Summary

The Twenty-Second National Symposium on Fracture Mechanics was divided into two dual sessions. Session I concentrated on experimental and theoretical aspects of fracture mechanics, while Session II concentrated on numerical and computational aspects of fracture. In Session II, there were 44 presentations made at the Symposium. For a variety of reasons, related to technical and time constraints in preparing a submission for publication, 26 papers appear in this volume. At the Symposium and in this volume, the presentations and papers were divided into four categories: Elastic Fracture Mechanics and Applications, Nonlinear Fracture Mechanics and Applications, Novel Mathematical and Computational Methods, and Composite Materials.

Elastic Fracture Mechanics and Applications

The papers in this section are concerned with the application of linear elastic fracture mechanics concepts to the analysis of three-dimensional crack configurations, fatigue-crack growth and fracture, and to the development of efficient methods of analysis.

Smith presented a review of two established optical methods to accurately measure the stress states for three-dimensional cracked bodies. In particular, he presented the results on several example problems: (1) stress-intensity factor distribution for a nozzle corner crack in a pressure vessel model, (2) a surface crack in a rocket motor propellant model, and (3) determination of the order of the singularity for a crack intersecting a free surface. Photoelastic results presented agreed well with numerical and analytical analyses from the literature.

Raju, Newman, and Atluri presented closed-form equations for the crack-mouth-opening displacements for a surface crack in a flat plate subjected to remote tension and bending loads. They used both the finite element and finite element alternating methods to analyze a wide range in crack shapes and sizes. Their results agreed well with experiments conducted by McCabe for remote tension. Their results agreed well with equations developed by Fett for nearly semicircular surface cracks but gave substantially higher displacements for low aspects ratio (low a/c) and deep (large a/t) cracks.

The finite element alternating method (FEAM) was also used by *Stonesifer, Brust, and Leis* to analyze a surface crack located on the inside of a large pipe. The FEAM included the Vijayakumar-Nishioka-Atluri (VNA) analytical solution which allows for high-order traction variations on the crack surfaces, a deficiency found in earlier alternating solutions. Their results compared well with the results for Raju and Newman except where the crack intersected the wall of the pipe. Here the boundary-layer effect causes difficulties in obtaining accurate solutions.

Dawicke, Shivakumar, Newman, and Grandt presented a hybrid experimental numerical method to determine fatigue crack-opening stresses along a crack front in middle-crack and compact specimens. The method combines experimental measurements of crack-growth rates and crack-front curvature with three-dimensional elastic finite element analyses to determine stress-intensity factor variations and, subsequently, crack-opening stresses. These calculations agreed fairly well with measured results from Sunder's fatigue striation technique and measurements from a remote displacement and near tip strain gages. The proposed method appears to offer a reliable method to study crack-closure effects for three-dimensional crack configurations.

The ASTM Standard Test Method for Plane-Strain Fracture Toughness of Metals Using Chevron-Notched Specimens has been in existence for two years. The paper by *Barker* discusses the origins, significance, and usage of the toughness values that are measured by ASTM E 1304-89.

Bittencourt, Barry, and Ingraffea presented results on the calculation of mixed-mode stress-intensity factors using three different methods (displacement, J-integral and modified crack-closure integral). The modified crack-closure integral showed very good performance for all the applied mixed-mode conditions analyzed.

The last two papers in this section were concerned with the application of efficient methods to analyze three-dimensional crack configurations under complex loading and structures. *Malik* using a weight-function method based on crack-surface-opening displacements and the Newman-Raju stress-intensity factor solutions. He made an extensive comparisons between the stress-intensity factor solutions of Raju and Newman for various crack configurations under remote bending to verify the method for application to general stress gradients. *Rithie, Voermans, Bell, and deLange* used the line-spring model to analyze surface cracks in complex welded structure. Comparisons made between predicted and measured fatigue crack growth patterns and lives agreed well.

Nonlinear Fracture Mechanics and Applications

The section on nonlinear fracture consisted of nine contributed papers on the subjects of experimental Hutchinson, Rice, and Rosengren (HRR) field analysis in homogeneous specimens, hybrid finite element studies of structures and fracture parameters, coupled problems of thermoelastic fracture, three dimensional fracture analysis of crack growth, fatigue crack growth with elastic and viscoelastic dynamic fracture. Specifically, two papers by *Dadkhan, Kobayashi, and Morris*, and *Chiang, Li, and Wang* utilized near tip optical methods to examine the extent and validity of HRR fields during crack initiation and growth. The paper by *Tong, Greif, and Chen* concerned the utilization of hybrid finite element techniques to study complex aircraft structures. The paper by *Nishioka, Fujimoto, and Sakakura* used a hybrid numerical and experimental scheme to combine the caustic experimental technique with the T^* fracture parameter. The paper by *Franco and Gilles* employed three-dimensional finite element methods to study the changes in validity of various fracture parameters from linear elastic, to HRR under contained yield, and finally the Central Electricity Generating Board's (CEGB) two-criteria approaches. The paper by *Brust, Ahmad, and Naboulsi* studied the effects of cyclic fatigue damage and plasticity on crack-growth behavior in terms of the J and T^* fracture parameters. The paper by *Gu* concerned the development of K-R curves for 2024-T531 aluminum alloy that are independent of specimen configuration. The work by *Chen and Huang* implemented a three-dimensional finite element method with path-independent integrals to study an embedded elliptical crack under thermal gradients. The final paper in this section by *O'Donoghue, Kanninen, Popelar, and Popelar* studied rate dependent fracture in polyethylene piping systems showing most notably a validity of linear elastic fracture mechanics (LEFM) provided the craze zone is small and contained. As a whole, this collection of papers represents an excellent cross section of the state of the art in nonlinear fracture research.

