Summary

The papers contributed to the 13th National Symposium on Fracture Mechanics cover a wide range of topics. Approximately 35 percent of the papers deal with the subject of fatigue crack propagation in engineering materials. These fatigue-related papers cover subjects such as variable-amplitude loading, residual stresses, overloads, crack closure, hold time, and temperature. In addition to the papers on fatigue crack propagation, approximately 15 percent of the conference papers deal with the calculation of stress-intensity factors for various crack geometries and an additional 15 percent deal with elastic-plastic fracture mechanics as related to J_{Ic} and the tearing modulus T. The remaining papers deal with a wide range of subjects such as creep-crack growth, correlations of fracture behavior with Charpy V-notch response, the effect of root radius on fracture behavior, behavior of composite materials, R-curves, and applications of fracture mechanics methods.

As in previous national symposia on fracture mechanics, the preponderance of papers contributed deal with fatigue crack propagation. The effect of variable-amplitude loading was investigated by J. B. Chang, R. M. Engle, and J. Stolpestad. Their study examines the fatigue crack growth behavior of 2219-T851 aluminum subjected to variable-amplitude loading. This loading includes single and periodic tensile and compressive overloads as well as high-low or low-high block loading. A load interaction model is developed which accounts for the overload retardation and compressive load acceleration effects on fatigue crack growth. Analysis of the experimental data was performed using a computer program which employed this model. The results show reasonable agreement with the experimental data. The effect of residual stress on fatigue crack growth measurements was investigated by R. Bucci. In his paper Bucci gives numerous examples to show how residual stresses can lead to an erroneous interpretation of fatigue crack growth rates as measured in accordance with current ASTM Test for Constant-Load-Amplitude Fatigue Crack Growth Rates Above 10^{-8} m/Cycles (E 647-78T). Bucci recommends various modifications to applicable ASTM documents so that proper recognition will be given to the effect of residual stresses on fatigue crack growth rate measurements. J. H. Underwood and J. A. Kapp investigated the benefits of overloads on fatigue crack initiation and growth from a 0.1-mm-radius notch in steel alloy K_{Ic} specimens. Other tests are described which measure the effect of tension overloads on fatigue crack growth and fatigue crack initiation from 3.4-mm-root-radius notches in similar specimens. Their results indicate that when one wishes to accelerate crack initiation from the root of the notch the compressive overload is a definite benefit. Also, the effect of the tensile overload is to provide an increased fatigue life for the notched specimens. A. U. de Koning describes the results of the simple crack closure model for the prediction of fatigue crack growth rates under variable-amplitude loading. This model is based on crack closure arguments and was designed to predict the crack acceleration and retardation observed under variable-amplitude loading. This model was incorporated into a computer program and used to analyze the behavior of specimens of 7075-T6 aluminum. B. N. Leis and T. P. Forte provide some insight into the fatigue crack growth behavior of physically short cracks in aluminum and steel plates. Their paper presents and analyzes an extensive data set related to the so-called short-crack problem. Included in the results are data for notched plates made from two aluminum alloys and a steel. Leis and Forte suggest that physically long as well as physically short cracks may behave in a manner inconsistent with linear elastic fracture mechanics (LEFM) descriptions. It can be implied from their arguments that in these cases this variation is principally due to the inability of LEFM to accurately describe the crack tip stress and strain conditions. The contribution of Saff and Holloway describes a study of crack growth gages for evaluation of service life. They show, based on the results of their program, that the response of the crack growth gages can be correlated with the stress history of the aircraft in the region of the gage site. However, the authors indicate that the potential usefulness of the crack growth gages for monitoring actual crack growth in aircraft structures has not been fully explored. They feel that considerable further research is required to verify this technique before it can be practically applied. G. Marci provides some insight into the effect of temperature on fatigue crack growth rates. He concludes that the fatigue crack growth threshold decreases linearly with increasing temperature. In Marci's paper a crack growth equation incorporating the effect of temperature on the fatigue crack growth threshold is demonstrated for Type 304 stainless steel. Saxena, Williams, and Shih provided discussion of an analytical modeling technique used to predict the effect of hold time on fatigue crack growth behavior at elevated temperatures. This model was evaluated for fatigue crack growth data with hold times of 0, 5, and 50 s for A470 Class 8 steel at 538°C (1000°F). Additional data on Inconel alloy 718 at the same temperature were also taken from the literature to evaluate this model. It is their conclusion that the model is capable of accurately representing and predicting the hold time effects on fatigue crack growth behavior at elevated temperatures. The authors describe some of the limitations of their model and some of the possible methods for eliminating these problems. Taylor and Barsom in their paper describe the effect of cyclic frequency on the corrosion fatigue crack initiation behavior of an A517 Grade F steel. Their tests were conducted on a compact tension specimen at a stress ratio of 0.1 in a room temperature 3.5 percent solution of sodium chloride. They show that the corrosion fatigue crack initiation life under full immersion conditions is significantly less than the fatigue crack initiation life in air. Metallographic studies indicate that the corrosion fatigue cracks initiate at corrosion pits on the surface of the notch tip in the specimens. It is proposed that these cracks initiate as microcracks that form by a sharpening of the corrosion pit tip under the combined influence of the environment and the cyclic loads.

