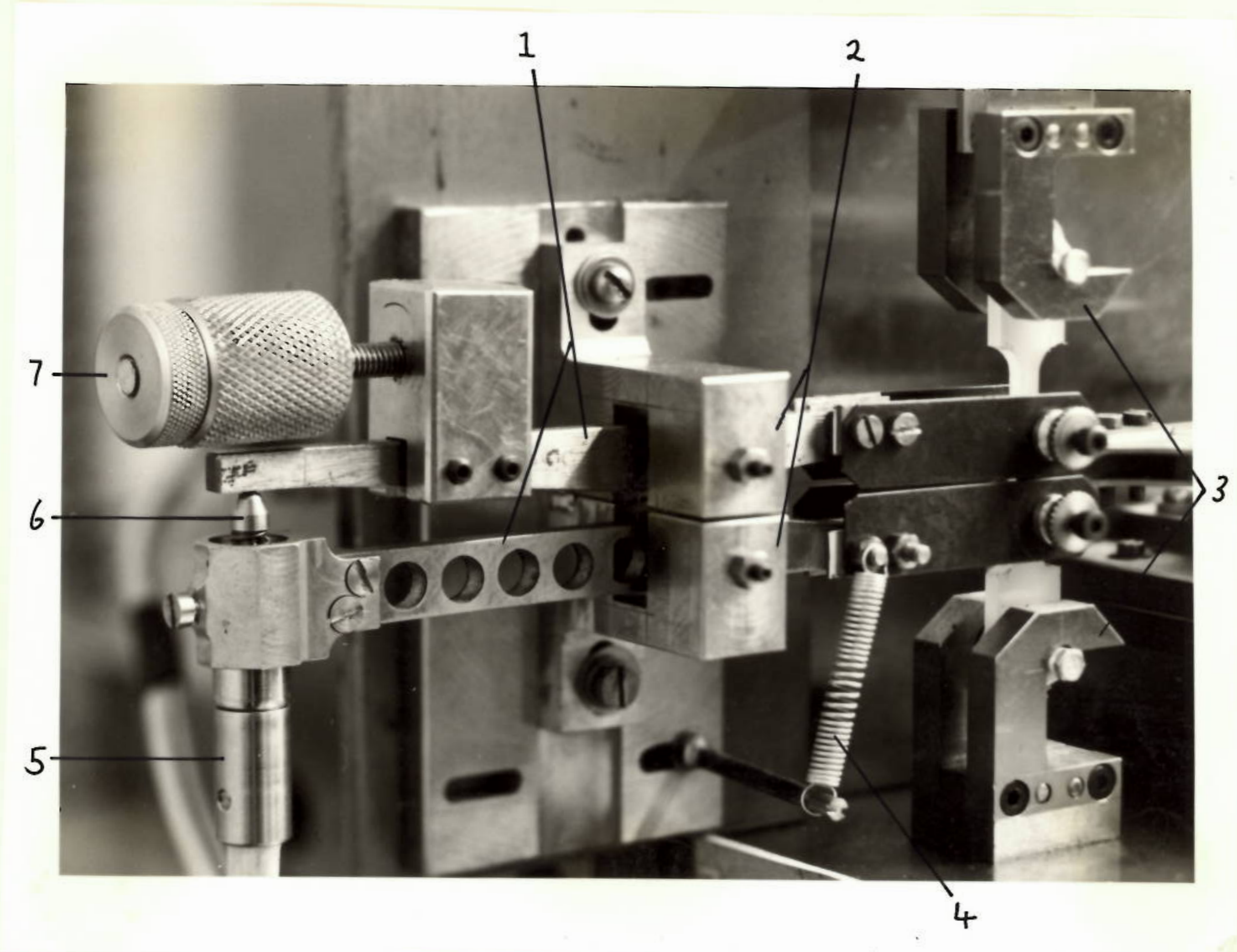

Figure 1 The tensile extensometer shown mounted on a specimen with 1.3 cm. gauge length.
1, extensometer arms; 2, bearing brackets; 3, specimen hooks; 4, balance spring; 5, transducer body; 6, transducer shaft, 7, counter-weight.

