Summary

The papers in this volume are basically of three types: papers that are concerned with testing techniques both from a theoretical as well as an experimental point of view; those concerned with the application of these techniques to particular brittle materials; and papers dealing with the use of fracture mechanics techniques to predict the fracture behavior of actual components.

The first two papers are concerned with the double torsion technique. This technique is particularly important because it represents a test configuration in which stress intensity is independent of crack length. This technique is widely used for determining fracture mechanics parameters of ceramic materials and is particularly useful at elevated temperatures because crack growth parameters can be obtained without the need for actually viewing the crack. In the first paper, Fuller discusses the assumptions made in the analysis of the double torsion specimen regarding the crack profile, the deflections beyond the crack tip, and possible influences of side grooves in the specimen, to guide the crack. He describes possible consequences of the invalidity of the assumptions, since many of these assumptions have yet to be proved for different specimens geometries. Pletka, Fuller, and Koepke discuss the procedures for actually conducting subcritical crack growth tests using the double torsion specimen. They recommend a particular specimen design for collecting valid data and discuss the precracking procedures needed to obtain good data. They show that the validity of the constant K_I conditions may be affected by the interaction of the crack with the microstructure.

The notched bend test is another widely used procedure because of the small specimen size, making it quite useful for examining experimental quantities of brittle materials. Bansal and Duckworth discuss the use of the notched bend technique to obtain both critical fracture toughness as well as work of fracture data on glass and ceramics. They point out the importance of the way in which the notch is introduced on the value of K_{Ic} that is obtained. They also show that notched bend test data can be significantly different than data obtained by other fracture mechanics techniques as shown by the findings of several investigators. Microcracking or residual stresses were suggested as being possible reasons for this difference. Flaw size microstructure interactions also may be a significant factor.

The double cantilever beam technique continues to be used extensively to obtain K_{Ic} as well as crack growth data in many varieties of brittle materials. Fourney and Kobayashi report on the effect of the loading system on crack jump lengths in a double cantilever beam system. Stress intensity factors were determined as a function of crack velocity in a birefringent polymer using high-speed photography of the isochromatic fringe patterns associated with the propagating and arresting crack. The stiffness of the loading system was shown to have an important effect on the crack propagation parameters for this material. In another paper, Champomier compares double torsion and double cantilever beam measurements of K_{Ic} as well as crack growth rates in glasses. Although he obtains equivalent values of K_{Ic} from the two techniques, he finds discrepancies in crack velocity-K_I curves obtained by the techniques. Possible reasons for these discrepancies are discussed. Barker discusses a modification of the double cantilever beam configuration in the recently developed short rod and short bar specimens. He presents K_{Ic} data for aluminum, alumina, and fused quartz that is in good agreement with that obtained by other experimental techniques.

One recently developed fracture mechanics technique involves the use of a hardness indentation to provide a well characterized flaw which can then be propagated to failure. Unlike other fracture mechanics techniques, this flaw is of the same size as the microstructure and is similar to flaws in actual components. Petrovic and Mendiratta discuss both the advantages and disadvantages of this controlled flaw technique. In their procedure a crack is introduced into a test bar using a hardness indentor; the bar is then fractured in bending; K_{Ic} is calculated from the fracture stress and the measured size and geometry of the initial crack introduced during indentation. Problems associated with the technique such as residual stress effects, flaw healing, etc., also are discussed. Petrovic and Mendiratta show that localized residual stresses due to the indentation are the most serious problems but that these can be eliminated by polishing off the indentations or annealing in vacuum. A variation of the controlled flaw technique uses the indentation process itself and the flaws it produces to determine fracture toughness. Two primary advantages of this variation are that only small amounts of material are required for testing and point-to-point variations in properties within a specimen can be determined. In the paper by Marion, the author examines effects of indentor geometry and specimen surface preparation on the fracture toughness measured by the indentation technique. Tests were performed on both polycrystalline ceramics and glasses. He concludes that one should use a Vickers indentor and fast loading rates in order to minimize effects of subcritical crack growth. The use of large loads reduces surface effects including residual stresses. Good correlation with other techniques for low toughness materials is obtained but the correlation between K_{Ic} values in higher toughness materials such as alumina (Al_2O_3) is not as good. Evans examines the basis for the use of indentation techniques to determine the fracture toughness of brittle materials. He derives expressions relating the formation of cracks under a hardness indentation to both the hardness and fracture toughness of the material, and shows the relationship between the fracture toughness and both the crack and indentation sizes formed on the surface. He shows that K_{Ic} can be determined from the size of the crack seen on the tensile surface without the need for fracturing the specimen as in the other indentation technique just discussed. Evans also shows that the relationship between K_{Ic} and indentation size seems to be valid for a wide range of materials, but the precision to which K_{Ic} can be obtained by this techniques has not yet been established. He also suggests that this technique might be used to obtain a measure of the residual stresses in a surface. Both Marion and Evans suggest that the indentation technique provides a good relative ranking of the fracture toughness of materials.

