

Use of Corrosion-Resistant Alloys in Oilfield Environments

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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 base metals.

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.

Rationale

In the period following the 2013 revision of this report, a substantial amount of new research, reportage, emerging applications, expanded utilization of existing grades, and the introduction of new CRA grades have surfaced. Some content from the previous report is now obsolete, while others necessitate modifications to accommodate recent developments and challenges. This revision comprehensively addresses these aspects and presents the most recent advancements.

AMPP technical 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.

Referenced Standards and Other Consensus Documents

Unless specifically dated, the latest edition, revision, or amendment of the documents listed in the table below shall apply.

AMPP, NACE/SSPC, www.ampp.org:

NACE/ASTM G193	Standard Terminology and Acronyms Relating to Corrosion
ANSI/NACE MR0175/ISO 15156	Petroleum and Natural Gas Industries—Materials for Use in H ₂ S-Containing Environments in Oil and Gas Production

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AMPP TR21522	Corrosion Testing for Additive Manufacturing
NACE TM0177	Laboratory Testing of Metals for Resistance to Sulfide Stress Cracking and Stress Corrosion Cracking in H ₂ S Environments
NACE TM0198	Slow Strain Rate Test Method for Screening Corrosion-Resistant Alloys (CRAs) for Stress Corrosion Cracking in Sour Oilfield Service
NACE MR0176	Metallic Materials for Sucker Rod Pumps for Hydrogen Sulfide Environments
AMPP TR21524	Commentary on Standards Development for Selection and Qualification of HSC-Resistant Materials in Subsea Service with Cathodic Protection
NACE SP0198	Control of Corrosion under Thermal Insulation and Fireproofing Materials—A Systems Approach
NACE NO.12, AWS C2.23M/ C2.23, SSPC CS-23	Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel

American Petroleum Institute (API), www.api.org:

API 5LD	Specification for CRA Clad or Lined Steel Pipe
API 6A/ISO 10423	Petroleum and Natural Gas Industries—Drilling and Production Equipment—Wellhead and Christmas Tree Equipment
API 6A718	Specification of Nickel Base Alloy 718 (UNS N07718) for Oil and Gas Drilling and Production Equipment
API SPEC 6DSS	Specification for Subsea Pipeline Valves
API RP 2RD	Design of Risers for Floating Production Systems (FPSs) and Tension-Leg Platforms (TLPs)
API STD 2RD	Dynamic Risers for Floating Production Systems
API TR 938-C	Use of Duplex Stainless Steels in the Oil Refining Industry
API STD 20S	Additively Manufactured Metallic Components for Use in the Petroleum and Natural Gas Industries
API RP 583	Corrosion Under Insulation and Fireproofing
API SPEC 5CRA	Corrosion-resistant Alloy Seamless Products for Use as Casing, Tubing, Coupling Stock, and Accessory Material
API STD 6ACRA	Age-hardened Nickel-based Alloys for Oil and Gas Drilling and Production Equipment
API TR 21TR1	Material Selection for Bolting
API SPEC 20F	Corrosion-resistant Bolting for Use in the Petroleum and Natural Gas Industries
API RP 582	Welding Guidelines for the Chemical, Oil, and Gas Industries - Fourth Edition

American National Standards Institute (ANSI), www.ansi.org:

ANSI H35.1	American National Standard Alloy and Temper Designation Systems For Aluminum
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American Society of Mechanical Engineers (ASME), www.asme.org:

ASME Boiler and Pressure Vessel Code (BPVC), Section VIII	Materials
ASME Boiler and Pressure Vessel Code (BPVC), Section VIII	Rules for Construction of Pressure Vessels
ASME Boiler and Pressure Vessel Code (BPVC), Section IX	Welding, Brazing, and Fusing Qualifications

ASTM International, www.astm.org:

