stress ratio of $R = 0.01$ [3]. By X-ray back-reflection they found a large variety of orientations. They also found that (1 1 1) facets were relatively flat and showed sets of parallel slip-line markings.

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Received 7 January and accepted 18 February 1977

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A method for measuring cyclic microstrains in both tension and compression

Microstrain tests have been carried out on different materials during the last years mainly to check the validity of current theories of yielding and to have a better knowledge of the behaviour of dislocations moving at low stresses. A review of the possibilities and experimental methods of microstrain measurement has been published by Brown [1].

Most studies of micro-deformation have aimed at measuring the lattice friction stress and the anelastic limit of crystalline solids. However the possibility of comparing the results obtained from microstrain tests with those of internal friction measurements has also been discussed by several authors [2–4]. Some difficulty arises when comparing the results obtained with these two techniques. This is mainly due to the fact that microstrains are usually measured in either tension or compression only. The work of Lukas and Klesnil [5] is the only research known to us where measurements in both tension and compression have been reported.

There are many problems associated with microstrain experiments in single crystals. They have already been discussed in some detail by Cowling and Bacon [6] who proposed at the same time a method to overcome them. Their method, useful for tests in compression only, is based on the introduction of a very high stiffness in parallel with the sample under test which reduces the instabilities usually associated with small loads. A method, useful for tests in both tension and compression, and which is based on an opposite principle is presented in this note.

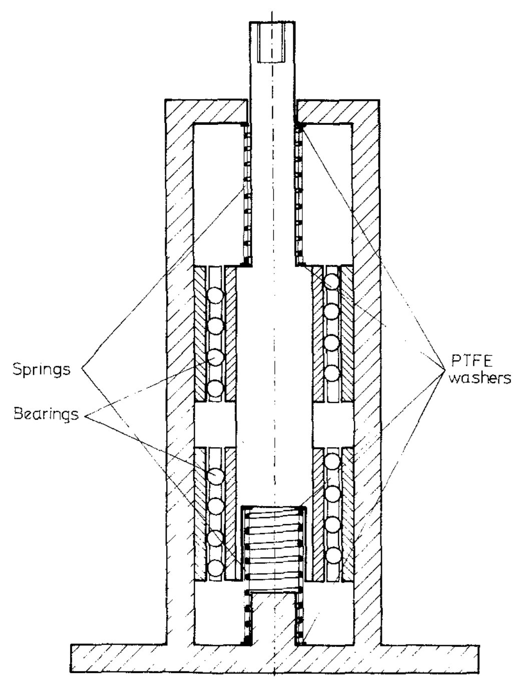

Figure 1 Drawing of the dash-pot arrangement.

A very low stiffness dash-pot is placed in series with the specimen, so that a very large displacement of the loading ram is transformed into a very small load on the sample under test. This technique has been used in conjunction with a servo-hydraulic testing machine which has the advantage over the screw-driven machines of better axial loading and unloading.

Fig. 1 is a drawing of the dash-pot arrangement. A central shaft moves along the line defined by two coaxial low friction cylindrical linear bearings deforming two helical springs, one at each end, which are always under load. The small vibrations in the movement of the shaft are damped by filling the dash-pot with oil. The specimens are inserted, as described later, between the top end of the shaft and the load cell. The dash-pot is mounted on the machine ram. If K is the combined stiffness of the two springs, a displacement of the ram equal to x applies to the specimen a force equal to Kx. If the sample, with Young's modulus E, deforms elastically, the ram displacement x is converted into a specimen elongation equal to

$$\Delta l = \frac{Kl}{ES}x,$$

where S and l are the cross-sectional area and length of the sample respectively. With typical values for the coefficients appearing in the above equation and with $K = 175\ \mathrm{g\,mm^{-1}}$, the movement x of the ram is reduced to a displacement at the specimen end equal to $\Delta l = 3.3 \times 10^{-6} x$. The amount of slip-stick of the ram, the machine vibrations, and any mechanical instabilities are thus reduced by the same factor. The elastic constants of the springs can be adjusted to the optimum value so that perfectly smooth and linear rates of loading are always obtained.

The jig described above has been used for micro-strain measurements in molybdenum single crystals in both tension and compression. The specimens used were of the dumb-bell type and they were prepared by spark machining and electropolishing. They had 5 mm shoulder diameter reduced to 3 mm gauge diameter and gauge length of either 5 mm or 9 mm.