The final paper in the section on test procedures deals with an indirect method of obtaining fracture mechanics information by fracture surface analysis. Mecholsky and Freiman show that the features formed on the fracture surfaces of brittle materials are quantitatively related to both the fracture stress and the fracture toughness of the material and describe the experimental procedures for obtaining reproducible results. They point up that microstructural and residual stress effects must be accounted for in the determination of K_{Ic} by a fractographic technique and examine effects of combined K_I and K_{II} loading on fracture.

The next three papers emphasize the use of fracture mechanics techniques to study the fracture behavior of various brittle materials. Buresch reports results of K_{Ic} measurements on a number of aluminum oxide bodies using the notch bend test. He shows that only specimens having a certain thickness and notch root radius give a valid K_{Ic}. He suggests that the required geometry is related to the grain size of the alumina and invokes the concept of a process zone to explain the results. Microcracking is proposed to occur within this zone. He suggests that the ratio of the process zone size to the specimens thickness is important for the determination of K_{Ic}. He also shows that the grain size can be important in establishing the value of fracture toughness for a particular material.

Schmidt and Lutz conducted fracture toughness tests on Westerly granite, a material used frequently as a model for brittle rocks because of its fine grain, homogeneous nature. They used both direct tension and compact tension specimens comparing K_{Ic} and J_{Ic}. J_{Ic} data indicates the validity of the K_{Ic} measurements despite observed nonlinear inelastic behavior. They find that K_{Ic} is insensitive to changes in specimen thickness ranging from 13 to 103 mm.

Naaman and Shah discuss the various fracture toughness tests techniques applicable to cement reinforced with steel fibers. This material behaves as a composite rather than an homogeneous material. The authors could not come to a conclusion regarding the validity of any one particular test and made no recommendations as to which test might be the best.

The final paper in this volume deals with the use of the fracture mechanics obtained by various test techniques for the prediction of failure of components in service. In this paper, Wiederhorn and Ritter discuss the use of fracture mechanics data to predict time to failure of ceramic structural components, through knowledge of the subcritical growth of intrinsic flaws. By assuming that crack growth follows a particular form, they are able to derive expressions for the probability of failure of a material in service given knowledge of the crack growth parameters, and the initial flaw size distribution. The use of proof testing to guarantee lifetimes also is discussed. They show that while theory and experiment agree quite well for some materials such as glasses, and some aluminum oxides, in others, agreement is not very good. In some cases, three different test procedures for determining crack growth parameters do not give self consistent results. The authors point out that the crack size and microstructure of the material have a significant influence on the values of the fracture mechanics parameters that will be applicable to the prediction of lifetimes.

In summary, while this volume cannot be considered to contain references to all of the various techniques used to measure fracture mechanics parameters of brittle materials it does provide a reasonable state-of-the-art review of many test procedures, as well as the use of fracture mechanics principles to determine the strength of these materials and to predict their behavior under long term loading. It is hoped that this volume will provide a basis for further experimentation and development of test techniques as well as increasing our understanding of the mechanism of brittle fracture.

S. W. Freiman

Fracture and Deformation Division, National Bureau of Standards, Washington, D.C. 20234; editor.