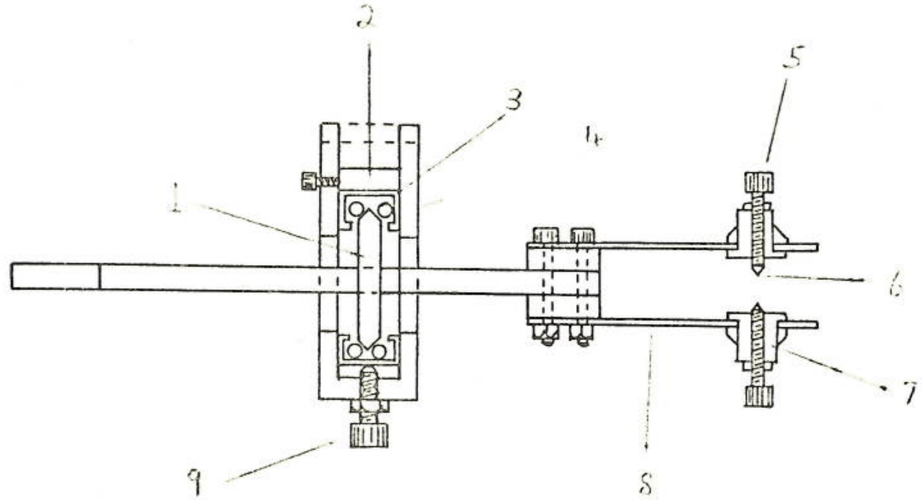

Figure 2

Diagrammatic representation of upper extensometer arm and supporting bracket.
1, rotating shaft; 2, brass plug; 3, solid pivot bearing; 4, bearing bracket; 5, pointed Allen screw; 6, specimen contact point; 7, threaded brass plug; 8, spring steel strip; 9, bearing adjustment screw.

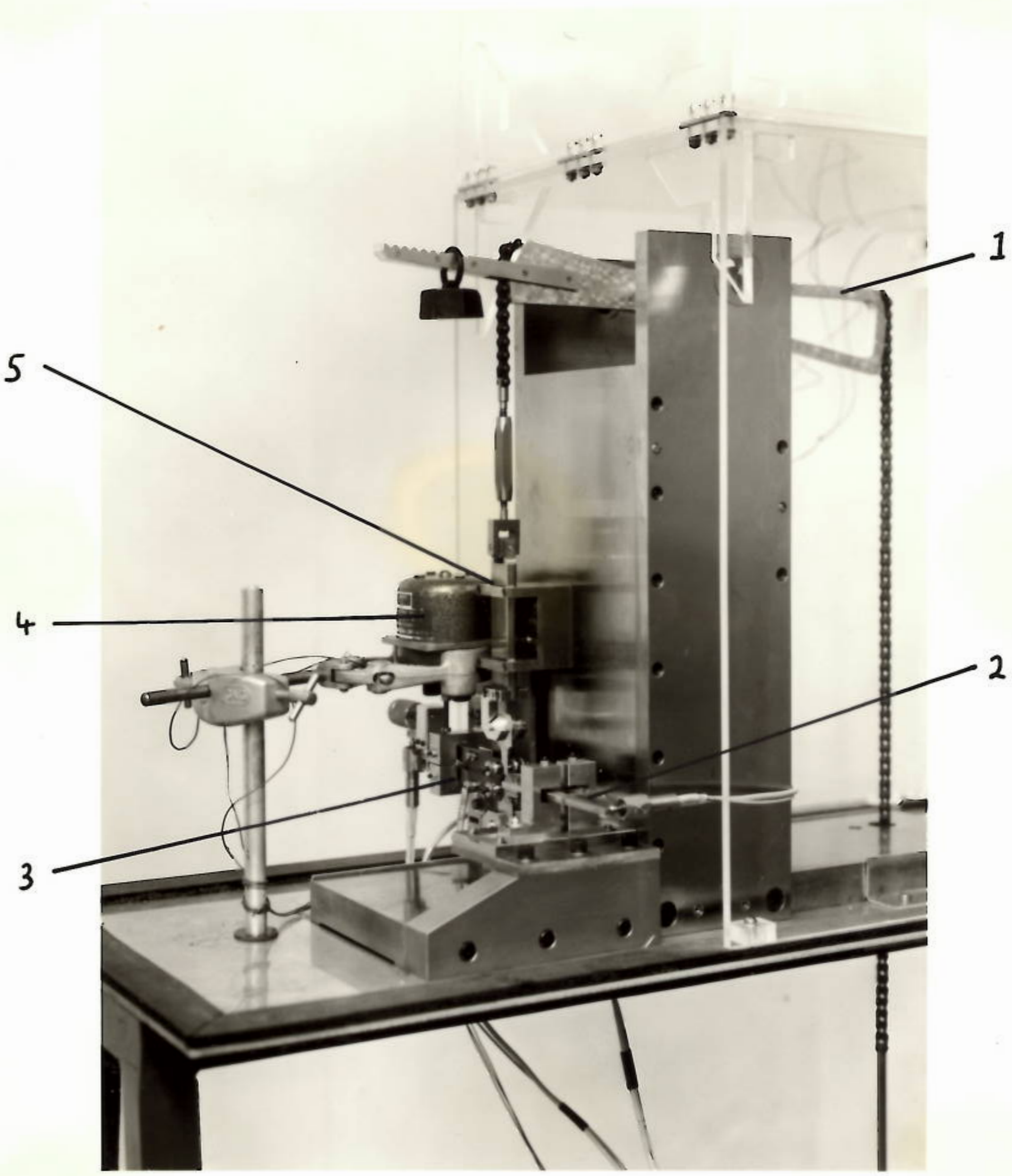

Figure 3 General view of a creep machine with a vibrator on the tensile extensometer.
1, lever loading arm, 2, lateral contraction extensometer, 3, tensile extensometer; 4, vibrator; 5, slide-guide assembly.

