Meetings

Fundamental Phenomena in the Materials Sciences

Elucidation of the various mechanisms responsible for fracture in different material was the general subject of the Fourth Annual Symposium on Fundamental Phenomena in the Materials Sciences held 31 January and 1 February 1966, in Boston and sponsored by the Ilikon Corporation of Natick, Massachusetts.

J. J. Gilman (University of Illinois) defined several areas where the incidence of fracture places constraints and limitations on both engineering applications and laboratory studies.

Discussing fracture in viscoelastic media, M. L. Williams (University of Utah) considered the simple case of a spherical flaw in a linearly viscoelastic material, subjected to hydrostatic tension.

Assuming the Griffith criterion in a spherical incompressible medium containing a spherical flaw, the critical stress calculated to enlarge this flaw is in good agreement (~8 percent) with the critical uniaxial stress required to cause fracture at a disc-shaped inclusion. With similar quantitative agreement in the case of cylindrical inclusions, it is justifiable to extend the elastic solution for the spherical flaw to the case of linearly viscoelastic materials. The formalism is established in order that an arbitrary time-dependent load may be inserted into the equations and, thus, a variety of practical problems can be investigated. For certain modes of applied stress, the instability condition can be applied to times $t > t_f$ (the time to failure under a given load), thus permitting a calculation of the velocity of the enlarging surface, at least up to the point where kinetic energy terms (previously omitted) become important. As with fatigue crack growth in metals, the predictions on flaw size in viscoelastic materials show that there are alternate growth and rest periods under cyclic loading.

G. T. Hahn and A. R. Rosenfield (Battelle Memorial Institute) discussed their use of computer techniques and systems analysis in order to relate the individual factors that enter into the overall problem of fracture. In their systems approach, a "structural" member (a physical body subjected to a given loading pattern) with average stresses and strains may be thought of as constituting a subsystem, with the loading pattern being a selected information input. Inasmuch as the stress-strain pattern in such a macroscopic body represents only average values, it is necessary then to examine in greater detail the variations in stress and strains that are a result of various focusing or concentrating agents or flaws.

Finally, where stress concentration results in localized forces which are large enough to promote plasticity and crack formation or both (by one of any number of possible mechanisms), the dissipation of energy by this last factor will then cause, by an ordinary feedback, a reevaluation of the stresses in the neighborhood of the stress-concentrating fault.

As is the case with a systems analysis to any problem, the general variables can usually be defined in a qualitative manner; but useful, reliable, predictive output data can only be obtained once quantitative input data for each of the subsystems have been supplied to the computer.

The problem of fracture in metal composites—fracture initiation and the various modes of failure for a system of brittle inclusions in a ductile matrix—was discussed by J. Gurland (Brown University). The effect of the distribution of brittle inclusions of various shapes on the resultant fracture strength, utilizing different statistical models, was stressed through consideration of the following models: (i) a distribution of strengths among dispersed elements having uniform size and shape; (ii) a distribution in strength of completely connected aggregates, utilizing a "weakest link" mode of failure; (iii) a strength distribution among fibers in a bundle of fibers, where no load is carried by a broken fiber; (iv) a strength distribution of a brittle particulate phase in a ductile matrix, where independent fracture of elements causes failure and the ductile phase acts as a crack-arrestor; (v) similar to (iv) but with parallel continuous fibers where broken fibers still carry part of the applied load. For each of these models, one may derive relations between the most probable strength of the composite and the intrinsic materials constants and standard deviations of the brittle phases.

In discussing the strength of glasses, R. E. Mould (American Glass Research, Inc.) presented the problem of classic fracture propagation, dismissing at the outset the phenomena of delayed elasticity and microplasticity often observed in glass. Confining himself to materials which the layman commonly refers to as "glass," Mould followed the established picture of glass fracture originating at an existing surface flaw in the material. Although this could satisfy all questions regarding fracture of glass, two points, he said, had to be considered in detail: (i) the identification and characterization of flaws which initiate fracture; and (ii) the slow growth of flaws and delayed fracture ("static fatigue").

