between the strengths of the aluminium alloys used in this study, in which relaxation was not established and aluminium alloys used in previous studies where relaxation had been established[4]. Intermediate values may be possible, but have not been experimentally established. The data of Piacesi[5] can be used to test these groupings.

The observed crater dimensions reported in Tables 1–3 were measured from the bottom of the crater to the original surface of the target. This method may introduce errors, since the spherical projectile literally turns itself inside out as the projectile and target make contact and remain in contact until the final stages of crater formation. The data reported earlier[6] showed that between 3·4 and 10·3 per cent of the projectile remained in the crater and support our theory of projectile-target interaction. The crater lip is, therefore, part of the crater, and contributes to the process of crater formation. In Table 4 we present the observed measurement of the crater depths including the crater lip and the value calculated from the expression $d^3 = mv^2/4\pi S$, using the ultimate tensile strength over the temperature range $+75°$ to $-320°$ F. No correction for relaxation was necessary, which implies that the lip may be part of the surface area under the applied pressure.

ROBERT F. ROLSTEN

5141 Crest Road,
Dayton, Ohio.

ALAN K. HOPKINS

Air Force Materials Laboratory,
Wright-Patterson Air Force Base,
Ohio.

HAROLD H. HUNT

Research Institute,
University of Dayton,
Ohio.

[1] Rolsten, R. F., and Hunt, H. H., Amer. Inst. Aeronaut. and Astronaut. J., 1, 1893 (1963).
[2] Rolsten, R. F., and Hunt, H. H., Spacecraft and Rockets, 351 (May–June, 1964).
[3] Rolsten, R. F., Amer. Inst. Aeronaut. and Astronaut. J., 3, 11, 2149 (1965).
[4] Gehring, J. W., Fourth Hypervelocity Impact Symp., Eglin Air Force Base, Florida, 2, 29 (1960); Eichelberger, R. J., J. Amer. Rocket Soc., 1583 (October 1962).
[5] Piacesi, R. (personal communication).
[6] Rolsten, R. F., and Schmitt, R. A., J. App. Phys., 34, 10, 3010 (1963).
[7] Atkins, W. W., and Halperson, S. M. (personal communication).

PHYSICS

Breaking Energy of Rubbers

RECENT investigations of failure of rubbers and plastics have indicated that hysteresial losses in a polymer are an important factor in fracture[1-8]. This communication reports experimental evidence that the energy density at break of a polymer is simply related to the hysteresis loss in the polymer.

A previously unstrained sample is stressed at a constant extension rate to rupture and the mean value of the rupture load is determined from a number of these measurements. A fresh rubber test piece is then extended under the same conditions until just before rupture, and then retracted at the same rate as was used for extending the rubber. The energy at or near break is determined by measuring the area under the load extension curve, and the hysteresis loss determined from the area between the extension and the retraction curves.

Fig. 1 shows a plot of the logarithm of the energy to break against the logarithm of the energy loss at break for several rubbers, both "not-filled" and "filled" with various types of carbon black, tested at temperatures between $-50°$ and $160°$ C. Results obtained with rubbers swollen in a suitable solvent and some natural rubber and styrene butadiene rubber aged for various periods of time at $100°$ C are included. The data fall on a single curve which can be described by the equation
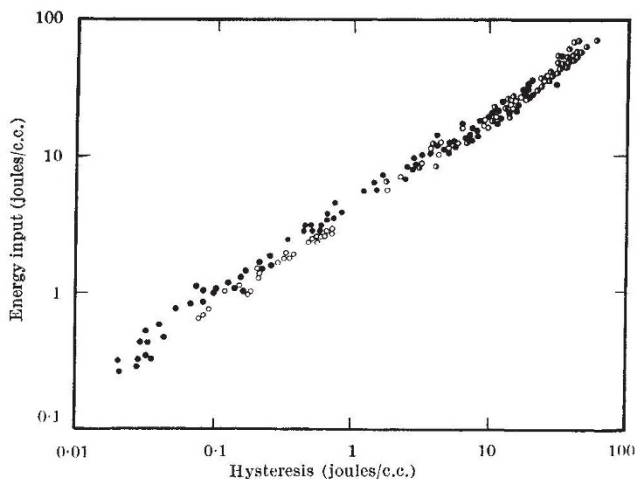
$$E = 4\cdot1\,H^{2/3} \qquad (1)$$

Fig. 1. Energy at break, E_B, versus energy loss at break, H. For natural rubber, isomerized natural rubber, styrene butadiene rubber, acrylonitrile butadiene rubber, butyl and cis-1-4 polybutadiene, both gum (●) and filled with carbon black (◑). Natural rubber and styrene butadiene rubber aged at $100°$ C for 1–7 days. Natural and styrene butadiene rubbers swollen to various degrees with solvent (○). The gum and filled rubbers were tested between $-50°$ and $+160°$ C.

where E is the energy density or work done at break in joules/c.c., and H is the hysteresis loss at break in joules/c.c. Equation (1) can be re-written as

$$E = 69R^2 \qquad (2)$$

where R is the hysteresis loss ratio at break, defined as the energy loss divided by the energy density at break. The simple empirical equations (1) and (2) provide an adequate description of the dependence of E on H or R over about three decades of energy input.

The importance of hysteresis loss in determining the ultimate energy at break of a rubber is now clearly established for various rubbers compounded with a wide range of technological variables such as grade and level of carbon black, and for swollen rubbers; it should also hold for different straining rates by inference from the work of T. L. Smith[1]. Although the two empirical equations (1) and (2) simplify a description of the ultimate properties of a rubber, an explanation of how hysteresis modifies the conditions around a flaw from which failure originates, and its subsequent propagation into the bulk of the rubber, still requires elucidation.

K. GROSCH
J. A. C. HARWOOD
A. R. PAYNE

Natural Rubber Producers' Research Association,
Welwyn Garden City, Hertfordshire.

[1] Smith, T. L., and Frederick, J. E., J. App. Phys., 36, 2396 (1965).
[2] Halpin, J. C., J. App. Phys., 36, 2975 (1965).
[3] Landel, R. F., in Fracture Processes in Polymeric Solids, edit. by Rosen, B., chap. 3 (John Wiley, New York, 1964).
[4] Grosch, K. A., and Mullins, L., Rev. Gen. Caoutch., 39, 1781 (1962).
[5] Berry, J. P., in Fracture Processes in Polymeric Solids, edit. by Rosen, B., chap. 2 (Interscience, New York, 1965).
[6] Mullins, L., Trans. Inst. Rubber Indust., 35, 213 (1959).
[7] Mullins, L., Trans. Inst. Rubber Indust., 32, 231 (1956).
[8] Andrews, E. H., J. Mech. Phys. Solids, 11, 231 (1963).

BIOPHYSICS

Optical Birefringence and Crystallinity of Wool Fibres in Formic Acid

RECENT infra-red and X-ray measurements by Bendit[1] show that the crystalline structure in α-keratin is only partially destroyed by the exposure of the structure to 98 per cent formic acid vapour. The optical birefringence measurements reported here also indicate that considerable crystallinity is retained when wool fibres are placed in 98 per cent formic acid. Measurements were made on