Novel Mathematical and Computational Methods

This section describes computational and mathematical methods that are new, novel, and efficient to analyze two- and three-dimensional crack configurations made of brittle and ductile materials.

Yagawa, Yoshimura, Yoshioka, and Pyo presented a study of a crack growing in a ductile material using hybrid experimental and numerical methods. A computer image process was used to measure the displacement field near a growing crack. The stress, strain, and near crack-tip (local) J-integral were evaluated from the measured displacement field. Their study on Type 304 stainless steel showed that the HRR field seems to exist outside a small nonlinear region where the crack tip is largely blunted and for a small amount of crack growth. The local J-integral showed good path independence outside the small nonlinear region and they agreed well with conventional J-integral evaluations for small amounts of crack extension. For large values of crack extension, the local J tended to approach a constant value while the conventional J estimates continued to rise.

Cruse and Novati formulated a traction boundary integral equation (BIE) for application to nonplanar curved cracks and multiple cracks. The nonplanar curved cracks were modeled as piecewise flat regions. These regions were modeled as triangular boundary elements. The implementation of the integral equations for these elements was presented. The new formulation was applied to several problems that are three-dimensional approximations to plane strain fracture problems. In all cases the piecewise flat traction BIE implementation agreed well with limited results from the literature.

Barsoum and Chen studied three-dimensional singularity fields for interfacial surface and corner cracks by a finite element iterative method. Their results on the bimaterial free surface singularity suggests that the two-dimensional analyses at the interfaces are nonconservative and three-dimensional analysis must be used.

Kuo, Shvarts, and Stonesifer presented an alternating analytical procedure for the analysis of an elliptical or part elliptical crack in an infinite flat plate of finite thickness subjected to arbitrary crack surface loading. In this method, in contrast to the other alternating methods, the uncracked infinite flat plate was analyzed by decomposing the residual stresses on the plate bounding surfaces into double Fourier series and by using Fast Fourier Transform methods. With this approach, three-dimensional crack problems are solved with great ease because no finite element model needs to be prepared as in the finite element alternating method (FEAM). However, this method appears to have limited applicability compared to the FEAM because it can only handle flat plate configurations.

Sun, Kienzler, Voss, and Schmitt studied the ductile fracture behavior of different specimens by continuum damage mechanics techniques. They used a modified Gurson model. The damage parameters used in the model were obtained from the tests on smooth bars. The critical distance over which void coalescence is active was determined by matching load against displacement from a cracked specimen. The model was then used to predict the deformation and fracture behavior of notched round bars and side-grooved compact specimens. In all cases, satisfactory agreement was obtained between the predictions and the test results.

Composite Materials

In the composite materials section, four papers were published. They are concerned with the analysis and prediction of strength and failure of laminated composite materials.

Zhu and Achenbach presented a numerical technique to calculate microlevel stresses for transverse loading of a unidirectional fiber-reinforced composite with hexagonal packing.

The composite fiber-matrix interphases were modeled by the spring-layer model. The numerical technique presented should be useful in modeling failure scenarios of radial matrix cracking and interphase failure.

Bouden and Datta used the finite element and integral representation technique to analyze scattering of waves by interfacial cracks in a layered half-space. With this technique, arbitrary crack configurations can be analyzed. An analysis of a interfacial crack subjected to both normal and shear loadings was demonstrated. For both loading cases, the normal crack-opening displacements (COD) are larger than the tangential COD's at low frequencies. Dynamic stress-intensity factors were found to attain high peak values at certain resonant frequencies.

Cheng and Lin presented two probabilistic fracture models—statistical and stochastic—for predicting the notched strength of laminated composites. The statistical model considered the case of constant load while the stochastic model dealt with the effect of monotonically increasing loads. The notched strength of boron/aluminum composites with various crack lengths was predicted using the statistical model. The predicted results agreed well with the experimental data. However, the stochastic model appears to be more accurate since it represents a more realistic loading situation and also this model provides upper and lower bound predictions. The probabilistic approach proposed appears to predict a power-law type relationship between fracture stress and notch size.

Li and Armanios introduced a simple analytical method using a sublaminate approach to analyze unidirectional and cross-ply laminates under torsion loading. Interlaminar stresses and total strain energy release rates were evaluated based on a displacement field that included shear deformation. Closed form expressions for the interlaminar stresses and total strain energy release rates were obtained for unidirectional and cross-ply laminates in terms of the laminate stiffness coefficients. The interlaminar stresses for these laminates, predicted by this simple method agreed well with a finite element solution and an exact elasticity solution.

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