FRACTURE TOUGHNESS TESTING AND ITS APPLICATIONS

Published by the
AMERICAN SOCIETY FOR TESTING AND MATERIALS
in cooperation with the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FRACTURE TOUGHNESS TESTING AND ITS APPLICATIONS

A symposium presented at the

SIXTY-SEVENTH ANNUAL MEETING

AMERICAN SOCIETY FOR TESTING AND MATERIALS

Chicago, Ill., June 21–26, 1964

ASTM Special Technical Publication No. 381

Published by the
AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race St., Philadelphia 3, Pa.
in cooperation with the
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Library of Congress Catalog Card Number: 65-16811

Printed in Baltimore, Md.
April, 1965
Second Printing, May 1970
Third Printing, January 1975
Fourth Printing, October 1981

FOREWORD

The development of various new high-strength alloys and the broadening range of their applications, particularly in aerospace and in cryogenics, has brought about increased emphasis on the study of fracture characteristics. As a result, the technology of testing for fracture toughness and crack propagation has grown rapidly in recent years. So, too, has understanding of how to apply this testing technology to design problems such as selection of materials, heat treatment, welding procedures, structural shape and size, and effects of environment.

This collection of papers constitutes an authoritative and reasonably complete statement of the current procedure and concepts in the field of fracture mechanics. It should thus be of primary value to those concerned with fracture testing and with applications of test data.

This publication is a cooperative effort of the American Society for Testing and Materials and the National Aeronautics and Space Administration. It helps to fulfill the obligation of the ASTM to provide the technical community with test methods, and with a sound understanding of their usefulness and their limitations. Through its Special Committee on Fracture Testing of High-Strength Materials (now ASTM Committee E-24 on Fracture Testing of Metallic Materials), ASTM has provided important technical leadership. This volume is the latest in a series of valuable publications on fracture testing and its application sponsored by this committee.

By cooperation with the ASTM, NASA is helping to fulfill its obligation to provide for the widest practicable and appropriate dissemination of results from its activities. Not only have aerospace problems directly furthered activity on fracture mechanics, but NASA scientists and engineers have directly contributed much to this new technology. It is the purpose of this publication to make the information in this important field as widely available as possible.

The Symposium on Fracture Toughness Testing and Its Applications was held at the Sixty-seventh ASTM Annual Meeting, in Chicago, Ill., June 21–26, 1964. It was sponsored by the ASTM Special Committee on Fracture Testing of High-Strength Materials. Chairman of the committee is J. R. Low, General Electric Co. Symposium chairman was W. F. Brown, Jr., National Aeronautics and Space Administration.

The symposium comprised three papers sessions and a panel discussion. Co-chairmen of the first session, on basic aspects of fracture mechanics, were T. J. Dolan, University of Illinois, and Harold Liebowitz, Office of Naval Research. Co-chairmen of the second session, on test methods, were Edward Steigerwald, Thompson Ramo Wooldridge, and Z. P. Saperstein, Douglas Aircraft Co. Co-chairmen of the third session, on practical applications, were B. M. Wundt, General Electric Co., and C. M. Carman, U. S. Army Ordnance. Mr. Brown was chairman of the panel discussion, and the other panelists were V. Weiss, S. Yukawa, P. Paris, J. E. Srawley, C. F. Tiffany, G. R. Irwin, T. J. Dolan, J. A. Kies, and W. F. Payne.

NOTE—The Society is not responsible, as a body, for the statements and opinions advanced in this publication.

CONTENTS

Test Methods

Practical Applications

FRACTURE TOUGHNESS TESTING AND ITS APPLICATION

INTRODUCTION

By W. F. Brown, Jr.[1]

The phenomenon of structural failure by catastrophic crack propagation at average stresses well below the yield strength has been known for many years. Rashes of such brittle failures have occurred with increasing frequency as the strength and size of our engineering structures have increased. In the past, each series of failures has given rise to a set of empirical tests and procedures that sometimes provided a solution to the specific problem at hand but did not result in a generally useful approach that would permit avoiding future failures.

Recent military and aerospace requirements for very-high-strength, lightweight hardware have given added importance to the problem of brittle fracture and greatly emphasized the need for a quantitative approach to the general problem of crack tolerance in structures. This need was dramatically highlighted several years ago by the repeated failures of early Polaris rocket motor cases at stresses well below the design value. The ASTM Special Committee on Fracture Testing of High Strength Materials was formed at the request of the Office of the Secretary of Defense to assist in providing a solution to this and related problems.

Over a period of the last five years this committee has been concerned with the question of how to evaluate the strength of metals in the presence of cracks or crack-like defects. The goal has been to provide laboratory tests and analytical techniques which will permit a quantitative measure of crack tolerance useful not only in evaluating materials for a given application but also in development of rational procedure for design against fracture. To achieve this goal requires the development of an essentially new branch of engineering science, and this, of course, is an evolutionary process which will take considerable time to complete. However, with the Irwin linear elastic fracture mechanics as a basis, considerable progress has been made in the desired direction, and today there are available reliable if somewhat overconservative procedures for avoiding failure by fracture in a new structure.

The primary purpose of this symposium was to review the methods for fracture toughness testing as proposed by the ASTM Special Committee on Fracture Testing of High Strength Materials, with a view toward defining their limitations and the extent to which they can be applied in structural design and alloy development. With this in mind the authors were asked to direct attention more toward clarification of concepts and procedures rather than toward presentation of new information. In order to further assist in this review function, the last session of the symposium consisted of a panel discussion

[1] Chairman of the symposium committee, NASA-Lewis Research Center, Cleveland, Ohio.

which gave those concerned with fracture testing an opportunity to put questions to a group of persons who have been active in the work of the ASTM Fracture Testing Committee.

There are, of course, many fracture test methods other than those discussed in this volume. Some of these often provide useful information regarding the fracture behavior of metallic materials. The pre-cracked Charpy impact test is a recent example of such a test which is easy to perform and uses only small specimens. Some efforts have been made to demonstrate a correlation between the results of pre-cracked Charpy tests and fracture toughness tests on larger specimens. A paper by G. M. Orner and C. E. Hartbower on this topic was presented at the symposium meeting, but because of space limitations does not appear in this volume. However, the reader should note that the panel discussion contains a considerable amount of information regarding the use of the pre-cracked Charpy test and references to investigations in this area.