In the conference session on stress-intensity factors a number of very important practical geometries were investigated. Smith, Peters, Kirby, and Andonian provide some insight into stress-intensity distributions for certain natural flaw shapes which approximate benchmark geometries. The studies described took the form of frozen stress photoelastic experiments carried out on certain model geometries which approach a so-called benchmark problem represented by a plate containing a surface crack loaded in remote simple tension. The authors describe the limitation of their studies with respect to flaw depth and surface flaw length. In the paper by Phillips and Sanford the effect of higher-order stress terms on Mode I caustics in birefringent materials is discussed. While being relatively new, this experimental technique can be used to determine stress-intensity factors for various crack configurations. The principal thrust of the work by Phillips and Sanford was to discuss how the first few non-singular stress terms affect the sizes and shapes of the caustic that are produced in the optically anisotrophic materials.

Along with the study of fatigue and the evaluation of stress-intensity factors, the elastic-plastic response as measured by J_{Ic} and T received considerable attention during the 13th National Fracture Mechanics Symposium. In the paper by Ernst, Paris, and Landes the evaluation of J and tearing modulus T from a single test record is investigated. The consequences of expressing J by the Merkel-Corton formula is explored in terms of J, the crack increment da, and the tearing modulus T. The authors provide additional physical interpretation to the material versus applied tearing modulus stability criterion. Also, a simpler method for evaluating J following the actual $P\Delta$ test record is suggested. This procedure is compared with other experimental data. Carlson and Williams present an attempt to provide a more basic approach to the analysis of multiple-specimen R-curves for the determination of J_c. Multiple-specimen J-R curves were developed for groups of 1T compact specimens with different A/W values and depths of side grooving. The purpose of the investigation was to determine J_c for each group. A more basic approach for the analysis of multiple-specimen R-curves is presented in the paper. This technique is applied and extensively discussed to show J_c estimates that closely corresponded to actual observed onset of crack extension. Joyce and Vassilaros present the results of an experimental investigation of tearing instability using compact tension specimens. They conclude for the range of aluminum, titanium, and steel alloys tested that whenever the $T_{applied}$ obtained from the generalized Paris model exceeds the $T_{material}$, a tearing instability is assured.

They show that side-grooving of these materials effectively reduces the $T_{material}$ and this reduction is related to a reduction in the $T_{applied}$ for instability. Additionally, they found that the value of $T_{applied}$ does not have any effect on the resultant J_I-R curves. Further, the J_I-R curves seem to be independent of the mode of crack extension observed over the range of $T_{applied}$. A reevaluation of procedures for calculating J_{Ic} is provided by G. A. Clarke. Clarke provides some insight into the various improvements to J_{Ic} and J-R curve testing which have occurred during the past five years. A description of many of these improvements is presented in the paper. Clarke highlights many of the pitfalls which one can encounter in J_{Ic} and J-R testing. In the paper by Andrews the utilization of small specimens to provide accurate predictions of the brittle fracture response of low alloy steels is examined. Andrews concludes that an accurate estimate of valid plane-strain fracture toughness, K_{Ic}, for low-alloy steels in the ductile-to-brittle transition temperature range may be made using J_{Ic}-valid specimens if one also accounts for size effect, which is evident for cleavage fracture. This size effect is explained using a weakest-link theory.

