

The Atomic Mechanisms of FRACTURE

A Conference Report by J. J. Gilman and David S. Lieberman

DURING the week of April 12, 1959, an International Conference on Fracture was held at Swampscott, Massachusetts. Plans for it had been in the making for the previous year and a half. Except for the commuting Boston (MIT) contingent, all of the attending scientists were housed most comfortably in the New Ocean House, a North Shore resort hotel of turn-of-the-century elegance on the ocean twelve miles from Boston. Some took advantage of the between-session breaks to walk on the private beach in the brisk 50° brilliant sunny weather, but many never left the hotel during the entire conference. Certainly living so completely together during the entire time of the conference fostered an intensive and extensive interchange of information and ideas which would not have been possible otherwise.

Sponsored jointly by the National Science Foundation, the Office of Naval Research, the Air Force Office of Scientific Research, and the Ship Structure Committee, the conference was under the general direction of the National Academy of Sciences—National Research Council. As indicated by the title, the central theme was “an understanding of the basic atomic mechanism by which fracture occurs in metals, ceramics, and polymers”, and emphasis was placed on “fundamental studies of the basic mechanism involved in cleavage, ductile, fatigue, and high-temperature fractures”.

The conference was divided into two parts. The first part was attended by over four hundred physicists, metallurgists, chemists, ceramists, and engineers from university, industrial, and government laboratories in the United States and nine foreign countries. It consisted of twenty-five invited papers in five half-day sessions beginning Sunday evening. About fifty scientists most active in the field were invited to remain for two additional days to participate in the second part, a closed panel discussion on the state of the art and outstanding problems in the field.

Invited papers (25) were preprinted (over 700 pages)

J. J. Gilman is a physical metallurgist at the General Electric Research Laboratory; D. S. Lieberman is associate professor of metallurgical engineering at the University of Illinois. The proceedings of this conference are scheduled to be published this month (Technology Press—John Wiley & Sons) under the title *Fracture*, with B. L. Averbach, D. K. Felbeck, G. T. Hahn, and D. A. Thomas as editors.

and provided to all registrants in advance. Full proceedings of the conference (including the edited papers, selected discussion, and the recommendations of the working group panel) will be published very soon.

During the first part of the conference each author was allowed twenty minutes to present the essence of his paper. After each set of three papers, written discussion was presented, followed by questions and discussion from the floor. Thus, although spirited, the latter was severely limited by lack of time. Since each registrant had received the preprinted papers well in advance, this unfortunate situation could have been avoided by the use of the rapporteur-summarizing method employed so successfully, particularly in England.

ALTHOUGH the attendance was limited at the panel discussion sessions (Part II) of the conference, the debates were not, and lively jousting occurred between persons of opposing views. About fifty people were in attendance whose interests ranged from the fracture of steel through glasses and high polymers. Three sessions were held: one on cleavage fracture, one on fatigue and ductile failure, and one on high-temperature fracture. A great many points were brought up, of which only a few can be covered here; naturally these will be the ones that excited the reporters' interest.

The great impact of World War II ship failures on fracture studies is still evident, as shown by the fact that the fracture of mild steel was the dominant theme of the session on cleavage fracture. The brilliant work of D. S. Wood has placed the phenomenology of steel fractures on a quantitative basis, so that given the specimen geometry, the yield stress as a function of strain-rate and temperature, and the fracture stress, one can calculate the fracture load in good agreement with experiment. The factors that determine the fracture stress remain uncertain. The promising dislocation mechanism for crack nucleation that A. H. Cottrell proposed some time ago has been questioned theoretically by A. N. Stroh, so it seems clear that clever experiments are needed to identify the nucleation mechanism in steel.

The need for more measurements and understanding of the crack propagation process was emphasized by



Slide shown by E. Parker illustrating fracture and slip in an Mg crystal. (Work done by R. J. Stokes, T. L. Johnston, and C. H. Li of the Minneapolis-Honeywell Research Center.) Photo courtesy *Philosophical Magazine*.

the work of W. S. Owen, et al., on steels and by the beautiful measurements of H. Schardin on crack velocities in glass. The former work confirms previous experiments by J. R. Low which show that microcracks often form early in the fracture process, and that final failure depends on their ability to propagate. Thus more experiments like those of G. R. Irwin should be performed which measure effective fracture surface energies under various conditions, in order to determine the factors that control crack propagation. Cracks in glass travel nearly with the speed of sound but their speeds do not correlate very well with the simplest theory. The theory, due to Mott, considers the speed of longitudinal one-dimensional waves to be the important parameter. O. L. Anderson suggested that variations of Poisson's ratio might account for the discrepancies. H. Kolsky believes that the theory of crack propagation is not sufficiently complete to make a definite prediction as to which combination of elastic constants is most significant.

