Chevron-Notched Specimens

Testing and Stress Analysis

Underwood/Freiman/Baratta
editors

ASTM STP 855

CHEVRON-NOTCHED SPECIMENS: TESTING AND STRESS ANALYSIS

A symposium
sponsored by
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on Fracture Testing
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The Society is not responsible, as a body, for the statements and opinions advanced in this publication.

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Foreword

This publication, *Chevron-Notched Specimens: Testing and Stress Analysis,* contains papers presented at the Symposium on Chevron-Notched Specimens: Testing and Stress Analysis which was held 21 April 1983 at Louisville, Kentucky. ASTM's Committee E-24 on Fracture Testing sponsored the symposium. J. H. Underwood, Army Armament R&D Center, S. W. Freiman, National Bureau of Standards, and F. I. Baratta, Army Materials and Mechanics Research Center, served as symposium chairmen and editors of this publication.

The symposium chairmen are pleased to credit D. P. Wilhem, Northrop Corp., for proposing and initiating this symposium.

Related ASTM Publication

Probabilistic Fracture Mechanics and Fatigue Methods: Applications for Structural Design and Maintenance, STP 798 (1983), 04-798000-30

Fracture Mechanics: Fourteenth Symposium, Volume I: Theory and Analysis; Volume II: Testing and Application, STP 791 (1983), 04-791000-30

Fracture Mechanics for Ceramics, Rocks, and Concrete, STP 745 (1981), 04-745000-30

Fractography and Materials Science, STP 733 (1981), 04-733000-30

A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

ASTM Committee on Publications

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SUMMARY

Introduction

The Symposium on Chevron-Notched Specimens: Testing and Stress Analysis was held at the Galt House, Louisville, Kentucky, 21 Apr 1983, as part of the Spring meetings of ASTM Committee E-24 on Fracture Testing. Chevron-notched testing and analysis has been a topic of considerable interest to ASTM Committee E-24. The work at NASA Lewis Research Center and Terra Tek Systems, which made up much of the initial chevron-notched work, has been presented often at E-24 subcommittee and task group meetings. Mr. David P. Wilhem, while chairman of ASTM Subcommittee E24.01 on Fracture Mechanics Test Methods, proposed this symposium to bring together the most up-to-date investigations on chevron-notched testing. The current focus is on cooperative, comparative test and analysis programs, and a proposed standard test method, coordinated by task groups of Subcommittee E24.01 and Subcommittee E24.07 on Fracture Mechanics of Brittle Materials.

The most important advantage in using chevron-notched specimens for fracture testing is that a precrack can be produced in a single load application, with the precrack self-initiating at the tip of the chevron. The sometimes difficult, and always time consuming, fatigue precracking operation can be eliminated. One important purpose of the work described in this publication, given the precracking and other differences in chevron-notched testing compared with existing tests, is to identify the conditions which will yield reproducible results. These conditions involve specimen material, specimen size and geometry, test procedures, and the stress analysis procedures used to evaluate results. Once consistent results are obtained, then detailed comparisons of test data obtained by chevron-notched techniques can be made with results from standard tests.

The papers in the volume are presented in three sections:

1. *Stress Analysis,* including primarily finite element stress analysis of several chevron-notched geometries, but also encompassing boundary integral, photoelastic, and analytical and experimental compliance methods of stress analysis.

2. *Test Method Development,* both experimental and analytical investigations of key concerns with chevron-notched testing, such as specimen size effects, different material behavior including metals and nonmetals, and various methods for measuring crack growth.

3. *Fracture Toughness Measurements,* with primary emphasis on chevron-notched measurement of fracture toughness of structural materials, including

aluminum alloys and a variety of hard/brittle materials such as oxides and carbides.

This publication is the first collection of information on chevron-notched testing, and it should provide a resource for the development and use of this type of specimen for fracture testing. The symposium chairmen/editors are pleased to acknowledge the help of the ASTM editorial staff listed herein and Committee E-24 staff manager, Matt Lieff. Each of us also acknowledges the support of his respective laboratory and support staff.

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Stress Analysis

J. C. Newman, Jr.[1]

A Review of Chevron-Notched Fracture Specimens

REFERENCE: Newman, J. C., Jr., **"A Review of Chevron-Notched Fracture Specimens,"** *Chevron-Notched Specimens: Testing and Stress Analysis, ASTM STP 855,* J. H. Underwood, S. W. Freiman, and F. I. Baratta, Eds., American Society for Testing and Materials, Philadelphia, 1984, pp. 5–31.

ABSTRACT: This paper reviews the historical development of chevron-notched fracture specimens; it also compares stress-intensity factors and load line displacement solutions that have been proposed for some of these specimens. The review covers the original bend-bar configurations up to the present day short-rod and bar specimens. In particular, the results of a recent analytical round robin that was conducted by an ASTM Task Group on Chevron-Notched Specimens are presented.

In the round robin, three institutions calculated stress-intensity factors for either the chevron-notched round-rod or square-bar specimens. These analytical solutions were compared among themselves, and then among the various experimental solutions that have been proposed for these specimens. The experimental and analytical stress-intensity factor solutions that were obtained from the compliance method agreed within 3% for both specimens. An assessment of the consensus stress-intensity factor (compliance) solution for these specimens is made.

The stress-intensity factor solutions proposed for three- and four-point bend chevron-notched specimens are also reviewed. On the basis of this review, the bend-bar configurations need further experimental and analytical calibrations.

