Overview

Background

In the past 40 to 50 years, there has been an increased awareness of the effects of service environments on the performance of engineering materials of construction. Of particular concern is the susceptibility of these materials to environmentally induced cracking. Environmentally induced cracking is a "catch-all" term that refers to a number of different modes of corrosive degradation involving brittle cracking through the combined action of an environment, tensile stress (either applied or residual), and a susceptible material. These types of failures can oftentimes occur unexpectedly at stresses that are below normal design stresses and without substantial deformation. Examples of such types of cracking are chloride stress corrosion cracking (SCC), caustic cracking, hydrogen embrittlement, and liquid metal embrittlement.

Any material may be subject to environmentally induced cracking under the right (or wrong) environment and enough stress. Environmental induced cracking is a major concern particularly as larger, more sophisticated and costly equipment, components, and structures are being fabricated. The economic, safety, environmental, and legal impact of failures in these systems are, in many cases, paramount considerations.

Due to the aforementioned concerns for environmentally induced cracking, corrosion and materials specialists have worked consistently for the development of better and more predictive laboratory tests for this phenomenon. The activities of ASTM G-1 (Corrosion of Metals) has been largely directed at standardization of corrosion testing methods and procedures including those for environmentally induced cracking. These methods have historically involved exposure of statically stressed specimens (i.e., tension, C-ring, bent beam, or fracture mechanics specimens) of a material to a particular corrosive environment. Oftentimes, such tests are conducted over a range of applied stress levels while monitoring for time-to-failure. These types of tests are described in many ASTM standards.

One problem often associated with tests for environmentally induced cracking conducted in the aforementioned manner is the amount of testing time required to initiate cracking and, in turn, the amount of time needed to conduct a proper evaluation of these types of phenomena. In some cases, the initiation time needed to produce cracking in some material/environment situations is in excess of 10 000 hours (>1 year). In order to reduce this initiation time, many investigators use aggressive, artificial solutions to chemically accelerate these tests. However, the problem often associated with tests conducted in these environments is one of producing test results that relate to real-world situations. These methods can often be used to screen one material from another, but their predictive capabilities are often in doubt.

Approximately 20 years ago, a new testing technique referred to as slow strain rate testing was first applied to the investigation of environmentally induced cracking of metals and alloys. In this test method, the specimen is not held at a constant load or deflection during the period of exposure. The slow strain rate test uses the application of *dynamic* straining of the specimen in the form of a slow, monotonically increasing strain to failure. The apparent advantage of slow strain rate testing over conventional techniques is the use of the dynamic straining to mechanically accelerate cracking. It is hoped that this technique will allow the use of more realistic environments and also reduce the total time requirement for evaluating various metallurgical or environmental parameters.

Previous ASTM Symposium on Slow Strain Rate Testing

In 1979, ASTM Committee G-1 sponsored its first symposium on slow strain rate testing techniques resulting in the publication of *STP 665* (G. M. Ugiansky and J. H. Payer, editors). In that symposium, many papers were presented on the new technique which, at that time, was largely restricted to fundamental studies and research investigations. In general, the conclusions made by many investigators at the first symposium was that this new test method offered many advantages to conventional testing techniques for investigating environmentally induced cracking. In many cases, correlations were obtained between slow strain rate test results and operating experience that were not predicted by conventional corrosion testing techniques. However, more experience would be required before the true benefit of slow strain rate testing would be realized.

During the decade since the previous symposium, use of the slow strain rate symposium has expanded and been used for a number of different purposes, from fundamental research studies to material lot release testing and monitoring of corrosive severity of service environments. Additional experience has been gained in many material/environment situations using a variety of test specimens and loading procedures.

The Current Symposium

On 18-19 May 1992, ASTM Committee G-1 sponsored a second slow strain rate symposium. The goal of this second symposium was to highlight some of the new directions in testing for environmentally induced cracking using a variety of slow strain rate techniques. At this symposium, presentations were made that described both fundamental research studies and more practical engineering applications. These presentations centered on the developments that have been made in the understanding of slow strain rate test data and extensions in this testing technique that have occurred over the past ten years.

The slow strain rate symposium involved researchers for industry, government agencies, and universities from the United States, England, Germany, Spain, and Japan. Focused sessions were held on the use of slow strain rate testing techniques for the evaluation of environmentally induced cracking in nuclear power, oil and gas production, chemical process, and marine service.

Development and Application of Slow Strain Rate Testing Techniques

The symposium contained keynote and plenary lectures as well as sessions that focused on specific applications of slow strain rate testing. In keeping with the historical perspective, a presentation was made by Dr. Redvers Parkins (Emeritus Professor, University of Newcastle Upon Tyne) that summarized 25 years of experience with the slow strain rate testing technique. Dr. Parkins, who has played a key role in the inception and development of this testing technique, provides an excellent review of this subject in this section.

