real materials [1], these properties in compression will probably decline with increasing volume fraction.

References

1. B. R. BUTCHER, *J. Mater. Sci.* 7 (1972) 877.
2. I. L. MOGFORD, *Met. Rev.* **12** (1967) 49.

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B. R. BUTCHER
Metallurgy Division, AERE,
Harwell, Didcot, Berks, UK

A capacitance gauge for microstrain measurement in tension

In the period since 1960 several high sensitivity (i.e. $\leqslant 2 \times 10^{-6}$) strain measuring techniques have been utilized to study micro-yielding in materials. These include resistance [1-3], optical [4] and capacitance [5-7] gauges and linear variable differential transformers [8, 9]. Of these methods, the Tuckerman optical gauge allows a direct reading of strain, while the other techniques require a prior- and post-test calibration. All the techniques require precise temperature control or compensation and are applicable (when mounted on the specimen gauge length) within limited and different temperature ranges. In addition, operation of both optical and resistance gauges is difficult at strain-rates $\geqslant 10^{-3}$ sec^{-1}. Consequently, more than one strain measuring technique may be required, either to obtain microstrain data over a range of temperature and strain-rate or for calibration, and it is desirable to have available two systems which can be mounted interchangeably on the same test specimen. In this note we wish to report a new capacitance gauge design, which has the advantage that it is suitable for use, together with the Tuckerman optical gauge, on the gauge length of a tensile test specimen with a rectangular cross-section (Fig. 1).

The capacitance gauge, which is shown in Figs. 2a and b, consists essentially of a parallel plate capacitor, with an active plate containing a foil ring concentric with the specimen, and a ground plate, which is mounted directly onto the test specimen with spring loaded grips. The active foil is insulated on both sides with a thin layer of Araldite by two guard rings, while the ground plate is seated on a micrometer thread to allow a variation of the initial plate separation. The gauge is connected to a Wayne Kerr DM 100B distance meter by a double shielded cable, with the first and second shields attached to the guard rings and adjustable ground plate, respectively.

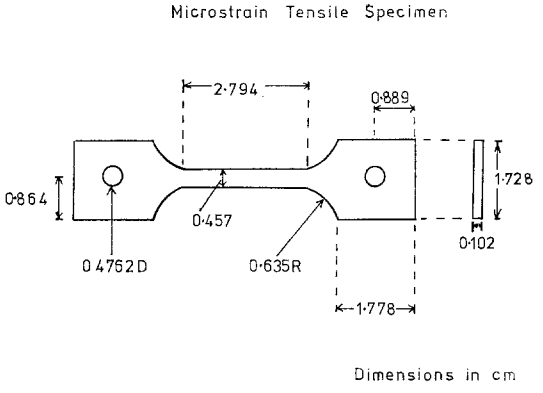


Figure 1 Test specimen for microstrain measurement in tension.

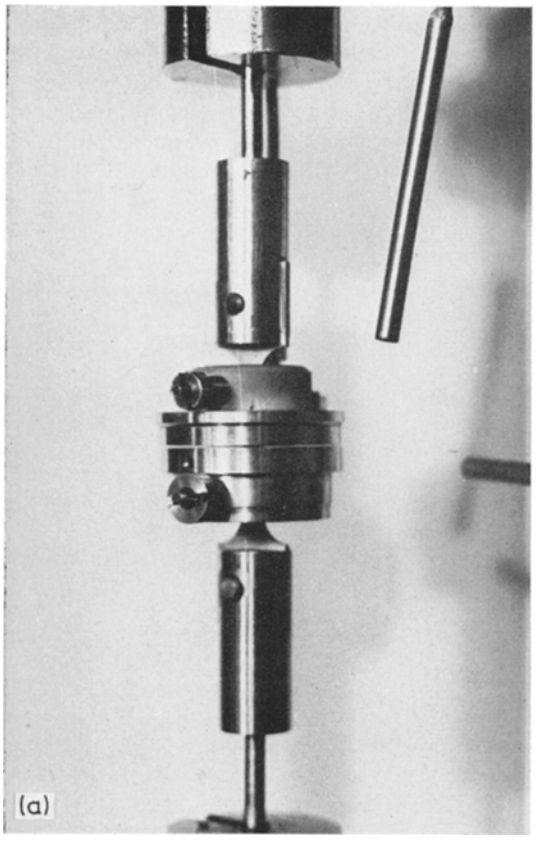
The absolute capacitance (C_g) of the gauge is given by:

