

Summary

There were twenty-one presentations at the Symposium on Chevron-Notched Specimens: Testing and Stress Analysis. Of these, twenty appear as completed, reviewed manuscripts in this volume. At the symposium there was a division into two categories, analytical and experimental, with considerable overlap in some presentations. For this volume, three categories were chosen: stress analysis, test method development, and fracture toughness measurement. Nearly every paper included information in two of these areas, some all three. Regardless of the overlap, the categorization still helps those new to the topic of chevron-notched fracture testing. The basic geometry used for most of the testing and analysis is an edge-notched specimen loaded in tension with the deep, angled side grooves which join to make the V-shaped chevron-notch. Specimens with round cross section are commonly called short rod, with rectangular cross section, short bar.

Stress Analysis

The first of the six papers in this area is the most comprehensive and the only paper in the volume which is primarily a review of the overall topic. The author, J. C. Newman, heads the cooperative analysis program of the ASTM Task Group E24.01.04 on Chevron-Notched Specimens, and therefore is in good position to describe the development of the various specimens. He reviews the early stress intensity factor expressions based on empirical comparisons and experimental compliance and the more recent stress-intensity factor and displacement results from finite-element and boundary-element methods. He presents consensus results for stress-intensity factor and displacement and a discussion of the applicability of various specimens which will be useful in further work with chevron-notched specimens.

The paper by I. S. Raju and J. C. Newman gives results from three-dimensional finite-element analysis of various specimens. The authors present complete stress-intensity factor distributions along the crack front using a compliance method. Their stress-intensity factors and load-line displacements were up to 5% lower than reported experimental values.

The paper by A. R. Ingraffea, R. Perucchio, T. Y. Han, W. H. Gerstle, and Y. P. Huang describes three-dimensional finite- and boundary-element results. Both average and local variation values of stress-intensity factors along the crack

front are given. Significant in their work are edge values of stress-intensity factor 20% higher than centerline values for an assumed straight crack front.

A. Mendleson and L. J. Ghosn present results from a three-dimensional boundary-element analysis. Load-line displacement and stress-intensity factors determined from both stress and compliance calculations were compared with the Raju and Newman results with close agreement.

The two remaining stress analysis papers used primarily experimental approaches. R. J. Sanford and R. Chona performed two-dimensional photoelastic experiments representing the midplane of a chevron-notched specimen. Numerical analysis of the photoelastic results using a "local collocation" around the crack tip gives the stress-intensity factor for the range of specimen geometry tested. The photoelastic results were also used to determine the size and shape of the near-field singular stress zone near the crack tip. The paper by I. Bar-On, F. R. Tuler, and I. Roman describes fracture toughness tests with various materials using both chevron-notched bend specimens and existing standard ASTM specimens. Analysis of these results gave experimental stress-intensity factors which compared well, in some cases, with results from a two-dimensional compliance analysis of a straight crack geometry.

Test Method Development

The seven papers in this section are all related to certain important variables and test procedures associated with fracture testing using chevron-notched specimens. The first, by L. M. Barker, describes systematic studies of several key test variables and procedures, including specimen size, elastic-plastic data analysis, and slot thickness and tip geometry. The paper describes the consistency of results in various metal alloys as related to the preceding and other test conditions. It also serves as a useful review of the general topic of chevron-notched testing.

The next three papers deal with fracture testing of hard, brittle materials, specifically glass and rock. R. T. Coyle and M. L. Buhl tested two glasses in a 30% relative humidity environment, and developed computer-assisted data collection procedures for measurement of crack velocity. The paper by A. R. Ingraffea, K. L. Gunsallus, J. F. Breech, and P. P. Nelson describes tests and test method development with limestone and granite. Chevron-notched results compare favorably with results from the conventional and more time consuming test methods. L. Chuck, E. R. Fuller, and S. W. Freiman describe chevron-notched bend testing of glass with humidity and loading rate as test variables. The authors focus on the experimental problems which they encountered, useful information for other prospective users of the test methods, information which too often is unreported.