Additionally, this section contains a critical assessment of the limits of the slow strain rate technique as applied to the evaluation of stress corrosion cracking. This assessment was conducted through the review of the published literature and through a survey of user experience. In general, slow strain rate testing provided results that were predictive for stress corrosion cracking. However, if focused attention on the need to use consideration of electrochemical potential in the evaluation of test data in order to relate laboratory and field behavior.

Uses of Slow Strain Rate Testing to Control or Monitor Industrial Processes: Applications in Nuclear Power

This section highlighted the results from both laboratory studies and in-plant tests related to the serviceability of stainless steels and nickel base alloys in nuclear power applications. Specific emphasis was on the role of slow strain rate test data in the evaluation of materials for service in various types of reactor environments of varying environmental severity.

The application of slow strain rate testing to the study of environmentally induced cracking in high-temperature, high-purity water environments highlights the benefits of this testing technique. In many cases, it was difficult to simulate actual service experience using conventional statically stressed specimens under laboratory conditions that simulated those producing in-service failures. However, when slow strain rate testing was employed, better correlation between laboratory and plant experience was obtained.

The sensitivity of the slow strain rate testing technique to environmental and metallurgial parameters is highlighted. In tests conducted in boiling water reactor environments, it was possible to verify reactor water chemistry requirements and to minimize cracking problems using tests on materials of known susceptibility. This work illustrates the benefits of slow strain rate testing outside of the laboratory.

Research Applications and Developments in Slow Strain Rate Testing Techniques

This section focuses on developments of modified slow strain rate test techniques. These modified techniques incorporate a conventional, slowly increasing load with fracture mechanics test methods and precracked specimens. They are applied to the evaluation of hydrogen embrittlement and SCC in steels and nickel alloys. While shortening the testing time required for evaluation of material or environmental variables, it is hoped that the combination of these techniques also provides fracture mechanics data usable in design of equipment, components, and structures. This is a new area for slow strain rate testing and further work and development will be needed.

Also examined in this section are fundamental studies of SCC of high-strength steels and titanium alloys in various aqueous environments. The advantages of the slow strain rate technique are highlighted. In the case of high-strength steels, rapid evaluation of these materials to many environmental conditions and electrochemical potentials can be easily accomplished, thus aiding in the identification of cracking mechanisms. In the case of titanium alloys, the use of slow strain rate techniques provides for more consistent test results through minimizing the effects of crack initiation on the test results. However, the effects of strain rate on the test results in titanium alloys requires further work.

Industrial Applications of Slow Strain Rate Testing to Evaluate Environmentally Induced Cracking

This section contains papers that have used slow strain rate testing techniques to evaluate the compatibility of environments and materials of construction in various chemical process environments. Case histories are presented that show the benefits of slow strain rate data in the materials selection process. Additionally, they show the use of this test technique in the development of (1) process control parameters to limit the aggressiveness of chemical process environment on materials of construction, and (2) hydrogen content limits for high-strength steel weldments.

Specific emphasis is placed on the use of slow strain rate techniques for the evaluation of liquid metal embrittlement (LME) of aluminum and stainless alloys in contact with mercury. The data present in these papers show the applicability of this corrosion testing technique for the evaluation of LME. It overcomes the problems of surface tension and crack initiation commonly observed in statically stressed specimens.

Use of Slow Strain Rate Testing for Qualification of SCC Resistance of Corrosion Resistant Alloys (CRAs)

This section presents a case study that highlights the application of slow strain rate testing techniques to the lot release testing of commercial heats of nickel-base alloys. The case study specifically focuses on the use of this testing technique and related experiences found in the petroleum industry to obtain nickel-base alloys with adequate resistance to SCC in severe hydrocarbon production environments containing chloride, hydrogen sulfide, and elemental sulfur. This industry has found that in order for slow strain rate testing techniques to be truly predictive of alloy performance strict adherence to standardized procedures must be obtained. The test results from interlaboratory studies and the effects of heat-to-heat variations are discussed along with the effects of various environmental and metallurgical parameters on SCC performance.

The results presented in this section indicate the degree of control and standardization required for slow strain rate tests to be predictive. The lessons learned from this petroleum industry experience will most likely apply to other practical applications of slow strain rate testing in the future. It is hoped that through the presentation of this case study, the development effort required for future use of this testing technique will be minimized.

Acknowledgments

As symposium chairman, I hope that this STP benefits both fundamental researchers and practical engineers. The authors of the various papers in this volume have worked diligently in the application and development of new corrosion testing techniques and, in some cases, have dedicated their careers to this task. I would like to acknowledge their personal and technical efforts in this regard. Additionally, I wish to greatfully thank the ASTM staff that has worked so hard to make this publication possible.

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