Some controversy arose concerning the mechanism of ductile fracture; that is, fracture that follows large amounts of plastic flow. There is general agreement that inclusions of "dirt" play an important role in this process by acting as nucleation centers for voids. However, some say that voids can nucleate even if no inclu-

sions are present, some say not. Since theory is powerless in this problem, it will need to be answered by experiment.

Further controversy surrounds the mechanism of fatigue, and N. Thompson reviewed the experiments which seem to bear on the fatigue mechanism. Two schools of opinion exist: first, those who think that degeneration of the material occurs due to the formation of vacancies and other lattice defects at "persistent" glide bands; second, those who think that the "intrusions" which are observed on the surfaces of fatigue specimens are really incipient fatigue cracks. Both schools have good supporting experimental evidence as well as persistent criticisms. Since the various arguments cannot be presented concisely, they will not be discussed here.

C. Crussard presented many intriguing fractographs. These, together with the ones presented by J. R. Low earlier in the conference, show that micrographic studies of fractured surfaces have come of age. This technique can now be used with some subtlety to diagnose fracture phenomena. One observation of special interest is that fractured grain boundaries sometimes show simple crystallographic patterns that strongly resemble the patterns produced by "thermal etching" (of hot silver in the presence of O_2 , for example). Thus, in-



Over 400 scientists attended sessions in ballroom of the New Ocean House, Swampscott, Mass.

ternal thermal etching seems to take place and may significantly affect the behaviors of grain boundaries.

Analogies and differences between the behaviors of metals and high polymers were discussed by A. Bueche. The Griffith-Orowan theory, that is the basis of all fracture discussions concerning metals and glasses, can be applied readily to "glassy" polymers but not to "rubbery" ones (elastomers). The strains in elastomers are so large that Griffith cracks do not exist except at the molecular level, so it seems preferable to discuss these materials in terms of the random breaking of molecular chains.

It will impress the reader of the proceedings how frequently the name of A. A. Griffith appears in almost every paper on fracture and crack propagation. Griffith did his work in the early 1920's and (in a way remarkably similar to the way Freud's name is a point of departure in psychoanalysis) almost every work since that time includes an explanation of how the Griffith theory is or is not applicable and/or why the material used in the experiment does or does not satisfy the proper criteria. The names of E. Orowan and C. Zener are asso-

ciated with important work beginning in the 1940's. The former's inimitable discussions at the conference gave it the proper historical perspective. Today, the emphasis is on the possible mechanisms of dislocation coalescence, crack initiation, and crack propagation. Fracture would appear to be in a position today similar to that of plasticity and the dislocation theory of slip 25 years ago.

Although there is some question about the quality, there is no doubt about the quantity of data on fatigue, crack propagation, etc., which has accumulated. It would appear from this conference that the most promising fundamental studies on fracture are being done abroad while the work in this country has by and large been of an applied or engineering nature. In decreasing order of our knowledge (i.e., our ability to interpret experimental observations in terms of reasonably simple models and mathematical analysis), a material can respond to stresses in a way described by elasticity, anelasticity, plasticity, and fracture. This is (or at least has been from Newton up to the recent past) also essentially the *decreasing* order of physicists' interest and participation.* However, it is of *increasing* order in terms of real materials, the difficulty and magnitude of the problems to be solved, and the importance to our technology. Hence it is gratifying to see physicists becoming somewhat more interested in the areas treated at this conference.

A word of appreciation is due to the chairman, B. L. Averbach, and his committee for arranging this timely and stimulating conference. One hopes that the conference, the published proceedings, and particularly the comments of the working panel and their delineation of the most pressing problems in this field will provoke more physicists to give some thought to the fundamental question of how and why materials fracture.



Left to right: D. K. Felbeck (NAS-NRC), secretary of the conference; B. L. Averbach (MIT), chairman; and A. H. Cottrell (Cambridge), keynote speaker.

* See, for example, comments by C. S. Smith, *Physics Today* 10, 10, August (1957).