The chevron-notched rod, bar, and bend-bar specimens were developed to determine fracture toughness of brittle materials, materials that exhibit flat or nearly flat crack-growth resistance curves. The problems associated with using such specimens for materials that have a rising crack-growth resistance curve are reviewed.

KEY WORDS: fracture mechanics, stress-intensity factor, cracks, finite-element method, boundary-element method, crack-opening displacement, chevron-notched specimen

Nomenclature

- A Normalized stress-intensity factor defined by Barker
- a Crack length measured from either front face of bend bar or load line
- a_0 Initial crack length (to tip of chevron notch)
- a_1 Crack length measured to where chevron notch intersects specimen surface
- b Length of crack front
- B Thickness of bar specimen or diameter of rod specimen

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C^*	Normalized compliance, EBV_L/P, for chevron-notched specimen
E	Young's modulus of elasticity
F	Normalized stress-intensity factor for straight-through crack specimen
F^*	Normalized stress-intensity factor for chevron-notched specimen
F_c^*	Normalized stress-intensity factor determined from compliance for chevron-notched specimen
F_m^*	Minimum normalized stress-intensity factor for chevron-notched specimen
H	Half of bar specimen height or radius of rod specimen
K	Stress-intensity factor (Mode I)
K_m	Minimum stress-intensity factor for chevron-notched specimen
K_{Ic}	Plane-strain fracture toughness (ASTM E 399)
K_{Icv}	Plane-strain fracture toughness from chevron-notched specimen
K_R	Crack-growth resistance
k	Shear-correction parameter in Bluhm's slice model
P	Applied load
P_{max}	Maximum test (failure) load
V_L	Load-point half-displacement
V_T	Half-displacement measured at top of specimen along load line
w	Specimen width
x,y,z	Cartesian coordinates
α	Crack-length-to-width (a/w) ratio
α_i	Crack-length-to-width (a_i/w) ratios defined in Fig. 2
ν	Poisson's ratio

Chevron-notched specimens (Fig. 1) are gaining widespread use for fracture toughness testing of ceramics, rocks, high-strength metals, and other brittle

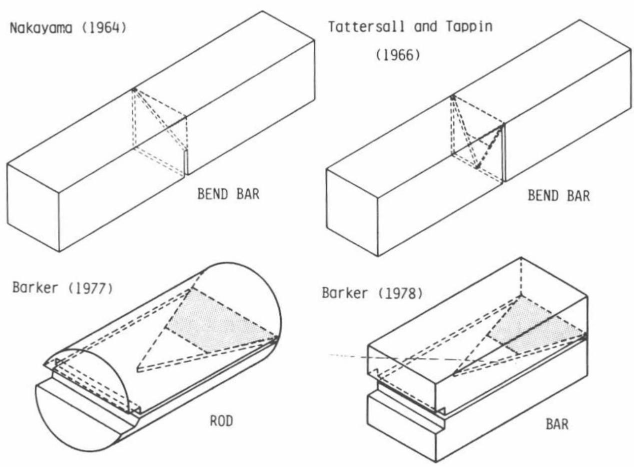

FIG. 1—*Various chevron-notched fracture specimen configurations.*

materials [*1–7*]. They are small (5 to 25-mm thick), simple, and inexpensive specimens for determining the plane-strain fracture toughness, denoted herein as K_{Icv}. Because they require no fatigue precracking, they are also well suited as quality control specimens. The unique features of a chevron-notched specimen, over conventional fracture toughness specimens, are: (1) the extremely high-stress concentration at the tip of the chevron notch, and (2) the stress-intensity factor passes through a minimum as the crack grows. Because of the high-stress concentration factor at the tip of the chevron notch, a crack initiates at a low applied load, so costly precracking of the specimen is not needed. From the minimum stress-intensity factor, the fracture toughness can be evaluated from the maximum test load. Therefore, a load-displacement record, as is currently required in the ASTM Test Method for Plane-Strain Fracture Toughness of Metallic Materials (E 399-83) is not needed. Because of these unique features, some of these specimens are being considered for standardization by the American Society for Testing and Materials (ASTM).

This paper reviews the historical development of chevron-notched fracture specimens. The paper also compares the stress-intensity factor and load-line displacement solutions that have been proposed for some of these specimens. The review is presented in four parts.

In the first part, the review covers the development of the original chevron-notched bend bars, the present day short-rod and bar specimens, and the early analyses for these specimens.

In the second part, the results of a recent "analytical" round robin conducted by the ASTM Task Group on Chevron-Notched Specimens are presented. Three institutions participated in the calculations of stress-intensity factors for either the chevron-notched round-rod or square-bar specimen. They used either three-dimensional finite-element or boundary-integral equation (boundary-element) methods. These analytical solutions were compared among themselves and among the various experimental solutions that have been determined for the rod and bar specimens. An assessment of the consensus stress-intensity factor (compliance) solution for these specimens is presented.

In the third part, some recent stress-intensity factor solutions, proposed for three- and four-point bend chevron-notched specimens, are reviewed.

In the last part, the applicability of chevron-notched specimens to materials that have a rising crack-growth resistance curve is discussed.

History of Chevron-Notched Specimens

In 1964, Nakayama [*1,2*] was the first to use a bend specimen with an unsymmetrical chevron notch. His specimen configuration is shown in Fig. 1. He used it to measure fracture energy of brittle, polycrystalline, refractory materials. All previous methods which had been developed for testing homogeneous materials were thought to be inadequate. This specimen is unique in that a crack initiates at the tip of the chevron notch at a low load, then propagates stably