The specimens were held rigidily between the dash-pot and the end of the load cell by means of self-centering collets, as shown in Fig. 2. Misalignment in the movement of the shaft was checked to be less than 0.01 mm over its full range of movement. Each specimen was aligned before testing

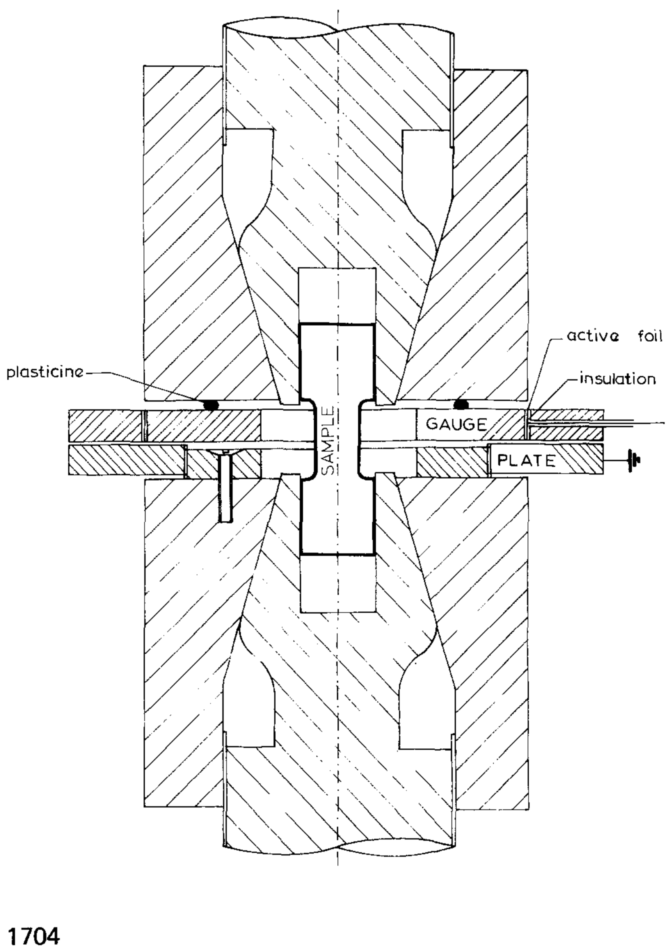

Figure 2 Detail of specimen clamps and displacement transducer.

and for this purpose a dial gauge, mounted on the collet, was rotated on a plane perpendicular to the specimen axis whilst the position of the dash-pot on the ram was adjusted until the eccentricity was less than 0.01 mm.

The strains were measured with a ring capacitance transducer [7], which is shown in position in Fig. 2, and a Wayne Kerr distance meter. The capacitance probe was thin enough to be fitted inside the gauge length of the sample and the sensitivity of the system was $0.3\,\mu\text{m}\,\text{mV}^{-1}$. The transduer ring plate (~ 2 mm thick) was fixed to one of the collets with plasticine. The ground plate, adjustable by means of a thread, was screwed to the other collet. Alignment and parallelism of the transducer plates was achieved by moving the ram and pressing the two plates together; hence the advantageous use of plasticine which remains rigid and stable after a waiting period of 2 h. This period is essential in any case to achieve stabilization of the whole system.

Some of the results obtained at room temperature with this technique are reproduced in Fig. 3a, b and c, which show the $\sigma - \epsilon$ loops obtained with the same sample in tension only, tension–compression, and compression only, in that order and under increasing stress amplitudes. A constant total strain rate of $9 \times 10^{-6}\,\text{sec}^{-1}$ was used for all