It has already been noted that approximately 60 percent of the papers contributed to the 13th National Symposium on Fracture Mechanics were in the general categories of fatigue, stress-intensity evaluation, and elastic-plastic fracture mechanics. The remaining papers did not conveniently fit into any single grouping. These papers represented a wide range of subjects from creep crack growth to Charpy V-notch correlations, composite materials, and fracture mechanics applications to name a few. In an attempt to provide a better understanding of creep crack growth, Donat, Nicholas, and Fu presented the results of an experimental investigation of creep crack growth in IN-100. They determined sustained crack growth rates in IN-100 at 732°C (1350°F). Their studies were conducted on two specimen geometries over a range of thicknesses. A number of various parameters such as the stress-intensity factor, net section stress, and a compliance-related integral were studied as possible crack growth rate correlating parameters. None of these parameters provided an effective means of correlating the observed growth rates. An upper-shelf correlation between the fracture toughness and the energy required to initiate cracking as measured in a Charpy V-notch specimen is presented in the work of Norris, Reaugh, and Server. Their correlation was obtained using data from 23 steels which possessed a wide variation in yield strength, fracture toughness, and Charpy toughness. The authors state that their correlation is only marginally better than that obtained by Rolfe and Novak, and Barsom and Rolfe, whose correlations use the entire Charpy fracture energy curves. In a series of J-integral fracture toughness tests, Tobler, Read, and Reed studied the effect of carbon and nitrogen on the fracture properties of an austenitic stainless steel having a base composition corresponding to AISI 304. The fracture toughness measured was observed to decrease with increasing carbon and nitrogen content. While many problems are quite obvious to a researcher when trying to apply fracture mechanics to an actual situation, they are not obvious all the time to most people. W. G. Clark, Jr., describes in his paper some of the problems that will occur in a typical application of fracture mechanics. The problems described by Clark range from the development of adequate material property data to the analytical and defect characterization aspects of the technology. These problems and their interaction are discussed with regard to their potential impact on structural life predictions and quantitative risk analysis. The material characterization problems associated with data scatter, prior loading effects, and time-dependent behavior are included along with consideration of the probability of flaw detection and the analysis of small defects and interacting flaws. Clark provides suggestions and recommendations for experimental work required to resolve some of these problems. A paper by Denyer also highlights fracture mechanics technology and its application. In this particular paper, the application of fracture mechanics to individual aircraft tracking is discussed. Denyer describes a crack growth analysis method which is designed to meet the intents and objectives of the U.S. Air Force requirements for durability and damage tolerance in their structures. The methodology described is currently being incorporated into the overall life monitoring of the USAF T-39 Utility Trainer. This is the first system to use crack growth principles for both durability and damage tolerance tracking. The behavior of composite materials as related to fracture mechanics was highlighted by three papers presented at the conference. The dependence of strength on particle size in graphite is discussed by Kennedy and Kennedy. The authors examine the strength to particle size relationship for specially fabricated graphites. They demonstrate that the utilization of fracture mechanics will provide an adequate basis for the observed performance. An application of the Dugdale crack extension model with simple modifications accounting for nonspherical pores and variable defect concentrations is used to explain the observed experimental data. In their study they also consider the particle size effect on coefficient of thermal expansion, electrical resistivity, fracture strain, and Young's modulus. Shih and Logsdon in their paper examine the fracture behavior of a thick-section graphite/epoxy composite. It was the authors' intent to examine the possibility of using advanced structural composities in the specific application of generator retaining rings. One aspect of this was to demonstrate the fracture behavior of the composite material. In particular, their tests served to permit an evaluation of the applicability of LEFM to composite materials in general and to thick-section composites in particular. Their results show that LEFM is not directly applicable to thick-section composites with cracks perpendicular to the fiber orientation. They found that the test composite was insensitive to cracks in a plane perpendicular to the fibers and that the load-carrying capability could be calculated based on net section considerations solely. The failure mode they observed in their test of composites tested in 3-point bending was interply shear failure. The third paper on fracture behavior of fiber composites was offered by Avery, Bradley, and King. This paper deals with fracture control in ballistic damage fiber composite wing structures. Their paper presents the fracture test data and analysis related to the development of a skin configuration for a graphite/epoxy wing box capable of sustaining limit loads following damage from a 23-mm high-explosive-impact projectile.

While not described in this summary, other very interesting papers were contributed to the symposium as evidenced by the index to this *Special Technical Publication*. A paper on fatigue fracture micromechanism in broad molecular weight distribution poly(methyl methacrylate) is offered by Janiszewski, Hertzberg, and Manson. A discussion of a final stretch model of ductile fracture by Wnuk and Sedmack is also included. Additionally, such things as the anomaly of toughness behavior with notch root radius are discussed by Datta and Wood; the relationship between critical stretch zone width crack-tip opening and fracture energy is investigated by Nguyen-Duy; Baker describes a new test method for short rod and short bar fracture toughness specimens; and Heritier examines a fracture mechanics study of stress corrosion cracking in austenitic and austenitic-ferritic stainless steels.

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