The next two papers, both from the People's Republic of China, are comprehensive investigations of chevron-notched testing, including combined analysis

and experiment. Thus, these papers provide a broad view of the topic, as well as a measure of progress of this topic in another country. Wu Shang-Xian concentrates on analytical compliance formulae for a wide range of chevron-notched geometries. These formulae are particularly useful for those who must use test specimens with unusual dimensions. The author compared fracture toughness measurements from chevron-notched and straight-notched standard specimens, with generally favorable results. The second paper, by Wang Chizhi, Yuan Maochan, and Chen Tzeguang, describes a compliance analysis for stress-intensity factor and an extensive series of tests with eight metallic materials, comparing chevron-notched and standard straight-notched results. A good comparison was noted when stable crack growth and limited plastic deformation were observed.

The last paper in this section, by J. L. Stokes and G. A. Hayes, describes an investigation of the use of acoustic emission with chevron-notched tests of four steels. Load versus deflection plots and load versus cumulative counts plots of the same chevron-notched test are directly compared.

Fracture Toughness Measurements

A primary purpose of these seven papers was to determine the fracture toughness of the particular materials in each of the investigations. In some cases, as discussed next, significant information on stress analysis and test method development was also included in the work. The first two papers describe fracture toughness tests of aluminum alloys. K. R. Brown gives data for seven alloys in various conditions, and points up conditions which affect comparisons between chevron-notched and standard fracture toughness measurements. Test conditions included in his work are toughness level, rising crack-growth resistance, and through-thickness material variation. J. Eschweiler, G. Marci, and D. G. Munz from West Germany, performed tests with one alloy, 7475-T7531, and a variety of test conditions, including specimen size, orientation, and different heats. The most significant difference between chevron-notched and standard toughness measurements was related to the overall toughness level, with higher fracture toughness leading to the larger difference between the two types of tests.

The next three papers involve tests of hard, brittle materials. J. L. Shannon and D. G. Munz describe tests of aluminum oxide with variations in specimen size, proportions, and chevron-notch angle. Differences in measured toughness are related primarily to differences in the amount of crack extension at maximum load. The rising crack growth resistance curve of the oxide is discussed as having important materials effect on measured toughness. The paper by J. R. Tingle, C. A. Shumaker, D. P. Jones, and R. A. Cutler describes toughness measurements of cemented tungsten carbides. Effects on toughness of the amount and distribution of tungsten and carbon were investigated. Also, up to 15% substitution of nickel for cobalt as the binder was found to have little effect. J. Hong

and P. Schwarzkopf tested cemented tungsten carbide samples using nine alloys of various cobalt content and carbide particle size. Results from short-rod and four-point bend specimens were compared, including microstructural characterization using optical and electron micrography.

The paper by R. F. Krause and E. R. Fuller describes fracture toughness measurements of polymer concrete materials, which are polymerized mixtures of monomers, portland cement, and silica sand. Effects on toughness of various test conditions were considered, including chevron-notch angle, chevron-vertex position, width of specimen in the crack plane, and the material rising crack-growth resistance curve.

The paper by J. J. Mecholsky and L. M. Barker describes a chevron-notched specimen which was developed to measure the fracture toughness of ceramic-metal interfaces. Specimens were made with the chevron-notch plane aligned with the interface between a glass ceramic and molybdenum and a glass ceramic and Hastelloy 276. The toughness measured from such chevron-notched specimens is a direct measure of the bond strength between ceramic and metal.

What Is Ahead For Chevron-Notched Specimens?

There are several indications that chevron-notched specimens will be often used in the future. First, the basic idea of a self-initiating precrack is sound and useful. Because of the unavoidable complexity of the current standard fracture toughness tests, particularly involving precracking, the chevron-notch concept is attractive and will be used. A second indication of interest in chevron-notched specimens is the response to the symposium and this publication. Research and development work from a variety of perspectives was performed and reported. Finally, this body of work will certainly spur additional research, development, and testing with chevron-notched specimens.

A key requirement for continued technical development and productive use of chevron-notched specimens for fracture testing is a standardized test method. ASTM Task Group E24.01.04 on Chevron-Notched Test Methods is now preparing a draft standard method. It will be based upon the results of interlaboratory analyses and test programs, portions of which are included in this publication. Additional interlaboratory testing, and analysis if required, will be performed to validate the standard test method and demonstrate its precision and accuracy. Then the entire body of testing and analysis, plus any additional work, will be available to assess just which particular combinations of material, geometry, and test procedures, give reliable measures of fracture toughness. It is now clear that for some combinations of test conditions, chevron-notched specimens will provide virtually identical measures of fracture toughness as those obtained from the current ASTM standard methods. It is also clear that some chevron-notched test conditions will give different measures of fracture toughness than those from current standards.

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