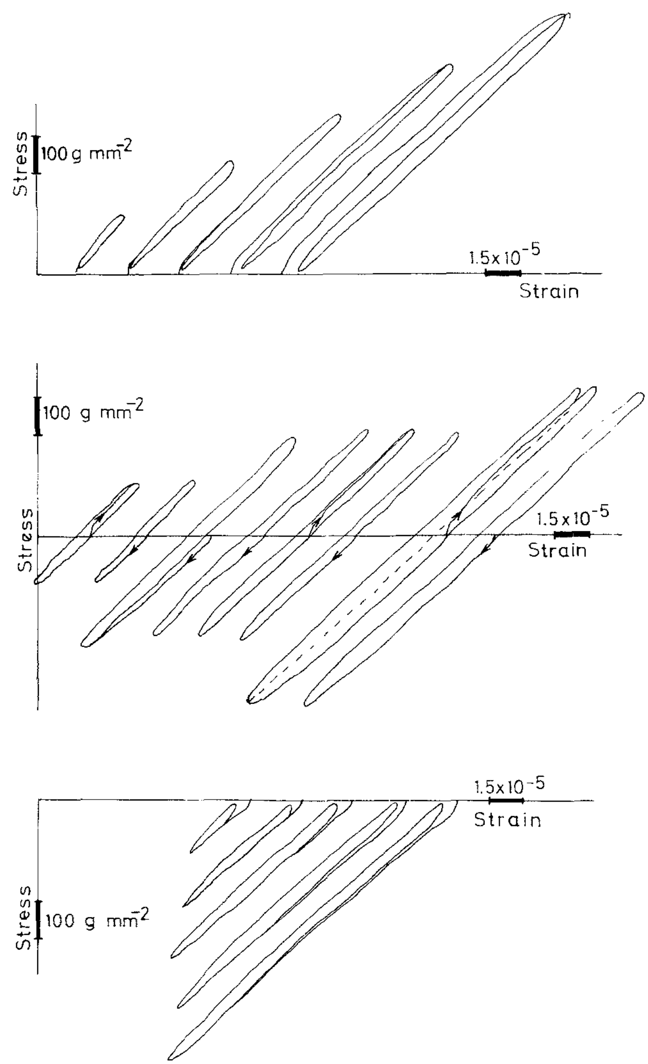

Figure 3 Mechanical hysteresis loops recorded at a total strain rate of $9 \times 10^{-6}\,\text{sec}^{-1}$: (a) in tension only, (b) in both tension and compression, (c) in compression only.

these tests, which were conducted with a specimen pre-deformed in compression at room temperature by about 2%. This specimen had a gauge length of 5 mm only, a fact that emphasizes the high sensitivity of the measuring system.

The results show very clearly features which can be predicted and interpreted from simple arguments of microdeformation [8, 9]. For example, at low stresses the loops may appear closed or open depending, in a predictible manner, on the sense of the previous loading cycle. The loops in the tensile cycle appear open if this cycle has been preceded by one in the opposite sense (compression) whilst they appear closed if it has been preceded by one in the same sense (tension). It follows therefore that a loop in tension–compression cannot have a "butterfly" shape, a fact which was already anticipated by Brown [10] and is clearly shown in Fig. 3b.

The loops are not of purely lenticular shape and they exhibit clearly an initial region with higher slope. The value of this initial slope is 1.7×10^4 kg mm^{-2} or about half the dynamic Young's modulus of molybdenum crystals with this ⟨1 0 0⟩ axial orientation. A change in slope is observed at a stress of about 50 g mm^{-2}. The reason why this initial slope is less than the unrelaxed elastic modulus of the material must be found in the fact that no correction has been made for the elastic shear of the collets where the transducer is attached. In those cases where long specimens are used and where the transducer can be attached to the gauge length of the specimen itself, true values of Young's modulus can probably be obtained. In all other cases, including compression, correction by calibration is required [11]. It is however worth noting that such correction is not always essential because the shape and width of the loops and the residual strains at zero load are not affected by elastic deflection.

A systematic study of microstrain in molybdenum single crystals is now under way and the results reported here are intended only to show the potential of the experimental method described.

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Received 14 January
and accepted 18 February 1977.

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Some factors controlling transverse cracking in cross-plied composites

When a resin based cross-plied fibrous composite is strained in tension beyond a (low) critical strain, a series of cracks form in those plies of fibres aligned with a substantial normal component to the applied stress. Although the cause has been identified as the strain concentration effects of the relatively stiff fibres [1, 2], the factors controlling the spacing of the cracks have not previously been defined. In this note we show that the relationship between stress and crack spacing can be explained in terms of shear-stress transfer from the adjacent longitudinal plies.

When orthogonal cross-plied laminate is stressed along one of the material axes, the strain increases linearly with the stress until the failure strain of the weakest section of the transverse ply is reached. The load carried by the transverse ply is obviously zero at the fracture and the total load must be carried by the intact longitudinal plies. The stress