$$C_g = \epsilon\pi \frac{Dt}{d} \quad (1)$$

where ϵ is the permittivity of air, D is the diameter of the active foil ring, t is the foil thickness and d is the plate separation. The design of the Wayne Kerr distance meter ensures that, provided $C_g \sim C_m$ (the capacitance of the meter) = 0.35 pF, then the output from the meter is inversely proportional to C_g and, hence, directly proportional to d. Another limit on the dimensions of the gauge is the requirement that $D > 1.67 \times 10^{-2}$ m (the specimen shoulder width). As the variation of C_g with d is given by:

$$\frac{\partial C_g}{\partial d} = -\epsilon\pi \frac{Dt}{d^2} \quad (2)$$

it is also desirable that the initial plate separation (d_0) should be small. The fixed gauge dimensions selected to best satisfy these conditions were $D = 2.25 \times 10^{-2}$ m and $t = 2.5 \times 10^{-5}$ m, which with an initial plate separation (d_0) of 5×10^{-5} m gave a gauge capacitance (C_g) of 0.31 pF.



The Wayne Kerr meter reading was represented on the X-axis of a Bryans X-Y recorder and calibrated against plate separation (d) by increasing d from 0 to 5×10^{-4} m (full scale deflection at a sensitivity of 50 mV cm^{-1}) in increments of 2.5×10^{-5} m (as measured from a graduated ring on the micrometer). The variation of the meter reading with plate separation was linear and reproducible within this range.

The test specimen, mounted with the capacitance gauge, was attached to the load cell and cross head of an Instron testing machine, with the gripping arrangement described previously [4], and the stress output from the Instron amplifier was connected to the Y-axis of the X-Y recorder. After equilibration at the test temperature [4] the specimen was deformed at a constant strain-rate, within the range 10^{-5} to 10^{-3} sec^{-1}, to a given stress level and then unloaded at the same strain-rate. This procedure was repeated for an increasing series of stress levels.

A typical series of load-unload cycles is shown in Fig. 3, which is a photograph of an actual X-Y recording of the microstrain characteristics of a polycrystalline beryllium test specimen. The X-axis has a strain sensitivity of 1.2×10^{-6} per mm of graph paper (recorder sensitivity 0.5

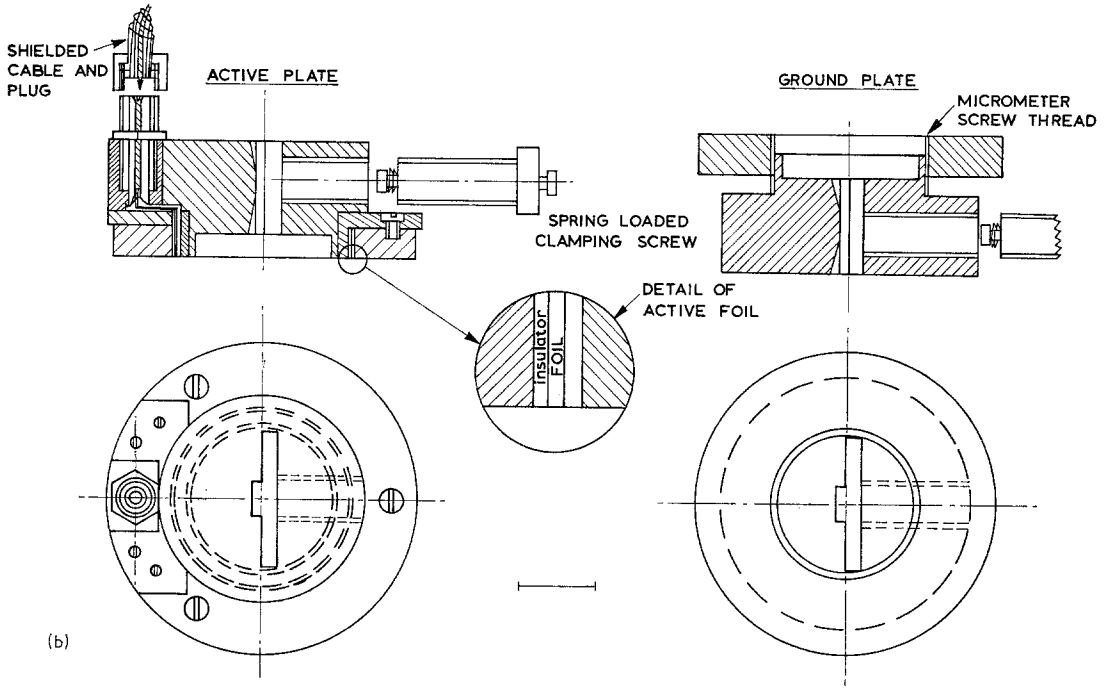


Figure 2 (a) Capacitance gauge mounted on a test specimen. (b) Diagram of gauge construction (scale 1 cm ≡ 2 cm).

