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DYNAMIC FAILURE MECHANICS OF MODERN MATERIALS—A SUMMARY OF THE LAST DISCUSSION SESSION

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The focus in the concluding discussion session, as in the conference overall, was on the dynamic failure of engineering materials, in the form of either dynamic fracture or localized deformation processes which are precursory to fracture. Such processes are central to a range of physical systems, for example, rupture of pressure vessels or natural gas transmission pipelines, high speed metal forming, explosive loading on a ship hull, meteor impact on a satellite casing and rapid deformations in the earth's crust, to name a few.

In the traditional approach to fracture of engineering materials, based on fracture mechanics, the constitutive behavior of the material and the fracture behavior have been treated separately. The fracture behavior of a material has been described in terms of a fully formed dominant crack, and the process of fracture has been understood to mean the extension of that crack. With this point of view, the mechanical response of the bulk material to applied stress is described pointwise by a local constitutive equation, whereas the tendency for the material to fracture is expressed through a *separate* postulate on material behavior involving a crack tip field characterizing parameter such as the stress intensity factor, the J-integral or a local deformation measure. This approach has been hugely successful in characterizing the fracture resistance, either brittle or ductile, of a host of engineering materials under quasi-static monotonic loading conditions. It has provided the cornerstone concepts for fatigue crack growth, and it has also been central to the development of dynamic fracture mechanics.

There are a number of important issues, however, which have defied understanding within the context of fracture mechanics. In broad terms, among the issues in this category are crack formation or nucleation, crack path selection, the role of material microstructure in macroscopic fracture response, material instability in the form of plastic strain localization, and the competition among possible separation mechanisms which are operative within a fracture process zone. Progress has been made on these issues within the past few years, as represented by the presentations at the conference.

The discussion took place against this background; it ranged over a number of relevant topics and, within each topic, over a number of perspectives. The issues can be summarized in the following way (with the order being more or less opposite to the order in which the issues were introduced into the discussion). The central goal of work in this area is a framework for predicting the mode of failure of a structural component subjected to dynamic loading, as well as for improving the failure resistance of that component through material selection or configurational alteration. The development process includes (i) experiments which are designed to isolate the possible failure modes and which are "interpretable", that is, they readily admit an association of the evolution of a failure mode with the prevailing conditions of loading, geometry and temperature; (ii) analytical simulations which incorporate the essential character of the material and which are designed to provide a framework for *quantitative* assessment of the phenomena observed in the experiments, and (iii) experiments which are designed to provide a constitutive description of the material over the full range of temperature strain and strain rate anticipated in the failure process.

While that description seems to be logical and relatively simple, it is in fact beset by a variety of demons, as noted by many participants. Some of the concerns and reservations expressed about each of these aspects are noted below.

Item (iii) above was commonly interpreted as being nominally homogeneous deformation of a material sample, at a predetermined temperature, to strains as large as those occurring in the failure mode envisaged in a way which permits direct measurement of applied stress. There are two fundamental problems to overcome here. One is that the deformation frequently departs from the desired homogenous deformation by the failure mechanisms which motivate the work. For example, a high strength steel which exhibits failure by propagation of an adiabatic shear band involving strains on the order of unity, can be deformed homogeneously only to strains on the order of 0.03 in a Kolsky bar, at a strain rate of 10^3 per second. The second difficulty is that the expectation of a homogenous deformation tacitly presumes that the material is without an intrinsic length scale. While this is sometimes acceptable, it has been established that a number of failure modes are very sensitive to material microstructure with length scales on the order of tens or hundreds of microns.

Computational simulation studies of dynamic failure phenomena are playing an ever more central role in studies of the processes, due in large part to the availability of computing resources and the accumulating experience at doing simulations. As pointed out by several participants, for this approach to be successful, it is essential that simulations be based on proper constitutive descriptions relating stress, strain, strain rate, temperature and possibly internal variables characterizing microstructural features. The essential ingredient, however, is that the assumed material response must admit the possibility that the deformation can localize or that the material can lose the capacity to transmit traction. It is this feature that obviates the need for *separate failure criteria*. This is particularly interesting for materials in which several mechanisms compete, with the predicted failure mode being established by the mechanics of the process. This brings the simulation to the point of representing the physics of the process in a realistic way. Incorporation of these features into a simulation which also represents realistic loading and geometrical features continues to be a great challenge due, in large part, to the need to resolve features on length scales ranging over several orders of magnitude, from the structural to the microstructural. A number of participants commented that it seems as if simulation studies have begun to capture the essential features of the processes observed.

There was general discussion on the types of experiments involving dynamic failure which should be conducted. Some participants favored "clean" experiments which isolate to some degree the phenomenon of interest and which permit relatively unambiguous quantitative evaluation, while others favored experiments involving the complexities of practical engineering systems, such as complex geometries, welds or other joints, and three dimensional deformations. Valid arguments were given in support of each point of view, and perhaps these perspectives should be viewed as complementary rather than competing.

The discussion concluded with consideration of the question, posed by a participant, of who it is that decides which ideas or issues are worth pursuing in the area of dynamic failure mechanics. Again, several views were expressed. For example, it was suggested that perhaps the members of the research community should agree to focus on a fairly narrow class of issues until there was some consensus view that the important questions had been answered. This would allow the community to set its own agenda. Others argued that the direction of the area should be set by outside influences, primarily through identification of the barriers to development of current engineering systems, but no natural vehicle for doing so was proposed. Yet other participants expressed the view that the principal function of the research community is to work toward fundamental understanding of phenomena. No consensus was approached on this topic, and the answer may ultimately be dictated by national policies beyond the control of the research community.