Item No. 24010
NACE International Publication 1F192 (2013 Edition)

This Technical Committee Report has been prepared by NACE International Task Group (TG) 328,* "Materials, Welding and Fabrication of Corrosion-Resistant Alloys (CRAs)—Corrosion Issues in Oil and Gas Production."

Use of Corrosion-Resistant Alloys in Oilfield Environments

Dedication

This report is dedicated to Richard S. (Dick) Treseder. Dick was the original chairman of the T-1F-21 work group that worked tirelessly for its conclusion. This report would not have been possible without his efforts and guidance. Dick died April 16, 1999, before the report could be completed. The succeeding chairman and other task group members knew Dick as a good friend and are deeply indebted to him for his dedication and leadership.

Dick was truly one of the pioneers in the area of corrosion and metallurgy in the oil and gas industry. He was a NACE Fellow and a NACE member for almost 52 years. We as an industry owe more to Dick than what we can convey here in this short dedication.

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Foreword

The use of corrosion-resistant alloys (CRAs) as a corrosion-control method in aggressive oil and gas production environments is now established; however, the complexity of the corrosion effects associated with these severe conditions and the metallurgical complexities of the many alloys being offered have resulted in challenging materials selection problems for the corrosion engineer. Further consideration is also given to the performance of the materials in the welded condition for many applications, as weldments sometimes do not retain the same corrosion resistance as parent materials.

The purpose of this technical committee report is to bring together state-of-the-art knowledge covering experiences in the application of CRAs and issues of welding, fabrication, and assessment for successful operation in oil and gas production environments with specific consideration of corrosion and environmentally assisted cracking, and to highlight technology gaps impacting the industry.

This report is intended to provide engineers worldwide who have knowledge of the characteristics of corrosion damage modes in oil and gas production with information to avoid repeated failures and the recurrence of concerns about CRA material selection. Some issues remain to be addressed, and these are highlighted as technology gaps. This report does not extend to refinery or distribution applications.

This technical committee report was originally prepared in 1992 by NACE Task Group T-1F-21, revised in 1993 by Work Group T-1F-21b, in 2000 by Work Group T-1F-21g, and in 2012 by Task Group (TG) 328. This report is published by NACE International under the auspices of Specific Technology Group (STG) 32, "Oil and Gas Production—Metallurgy."

NACE technical committee reports are intended to convey technical information or state-of-the-art knowledge regarding corrosion. In many cases, they discuss specific applications of corrosion mitigation technology, whether considered successful or not. Statements used to convey this information are factual and are provided to the reader as input and guidance for consideration when applying this technology in the future. However, these statements are not intended to be recommendations for general application of this technology, and must not be construed as such.

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Section 1: Introduction

1.1 Definition of CRA: A corrosion-resistant alloy (CRA) is commonly defined as an alloy with an inherently low corrosion rate in the operating environment of interest, typically much lower than carbon and low-alloy steels (e.g., 1 to 2 orders of magnitude less). However, they are sometimes subject to localized corrosion (crevice and pitting corrosion) or environmentally assisted cracking, which often determines their envelope of application. Processing and welding of these alloys sometimes significantly influences their corrosion resistance, and thus it is important that the final product form and manufacturing route are considered in the assessment of the suitability of the alloy for the intended operating environment.

In addition, the mode of operation of the equipment commonly determines the acceptable extent of material degradation. For example, downhole tools and equipment operating for short periods of time in harsh conditions sometimes use a lower-grade alloy on a fitness-for-purpose consideration in contrast to permanently installed equipment, provided they retain suitable performance in normal operating conditions.

1.2 Coverage of Report: This report covers a wide range of corrosion mechanisms, including stress corrosion cracking (SCC), forms of hydrogen embrittlement (HE), general corrosion, pitting and crevice corrosion, corrosion fatigue, and liquid metal cracking. The oil and gas sector is continuing to develop more demanding wells which are corrosive to carbon steel because of the composition of the fluids produced, the production temperature, and the pressure in these wells; as a result, CRAs are used for successful completion and operation.

However, such alloys present a range of technical challenges in fabrication and assessment for selection in new fields, which are often close to limits of known applicability in extreme cases, or that possibly have reduced corrosion or cracking resistance as a result of issues arising in manufacturing and welding practices.

This report is written for the engineer who has knowledge of the characteristics of corrosion systems encountered in oil and gas production, and who has experience with oilfield applications of CRAs.

1.3 Organization of Report: This report is organized to allow information on a specific subject to be found without reading the entire report. However, it is desired that the reader consider both the general information and that provided specifically by alloy type, before referring to the information on performance experiences.

1.4 Use of SI and English Units: Measurements in this report follow the *NACE International Publication Style Manual* (Fifth Edition, 2008). Some measurements are listed in U.S. customary units followed by the Systeme Internationale (SI) conversion, while others are listed in SI units first. In accordance with the *Style Manual*, the actual measurements recorded are shown first followed by the conversion.

1.5 Limitations of Use: This NACE technical committee report does not present standardized materials selection methods or materials specifications. This report presents information on current industry practices only and is not to be interpreted as recommending use of the materials listed herein.

In addition, comment on the influence of welding and joining techniques on the CRA materials does not remove any requirements to undertake qualification and acceptance tests for the appropriate application as determined by the prevailing standards and end client requirements pertaining to the same.

This report aims to highlight major considerations for the materials/corrosion engineer in the oil and gas production sector and to identify current technology gaps that industry wants to address to support the demands for applications in increasingly harsh environments of pressure, temperature, and corrosiveness.

1.6 Updating: Users of this report are encouraged to provide information on experiences of materials' performance both in terms of failures and detailed documented information on satisfactory operation in more aggressive conditions. Also, identification of additional technology gaps is likely to be useful to focus development of activities in the future. Please advise STG 32 by sending correspondence to NACE International to allow suggested revisions to be reviewed by TG 328, which is assigned this responsibility under STG 32.

Section 2: General

2.1 Definitions: The definitions used in this version are based on those in NACE/ASTM(1) G193 "Standard Terminology and Acronyms Relating to Corrosion." Therefore, the previous version has now been modified and the section that gave individual definition of terms has been reduced significantly. However, below are listed terms with specific meaning in this report when it is necessary to clarify for the reader. Note ISO 8044[2] has not been cited as an existing International Standard with additional corrosion terminology.

Activation: The changing of a passive surface of a metal to a chemically active state.

Active Metal: A metal ready to corrode, or being corroded.

Active Potential: The potential of a corroding material.

Air Induction Melting (AIM): A process for melting and refining metals in which the metal is exposed to air and melted by induction heating.

Anion: A negatively charged ion that migrates through the electrolyte toward the anode under the influence of a potential gradient (expands definition).

Argon-Oxygen Decarburization (AOD): A refining process used in the production of stainless steels and nickel-based alloys in which an argon-oxygen mixture is blown into the molten metal bath.

Cation: A positively charged ion that migrates through the electrolyte toward the cathode under the influence of a potential gradient (expands definition).

Duplex Stainless Steel: A stainless steel whose microstructure at room temperature consists primarily of a mixture of approximately equal proportions of austenite and ferrite.

Electroslag Remelting (ESR): A consumable-electrode remelting process in which heat is generated by passage of current through a conductive slag.

Hydrogen Embrittlement (HE): A loss of ductility of a metal resulting from absorption of hydrogen.

Hydrogen Stress Cracking (HSC): Cracking that results from the presence of hydrogen in a metal in combination with tensile stress. It occurs most frequently with high-strength alloys (also called hydrogen-induced stress cracking, HISC).

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