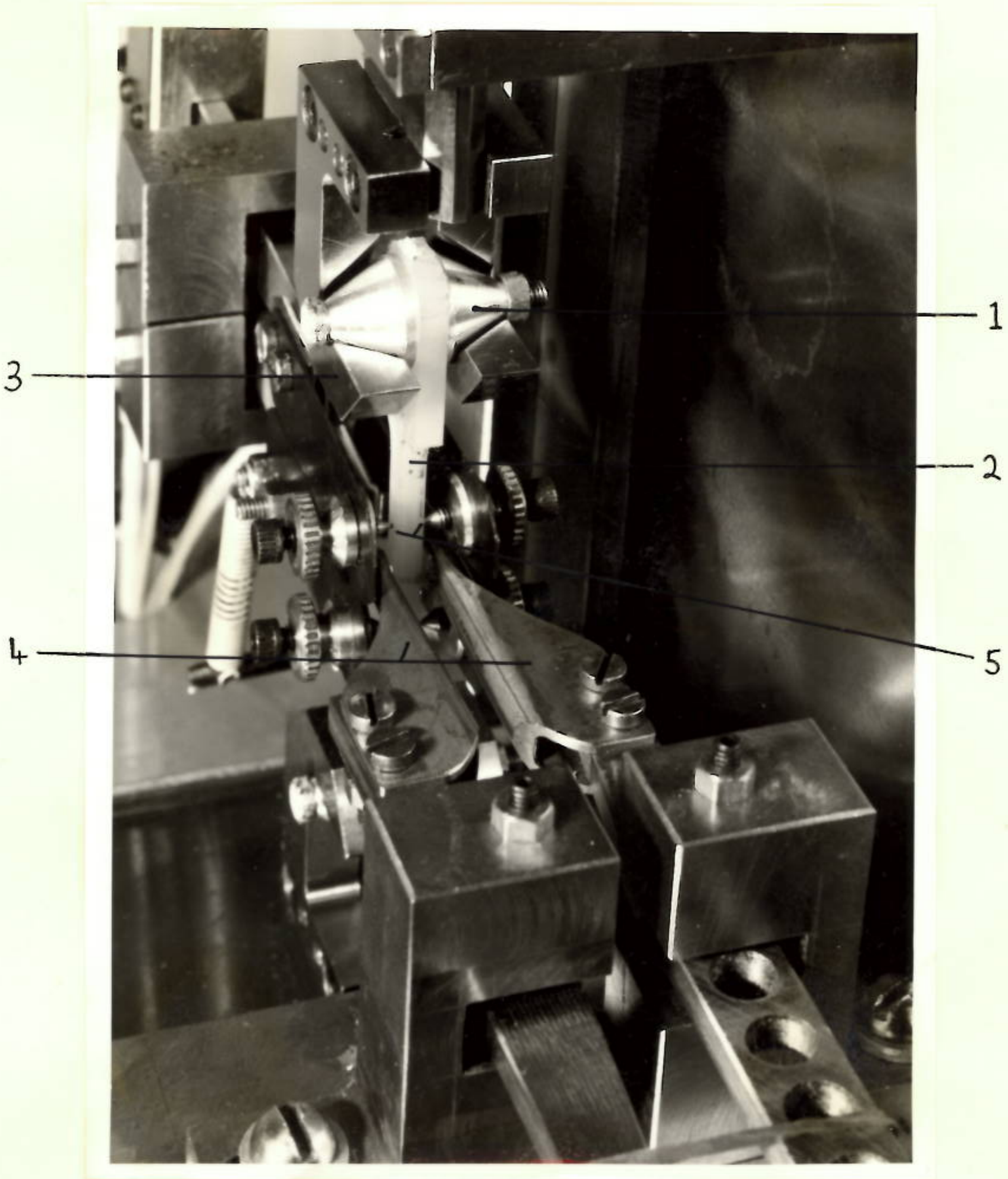

Figure 4 Close-up of a mounted specimen showing the methods of attaching the extension and contraction devices to the specimen.
1, cone-shaped clamps; 2, specimen; 3, specimen hooks; 4, feelers of contraction extensometer; 5, gauge points of tensile extensometer.