In reference to static fatigue, it must first be noted that the application of a stress less than the value necessary to result in instantaneous failure will result in a delayed fracture, on the order, perhaps, of a few milliseconds. Inasmuch as delayed fracture is not observed at low temperatures (~77°K), it is instructive to plot the ratio of applied stress to instantaneous fracture stress S^* against the reduced time to failure T^* where $T_{1/2}^*$ is the time to failure for $S^* = _{1/2}$ and is also called the characteristic duration. The curve of S^* plotted against $T^*_{1/2}$ is essentially a single "universal fatigue curve" for a large number of specimens abraded in the same manner.

R. J. Stokes (Honeywell) discussed fractures in ceramics, consolidating much of his own work on dislocations, plastic flow, and associated phenomena in MgO, including both static and dynamic behavior of ionic solids. The presentation was generally divided into three specific areas: (i) definition of different degrees of brittleness in ceramics, in terms of the mobility and maneuverability of dislocations; (ii) an indication of the origins of brittleness; and (iii) suggestions on reductions of brittleness. In summarizing the situation with ceramics, he suggested several techniques to improve fracture resistance in the various classes of brittle materials. Since completely brittle ceramics fracture in a manner similar to glass, a reduction in flaw size and density is necessary. Improvements in semibrittle ceramics may be obtained by increased ductility or strength. Solid solution and precipitation hardening have been attempted, but grain size refinement and elimination of porosity appear to be the best avenues of approach. Finally, improvement in the ductile fracture resistance at high temperatures implies an improved creep resistance. At present, he said, it appears that high density polycrystalline ceramics containing a second phase may provide the most satisfactory properties.

In an analysis of the brittle-to-ductile transition in polycrystalline metals, T. L. Johnston (Ford) placed major emphasis on factors related to the plastic resistance associated with grain boundaries and the effects of plastic anisotropy. Utilizing a generalized form of the Griffith criterion, he said it can be readily shown that several individual factors may be made reasonably quantitative and that the nature of plastic response can be predicted. Specifically, it can be shown that a critical factor relates to the length of a plastic shear zone which is constrained by an elastically loaded matrix. As this length increases, the Griffith inequality is satisfied and brittle failure occurs; however, the use of decreased grain sizes or the refinement of dislocation or twin distribution can further tend to "homogenize" the plastic flow and to decrease the magnitude of the shear zone. Of considerable importance in the consideration of plastic resistance is the availability of favorably oriented slip systems in an unsheared crystallite. This factor takes a semiquantitative form in the expression of the Von Mises criterion, which states that plastic deformation of a polycrystal will proceed with relative ease if each grain possesses five independent slip systems. In the case of hexagonal-close-packed lattices, for example, if slip is confined to basal slip, each grain will have an average of two systems, so that the grain boundaries will serve as effective barriers for plastic flow and brittle fracture may result. He demonstrated that if the product of applied tensile stress, grain size, and plastic shear resistance reaches a value proportional to modulus and surface energy, brittle fracture will result. Similarly, the appropriate variation (in temperature) with any of these "intrinsic" variables will provide a situation where the material is ductile as would be the case where high temperature promotes the ease of cross slip and an attendant decrease in grain boundary resistance.

N. S. Stoloff (Rensselaer Polytechnic Institute) reviewed the effects of solutes on the fracture behavior of metals, discussing the influence of various alloy additions on the different factors entering the expression of the fracture criterion. He said that a detailed study on such a problem is complicated from the outset, since it may be difficult to isolate individual parameter changes because a given alloying element can produce multiple (and sometimes competing) effects. However, since there has been considerable research in this field, several general conclusions can be drawn. It is clear that the Cottrell-Petch theory of fracture, including modifications to take into account slip character, provides an adequate qualitative picture of alloying effects, but it is not yet possible to unambiguously predict the influence of a given solute on the transition temperature of a base metal.

