Introduction

A proliferation of test methods relative to hydrogen embrittlement prevention and control has been generated since the publication of *Hydrogen Embrittlement Testing, ASTM STP 543.* As a result, only one voluntary consensus standard, ASTM Method for Mechanical Hydrogen Embrittlement Testing of Plating Processes and Aircraft Maintenance (F 519-77), has been generated since that time. Over 30 other standards, either federal, military, international, or industrial, have incorporated variations on this single test standard to provide some semblance of consistency throughout the industry.

A recent rash of failures due to hydrogen embrittlement, including failures in alloys other than high-strength steels, has caused a revitalized interest in this activity. The need for more standard test methods has never been more apparent. To this end, it was felt that the time had come to put together a symposium bringing in experts throughout the world to provide ASTM with a state-of-the-art review of the technology, its applications, and a focus on how to prevent hydrogen embrittlement failures in the future. These failures can be prevented either: (1) by eliminating the sources of hydrogen in the making of alloys (primarily steel); (2) by the manufacturing of hardware; or (3) by the ultimate generation of hydrogen under different environmental conditions generally associated with dissimilar metals producing galvanic couples that are primarily used as sacrificial anodes to prevent corrosion.

As of this writing, hydrogen embrittlement has now been documented as the cause for failure in high-strength aluminum alloys, specifically aged to avoid stress corrosion cracking, for such critical applications as main rotor fittings for helicopter blades. Fractures have occurred, as with steel, simply with time after being exposed to moisture in a storage box that encounters common atmospheric temperatures. These failures are found with a prestressed T-73 specifically designed to eliminate susceptibility to stress corrosion cracking overage condition for a 7000 series aluminum alloy.

The response to the call for papers in 1984 was expansive. The papers were divided primarily into seven sections:

1. Overview or state-of-the-art tutorial.
2. Existing standards, both on a national and international scale.
3. Hydrogen introduced during the making of steel or other alloys.
4. Methods for measuring the relative susceptibility of other metals and alloys to hydrogen-assisted stress cracking.
5. Hydrogen induced during welding.
6. The application of coupon test techniques to the testing of actual hardware.
7. Research in progress, which will be the foundation of future research and direct the activities of universities and other research institutes in future research activities.

This volume meets the purposes for which it was organized, provides the reader with a state-of-the-art review with specific details, and offers many new ideas.

Section 1 is an overview section that provides a backdrop for topics related to the processing of steel and titanium, service environment, manufacturing and processing, prevention and control, and research in progress.

Section 2 examines current standards and their significance and identifies qualifying factors in the use and interpretation of their results. The main focus is on the introduction of hydrogen

Copyright © 1988 by ASTM International www.astm.org

during manufacturing and processing, about which most of the specifications are written. ASTM Standard F 519 clearly illustrates that the standard is written solely to ensure that no hydrogen is introduced into the steel during a plating operation or during the use of maintenance chemicals in the cleaning of high-strength steels. Other technical societies have been surveyed to see how they use a variety of hydrogen embrittlement processing and control standards.

Section 3 focuses on the measurement of the hydrogen introduced during the making of steel, which can be measured as a total or diffusible hydrogen. This section summarizes advances in vacuum fusion and electrochemical methods for the measurement of both the total and diffusible hydrogen.

Section 4 provides a variety of new tests encompassing testing in high-pressure hydrogen gas environments to hydrogen sulfide stress cracking conditions encountered in the petroleum industry. The methods appear to focus on accelerated and rapid testing techniques that would be more consistent with the scheduling or time constraints of industry, with a concern about the cost impact to such controls.

Section 5 is dedicated totally to advances in hydrogen embrittlement prevention and control in welding. Real-time monitoring techniques of hydrogen during the weld metal deposition are described in addition to post-weld methods of hydrogen analysis, including mechanical tests that provide constraints that rank or evaluate hydrogen stress cracking susceptibility in welds.

Section 6 focuses on applying our knowledge of the behavior of hydrogen under sustained loads in production applications, whether these loads are externally induced or through residual stresses from processing, to actual hardware such as submunitions, fasteners, and hydraulic actuators.

Section 7 identifies research in progress related to a broad range of applications from slow strain rate tension testing to hydrogen-assisted fatigue failures in niobium. Methods of measuring hydrogen in fabricated hardware and their precision and accuracy are discussed. This STP provides a variety of new proposed test methods, interpretation of data, and use in a variety of fields that include petroleum, nuclear, aircraft, and space, in addition to the more common military applications of high-strength steels.

The STP serves as a foundation for any manufacturer involved in the plating of parts for corrosion protection and provides an awareness of the sensitivity of these parts to the environment relative to any embrittling factors that might be produced because of conditions for environmentally assisted fracture that are not commonly identified. The most prominent experts in the field of hydrogen embrittlement have contributed to this STP and can be readily identified with regard to any further information or specific details of their work that might support the prevention and control of hydrogen embrittlement failures in any new applications.

In summary, we are encountering an era where high-strength materials are being selected for applications based on ballistic impact, wear resistance, hardened surfaces for implementation of accelerated manufacturing techniques (as with self-drilling fasteners), and even hard-facing for improved wear resistance. All these methods in one way or another eventually require corrosion protection systems or the introduction of dissimilar metals. Because of the types of fabrication employed to produce hard surfaces or high-strength materials, residual stresses are inherent to the manufactured hardware. All of these factors in combination provide a potential for hydrogen embrittlement failure which cannot be ignored. Routine, conventional 3-h to 23-h baking treatments at 375°F (190.5°C) are no longer sufficient to prevent embrittlement failures with hydrogen, especially in-service.

The articles in this STP provide us with an awareness of the problems and the tools with which to address the prevention and control of any hydrogen stress assisted failures. Only by implementing this knowledge and properly interpreting test results can unanticipated hydrogen embrittlement failures of fracture critical parts be avoided. Therefore, this STP is not the completion or summary of a large amount of work that puts the problem of hydrogen embrittlement prevention and control to rest, but instead should be considered as the foundation for developing standards that will help us avoid costly life-threatening catastrophic failures in the future.

Louis Raymond, Ph.D.,

L. Raymond & Associates, P.O. Box 7925, Newport Beach, CA 92658-7925; symposium chairman and editor.