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Slow Strain Rate Test Method for Screening Corrosion-Resistant Alloys for Stress Corrosion Cracking in Sour Oilfield Service

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ABSTRACT

Provides a standardized method for screening corrosion-resistant alloys (CRAs) for use in oilfield production environments. The SSR test, which is relatively short in duration, incorporates a slow, dynamic strain applied at a constant extension rate. This results in acceleration of the initiation of cracking in susceptible materials, thereby simulating rather severe conditions. The test is useful in evaluating stainless steels and nickel-based alloys for resistance to stress corrosion cracking (SCC) in simulated oilfield production environments at elevated temperatures. .

KEYWORDS

corrosion-resistant alloys (CRAs), corrosion testing, hydrogen sulfide, metals, slow strain rate test, sour environments, stress corrosion cracking, TG 133

Foreword

In NACE standards, the terms shall, must, should, and may are used in accordance with the definitions of these terms in the NACE Publications Style Manual. The terms shall and must are used to state a requirement, and are considered mandatory. The term should is used to state something good and is recommended, but is not considered mandatory. The term may is used to state something considered optional.

Failures of metals exposed to hydrogen sulfide (H₂S)-containing (sour) oilfield production environments have been reported for more than 50 years and have usually occurred in carbon or low-alloy steels.^{1,2} Failures of high-strength steels by brittle cracking (sulfide stress cracking [SSC]) and of lower-strength plate and pipe steels by blistering and hydrogen-induced (stepwise) cracking have also been reported. As a result, engineers and scientists have developed test methods to evaluate steels for resistance to failure by these mechanisms in sour environments.

These and other considerations led to the establishment of NACE Task Group (TG) T-1F-9, "Metallic Materials Testing Techniques for Sulfide Corrosion Cracking," which originally developed NACE Standard TM0177³ in 1977. The task group (now TG 085) has continued to revise that standard.

An additional interest of the original TG T-1F-9 was the application of corrosion-resistant alloys (CRAs), primarily stainless steels and nickel-based alloys, in oilfield production environments. Some of these CRAs have experienced stress corrosion cracking (SCC) when exposed to H₂S, carbon dioxide (CO₂), and brine. Therefore, a standardized method for screening CRAs for use in oilfield production environments is of extreme importance to the entire petroleum industry, and work group TG T-1F-9e (now TG 133) was formed to address this issue.

Several screening methods were considered: autoclave tests with statically stressed specimens, fracture mechanics methods, and the slow strain rate (SSR) test methods. Each has advantages and disadvantages that make the selection of a single test method for standardization difficult. However, the SSR test has emerged as a relatively quick, simple method that can be used for the evaluation of CRAs for resistance to a variety of environmental cracking phenomena, including SCC, hydrogen embrittlement, and liquid metal cracking.^{1,2} The use of SSR test methods, particularly in screening tests, has become more common in many laboratories for evaluation of CRAs for downhole applications.

The SSR test incorporates a slow (compared with conventional tensile tests), dynamic strain applied at a constant extension rate. Extension rates of 2.54×10^{-9} to 2.54×10^{-7} m/s (1.00×10^{-7} to 1.00×10^{-5} in/s) are commonly used. The principal effect of the constant extension rate, in combination with environmental or corrosive attack, is to accelerate the initiation of cracking in susceptible CRAs. By doing so, the SSR acts in much the same way as a notch or precrack in statically stressed environmental cracking tests. Failure is obtained within a few days for commonly used extension rates.

Because of its relatively short test duration, the SSR test has been found useful in evaluating CRAs for resistance to SCC in simulated oilfield production environments at elevated temperatures.^{4,5} By comparison, it has been observed that it may take thousands of hours of exposure time to evaluate CRAs using more conventional statically stressed specimens.^{6,7}

In an SSR test, the test specimen is pulled to failure. One benefit of this method is that the ultimate failure of the test specimen is a positive result. That is, parameters (including reduction in area and plastic elongation) and visual observations can always be quantified. These results are usually further quantified by comparison with the results of similar tests performed in an inert environment. Accelerating the crack initiation by this mechanical technique tends to make the SSR test appear to be a rather severe test by being able to fail CRAs under environmental conditions in which no other test method (at reasonable exposure times) can produce failures. Because the exposure time is short and the strain rate is somewhat arbitrary, the results of SSR testing are not intended to be used directly to infer service performance. It is primarily a screening or ranking method that should be used in combination with a more extensive laboratory evaluation involving complementary testing for corrosion and environmental cracking. Service experience should be reviewed before material selection decisions are made.

A round-robin testing program was conducted by former TG T-1F-9 during the early development of this standard to evaluate the variability of SSR test data and the influences of various testing-related parameters. Draft #5 of the proposed test method was used as the basis for the round-robin testing program, and a total of seven companies participated. The results of the round-robin testing program indicated that large deviations in the SSR test data were observed for some conditions. However, with the evaluation of the procedures used by the round-robin participants, several recommendations for changes in SSR test procedures were made. Most of the recommended changes were included in this standard to reduce the amount of deviation in the test results. These changes included:

- (1) Ground surfaces (not turned) and finer surface finish on the test specimen gauge section;
- (2) Additional specifications regarding testing machine compliance;
- (3) Improved calculation technique for reduction in area; and
- (4) References to industry standards containing accepted procedures for autoclave and SSR testing.