In his discussion of tensile failure, C. J. McMahon (University of Pennsylvania) emphasized the role of microstructure and the mechanisms of crack initiation and propagation. For brittle fracture, he demonstrated that the probabilities of both initiation (P_i) and propagation (P_p) must contribute to the total fracture probability, and that these factors may affect properties to widely differing degrees. For example, in iron-containing carbides, cleavage microcracks can be nucleated readily at low stress by carbide cracks, but fracture will not occur (except at very low temperatures) until P_p has been raised by work hardening. Here P_p controls fracture. In the case of polycrystalline and single crystal chromium below the ductility transition temperature, it has been demonstrated that fracture is very definitely initiation-controlled and that large ductility can be achieved by rendering potential crack sources inoperative.

S. Sternstein (Rensselaer Polytechnic Institute), in a discussion of fracture in polymeric materials, noted the differences between values of the surface energy calculated from "first principles" and those determined experimentally from an application of the Griffith criterion. The main conclusion from a series of experiments on controlled crack formation and propagation relates to the fact that the "crack size," as normally considered in the Griffith relation, must be modified. Previous work had suggested that the excess values of surface energy (sometimes high by a factor of 100 to 1000) might be rationalized in terms of a thin layer of plastic deformation or reorientation near the fresh fracture surface. However, this assumption, he said, is inconsistent with what might normally be expected in an examination of the temperature-dependence of the surface energy. Sternstein and coworkers have, on the other hand, determined that the discrepancies observed can be rationalized in terms of a crack-tip size which is modified by a parameter dependent on the history of the crack. For example, they have shown that where cracks are introduced into polymers at different temperatures and then the polymers are fractured at the same temperature, the fracture characteristics are markedly different.

Superposed on this "static" behavior, it is important to consider the dynamic effects observed in the fracture of polymers, and the related fact that the size of the region around the crack tip will depend, in part, on the rate at which the crack tip grows. Thus, there is a cyclic problem: the size of the region at any instant will govern its growth at that instant, but the growth will in turn determine the ability to grow in the next instant of time, since the stress-concentration factor will be changing with time. He concluded that, in general, the rheological response of the material will be linked to the ability of the material to undergo a plastic deformation and that this link is achieved through a time-dependent stress-concentration factor.

Bernard Rosen (Southern Research Institute), continuing the discussion of failure in polymeric systems, spoke on homogeneous fatigue processes, in particular, the salient micro-failure habits of a class of polymeric bodies that are both fully amorphous and soft. These supercooled liquids are taken as being composed of long and linearly-chained molecules, including unvulcanized rubbers, synthetic leathers, and soft organic glasses. Through a qualitative description of the effect of tensile forces on the reorientation of long chain molecules, he discussed models which may account for "work-hardening" and optical and mechanical anisotropies in polymers. An interesting consequence of this analysis is the observation that it can be easier to initiate a new crack than it is to propagate an already existing crack.

Turning to what is termed "homogeneous submicrocavitation," he pointed out that two types of analyses may be attempted: a consideration of a solid body complicated by liquid-like responses (the approach chosen by Sternstein), or a consideration of a liquid body complicated by solid-like responses (Rosen's choice). The model is developed through the introduction of a cavitation process (the existence of which has been supported through permeation experiments) which produces exceedingly small voids within the matrix. The subsequent failure may occur through either of two mechanisms: (i) a dense population of such cavities, or (ii) the presence of a few independent cracks. Whether one of these mechanisms dominates will depend strongly on the period of loading and the time required for relaxation. Rosen carried the argument, again in a qualitative sense, to the description of slipping of chain-like molecules and primary-bond scission of chains, thereby building a "molecular plane of reasoning" to obtain a self-consistent, though still qualitative, description of the flow and fracture of soft polymeric bodies.

In addition to the formal papers presented at the conference and the question-and-answer periods, two highly informative panel discussions, held in connection with the general considerations of fracture in a variety of different solids, provided a deeper insight into the limitations imposed when one attempts to translate one disciplinary approach to another field, while at the same time providing an atmosphere in which it was possible for the various backgrounds—metallurgy, ceramics, physics, chemistry—to supply "hints" to the solution of old problems.

The proceedings of this Fourth Symposium on Fundamental Phenomena in the Materials Sciences, including the papers presented, the question-and-answer periods, and the panel discussions, will be published by Plenum Publishing Corporation, 227 West 17 Street, New York 10011.

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