## Birefringence in Rubbers

It has been shown, both theoretically[1] and experimentally[2,3], that in simple elongation of a sample of a pure gum vulcanizate, an approximately linear relationship between the tensile stress t and the birefringence $(n_1 - n_2)$ obtains, provided the strain is not sufficiently large to produce crystallization. We may write

$$(n_1 - n_2) = Ct, \qquad (1)$$

where C, the constant of proportionality, is termed the 'stress-optical coefficient', and is theoretically independent of the degree of cross-linking (vulcanization) of the vulcanizate and should be identical for all pure rubbers.

Thibodeau and McPherson[3] have shown that the stress-optical coefficient is dependent upon the type of vulcanization. In particular, for gum vulcanized by means of sulphur without accelerators but in the presence of stearic acid and zinc oxide, they found the stress-optical coefficient to depend linearly on the amount of combined sulphur. This dependence upon degree of vulcanization suggests that the sulphur is modifying either the polarizability or the stiffness of the molecular chains of the network. An extrapolation of the linear relation to zero combined-sulphur content has been used by Treloar as a measure of the birefringence of the actual molecular network.
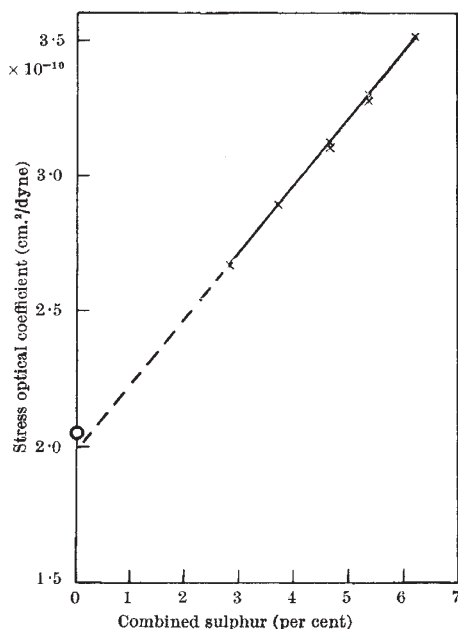
$\times - \times -$, Sulphur vulcanizate (Thibodeau and McPherson); O, peroxide vulcanizate (Saunders)

Recently a vulcanized rubber has been produced which is free from all additions to the rubber; particularly it is free from sulphur. The vulcanization is achieved by a peroxide reaction[4], and all the by-products can be removed, leaving a pure hydrocarbon vulcanizate. It is interesting to determine the stress-optical coefficient for this material and compare it with the results obtained by Thibodeau and McPherson.

The birefringence of a thin strip of the peroxide vulcanizate elongated under a known load was measured using crossed Nicol prisms and a Babinet compensator. The relation between the stress and the birefringence was found to be linear and reversible up to strains of about 100 per cent, and the stress-optical coefficient was $2 \cdot 05 \times 10^{-10}$ cm.^{2}/dyne. This compares very well with the value obtained by extrapolating the results of Thibodeau and McPherson to zero combined-sulphur content.

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[1] Kuhn and Grün, Koll. Zschr., 101, 248 (1942).
[2] Treloar, Trans. Farad. Soc., 43, 284 (1947).
[3] Thibodeau and McPherson, Bur. Stand. J. Res., 13, 887 (1934); Rub. Chem. and Tech., 8, 183 (1935).
[4] Farmer and Moore, unpublished work; but see Gee, Trans. Inst. Rub. Indust., 25, 88 (1949).

Elastico-Plastic Straining when the Principal Stresses Rotate

In recent years there has arisen a controversy, on theoretical grounds[1], on whether post-yield straining of metals should be analysed by considering: (I) plastic increment-strain components only (Levy, about 1870, and Mises later[2]); (II) plastic total-strain components only attained instantaneously (Nadai, 1931 [3]); (III) plastic + elastic increment-strain components (Prandtl, 1924, and Reuss, 1930 [4]); (IV) plastic + elastic total-strain components attained incrementally (Swainger, 1945 [5]). It is shown in this communication that, from experimental evidence, none of these theories is correct; but that a simple modification to my theory in (IV) leads to correct predictions; that is, one must consider (V) plastic increment-strain components + elastic total-strain components attained incrementally.

This step was not taken arbitrarily, but reached from the consideration that continuity of straining-displacement[6] must be assured for a body *as a whole*, and its instantaneous shape under elastico-plastic straining should be the reference for the next increment of deformation.

A searching test of a theory predicting post-yield strain values is given by rotating the principal normal-stress system relative to the substance at a given point in the body. Peters, Dow and Batdorf[7] undertook the test by loading with combined axial compression and torsion on two thin-walled duralumin cylinders. Each cylinder was made to yield by axial compression stress S_{xx}, and then complex rotating stresses were induced by applying axial torsion to induce shear stress S_{xy}. In two tests the axial compression stress was maintained constant while applying shear, and the compression strain e_{xx} allowed to increase correspondingly as the shear strain $2e_{xy}$ increased. In a third test, the longitudinal compression strain was maintained constant while applying shear, and the longitudinal compression stress allowed to decrease correspondingly. The maximum strains were approximately $1 \cdot 6$ per cent compression and $0 \cdot 7$ per cent shear on the classical definition. Dr. Peters was kind enough to send me a copy of the N.A.C.A. paper in advance of publication[7].

Each theory states that the 'principal' directions θ, of the strains it considers, coincide with φ, those of the principal normal stresses in an isotropic sub-