Based on the above-mentioned considerations, TG T-1F-9 developed this standard test method incorporating the SSR test to be used by laboratory investigators for screening CRAs for SCC in sour oilfield service. This NACE standard was originally developed by TG T-1F-9 in 1998 under the direction of Unit Committee T-1F, "Metallurgy of Oilfield Equipment." It was revised in 2004 and 2011 by TG 133, "Review and Revise as Necessary NACE Standard TM0198-2004." TG 133 is administered by Specific Technology Group (STG) 32, "Oil and Gas Production—Metallurgy." This standard is issued by NACE under the auspices of STG 32.

NACE International Standard Test Method (TM0198-2016)

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1.	General	4
2.	Reagents.....	4
3.	Test Specimen.....	5
4.	Test Equipment	6
5.	Determination of Baseline Material Properties.....	7
6.	Environmental Test Conditions.....	8
7.	Mechanical Test Conditions	10
8.	Test Procedure.....	10
9.	Analysis and Reporting of Test Results.....	14
	References.....	19
	Appendix A: Safety Considerations in Handling H ₂ S (Nonmandatory).....	20
	Appendix B: Explanatory Notes on Test Method (Nonmandatory).....	21

Figures and Tables

Figure 1: Standard SSR Test Specimen	5
Figure 2: Schematic Presentation of the Possible Effects of Strain Rate on Various Types of Cracking Behavior	10
Figure 3: Schematic of Typical SSR Test System	11
Figure 4: Typical Load-versus-Time Plots for SSR Test of a Ni-Fe-Cr-Mo Alloy Performed at an Extension Rate of 1×10^{-7} m/s (4×10^{-6} in/s) in Several Test Environments. (Test Environment A is a Reference Inert Environment)	13
Figure 5: Schematic Illustration Based on Data for a Super-13 Cr Stainless Steel Showing Basis for Determining the Plastic Strain to Failure (E_p) Based on the Total Strain to Failure (E_{tot}) and the Elastic Contribution (E_{el}).....	15
Figure 6: Typical Nickel Alloy Stress-Strain Curve, Where There is No Work-Hardening	16
Table 1: NACE Uniform Material Testing Report Form (Part 1)—Testing in Accordance with NACE SSR Test.....	17

Section 1: General

- 1.1** This standard establishes a SSR test method for screening CRAs (i.e., stainless steels and nickel-based alloys) for resistance to SCC at elevated temperatures in sour oilfield production environments. The fact that this test method is a screening method implies that further evaluation or additional experience may be required before materials selection decisions can be made.
- 1.2** This standard specifies reagents, test specimen, test equipment, determination of baseline material properties, environmental and mechanical test conditions, test procedure, and analysis and reporting of test results.
- 1.3** The test procedure can be summarized as follows: An SSR test specimen is exposed to a continuously increasing uniaxial tensile stress imposed by a slow and constant extension rate in the presence of an acidic aqueous environment containing H_2S , CO_2 , and brine at an elevated temperature. The ductility parameters (plastic elongation and reduction in area) obtained from evaluation of the SSR test specimen along with visual observation of its gauge section and fracture surface morphology are used as indicators of the material's resistance to SCC in the test environment. These results are then compared to the results of a similar test performed in an inert environment to quantify the resistance or susceptibility to SCC in the test environment.
- 1.4** Procedures for SSR testing shall be consistent with those provided in ASTM⁽¹⁾ G129.8 Tests involving high pressure or high temperature, or both, shall be performed using procedures consistent with those provided in ASTM G111.⁹ The only deviations from these procedures shall be those specifically stated in this standard.
- 1.5** Safety Precautions
- 1.5.1** H_2S is an extremely toxic gas that must be handled with extreme care. (See Appendix A [nonmandatory] for a discussion of safety considerations and toxicity of this gas.)
- 1.5.2** Precautions must be taken to protect personnel from the hazards of rapid release of hot gases and fluids and explosion when working with the high-pressure, high-temperature test conditions.
- 1.6** This standard is not intended to include procedures for cyclic SSR testing. However, such procedures are currently under development and are in use in some laboratories.

Section 2: Reagents

- 2.1** Reagent Purity
- 2.1.1** The gases, sodium chloride (NaCl), and solvents shall be reagent or chemically pure grade chemicals. The reasons for this reagent purity are discussed in Appendix B (nonmandatory).
- 2.1.2** The water shall be distilled or deionized and of quality equal to or greater than ASTM Type IV in accordance with ASTM D1193.¹⁰ Tap water shall not be used.

⁽¹⁾ ASTM International (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.