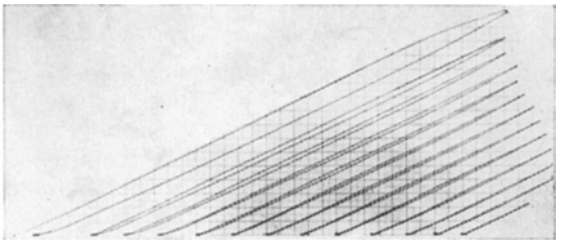


Figure 3 An *X-Y* recording of a series of hysteresis loops for a polycrystalline beryllium specimen deformed in tension at a strain-rate of 3×10^{-4} sec^{-1} at 27°C. (*x*-axis, 1 mm ≡ $1{\cdot}2 \times 10^{-6}$; *y*-axis, 1 mm ≡ 0·61 MN m^{-2}.)

mV cm^{-1}), while the *Y*-axis represents a stress of 0.61 MN m^{-2} per mm. It can be seen that the initial straight line obtained on loading and unloading (on the right of the figure), is succeeded by a series of closed hysteresis loops of increasing amplitude and, finally, by open hysteresis loops (with plastic strain after unloading). Individual loops could be examined in more detail by increasing the recorder sensitivity to 0.2 mV cm^{-1}, at which level a strain sensitivity of 4.8×10^{-7} was obtained.

Alternatively, the test specimen could be deformed in a continuous manner and the stress-total strain variation recorded. Fig. 4 shows a typical result obtained for a compact bone specimen, together with a corresponding measurement taken with a Tuckerman optical strain gauge. It can be seen that there is good agreement (generally within 5%) between the two techniques.

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References

1. R. D. CARNAHAM and J. E. WHITE, *Phil. Mag.* **10** (1964) 531.
2. M. J. COWLING and D. J. BACON, *J. Mater. Sci.* **8** (1973) 1355.
3. W. BONFIELD and E. A. CLARK, *ibid* **8** (1973) 1590.
4. W. BONFIELD and C. H. LI, *Acta Metallurgica* **11** (1963) 585.
5. J. M. ROBERTS and N. BROWN, *Trans. Met. Soc. AIME* **218** (1960) 454.
6. W. BONFIELD and C. H. LI, *J. Appl. Phys.* **38** (1967) 2450.
7. N. BROWN, *Adv. Mat. Res.* **2** (1968) 45.
8. J. D. MEAKIN, *Canad. J. Phys.* **45** (1967) 1121.
9. J. C. BILELLO, *Phil. Mag.* **19** (1969) 583.

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W. BONFIELD
P. K. DATTA
B. C. EDWARDS
D. C. PLANE
Department of Materials,
Queen Mary College, London, UK

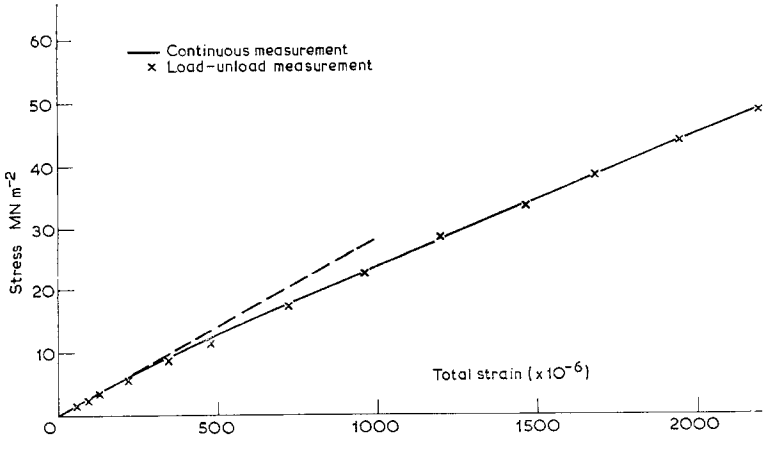

Figure 4 Stress-total strain curves for a compact bone specimen deformed in tension at a strain-rate of 3×10^{-4} sec^{-1} at 27°C, measured with the capacitance gauge (—) and a Tuckerman optical gauge (×). The elastic region is extended (— —) to show the departure from linear deformation.