ASTM G48	Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution
ASTM A263	Standard Specification for Stainless Chromium Steel-Clad Plate
ASTM A264	Standard Specification for Stainless Chromium-Nickel Steel-Clad Plate
ASTM A265	Standard Specification for Nickel and Nickel-Base Alloy-Clad Steel Plate
ASTM A666	Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar
ASTM A268	Standard Specification for Seamless and Welded Ferritic and Martensitic Stainless Steel Tubing for General Service
ASTM A995	Standard Specification for Castings, Austenitic-Ferritic (Duplex) Stainless Steel, for Pressure-Containing Parts
ASTM C923	Standard Specification for Resilient Connectors between Reinforced Concrete Manhole Structures, Pipes, and Laterals
ASTM B601	Standard Practice for Temper Designations for Copper and Copper Alloys-Wrought and Cast
ASTM A262	Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
ASTM G28	Standard Test Methods for Detecting Susceptibility to Intergranular Corrosion in Wrought, Nickel-Rich, Chromium-Bearing Alloys
ASTM A923	Standard Test Methods for Detecting Dispersed Intermetallic Phase in Duplex Austenitic/Ferritic Stainless Steel
ASTM E562	Standard Test Method for Determining Volume Fraction by Systematic Manual Point Count
ASTM E140	Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness
ASTM B622	Standard Specification for Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube
ASTM B564	Standard Specification for Nickel Alloy Forgings
ASTM B622	Standard Specification for Seamless Nickel and Nickel-Cobalt Alloy Pipe and Tube
ASTM B366	Standard Specification for Factory-Made Wrought Nickel and Nickel Alloy Fittings
ASTM B994	Standard Specification for Nickel-Cobalt Alloy Coating
ASTM B127	Standard Specification for Nickel-Copper Alloy Plate, Sheet, and Strip
ASTM B163	Standard Specification for Seamless Nickel and Nickel Alloy Condenser and Heat-Exchanger Tubes
ASTM B164	Standard Specification for Nickel-Copper Alloy Rod, Bar, and Wire
ASTM B165	Standard Specification for Nickel-Copper Alloy Seamless Pipe and Tube
ASTM B809	Standard Specification for General Requirements for Nickel and Nickel Alloys Seamless Pipe and Tube
ASTM A494	Standard Specification for Castings, Nickel and Nickel Alloy
ASTM E399	Standard Test Method for Linear-Elastic Plane-Strain Fracture Toughness of Metallic Materials
ASTM A434	Standard Specification for Steel Bars, Alloy, Hot-Wrought or Cold-Finished, Quenched and Tempered

ASTM A453	Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steels
ASTM B265	Standard Specification for Titanium and Titanium Alloy Strip, Sheet, and Plate
ASTM B363	Standard Specification for Seamless and Welded Unalloyed Titanium and Titanium Alloy Welding Fittings
ASTM B348	Standard Specification for Titanium and Titanium Alloy Bars and Billets
ASTM B381	Standard Specification for Titanium and Titanium Alloy Forgings
ASTM B861	Standard Specification for Titanium and Titanium Alloy Seamless Pipe
ASTM B862	Standard Specification for Titanium and Titanium Alloy Welded Pipe
ASTM B196	Standard Specification for Copper-Beryllium Alloy Rod and Bar
ASTM B446	Standard Specification for Nickel-Chromium-Molybdenum-Niobium Alloy, Nickel-Chromium-Molybdenum-Silicon Alloy, and Nickel-Chromium-Molybdenum-Tungsten Alloy Rod and Bar
ASTM B928	Standard Specification for High Magnesium Aluminum-Alloy Products for Marine Service and Similar Environments
ASTM B209	Standard Specification for Aluminum and Aluminum-Alloy Sheet and Plate
ASTM A380	Standard Test Method for Corrosion Testing of Decorative Electrodeposited Coatings by the Corrodkote Procedure
ASTM A967	Standard Specification for Chemical Passivation Treatments for Stainless Steel Parts
ASTM A1084	Standard Test Method for Detecting Dual-Phase Phases in Lean Duplex Austenitic/ Ferritic Stainless Steels

American Welding Society (AWS), www.aws.org:

AWS A5.13	Specification for Solid Surfacing Welding Rods and Electrodes
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Det Norske Veritas (DNV), www.dnv.com:

DNV RP-F112	Duplex stainless steel – design against hydrogen induced stress cracking
DNV-RP-B204	Welding of subsea production system equipment
DNV-RP-G109	Risk based management of corrosion under insulation
DNV-ST-B203	Additive manufacturing of metallic parts
DNV-RP-C203	Fatigue design of offshore steel structures
DNV-RP-B401	Cathodic protection design

Engineering Equipment and Materials Users Association (EEMUA), www.eemua.org:

EEMUA Publication 234	90/10 Copper nickel alloy piping for offshore applications (Specification)
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European Federation of Corrosion (EFC), www.efcweb.org:

EFC Publication 17	Corrosion Resistant Alloys for Oil and Gas Production: Guidance on General Requirements and Test Methods for H ₂ S Service
EFC Publication 5	Corrosion Under Insulation (CUI) Guidelines

International Organization for Standardization (ISO), www.iso.org:

ISO 13628 (Series)	Petroleum and natural gas industries - Design and operation of subsea production systems
ISO 21467	Petroleum, petrochemical and natural gas industries - Materials selection and corrosion control for oil and gas production systems
ISO 17781	Petroleum, petrochemical and natural gas industries – Test methods for quality control of microstructure of ferritic/austenitic (duplex) stainless steels
ISO 2063 (Series)	Thermal spraying – Zinc, aluminium and their alloys

ISO 14918	Thermal spraying – Qualification testing of thermal sprayers
ISO 15546	Petroleum and natural gas industries - Aluminium alloy drill pipe
ISO 13680	Oil and gas industries including lower carbon energy — Corrosion-resistant alloy seamless products for use as casing, tubing, coupling stock and accessory material — Technical delivery conditions

Standards Norway, www.standard.no:

NORSOK M-001	Materials selection - Edition 5
NORSOK M-630	Material data sheets and element data sheets for piping
NORSOK M-601	Welding and inspection of piping - Edition 6
NORSOK M-501	Surface preparation and protective coating - Edition 7

Scope

The technical report brings together state-of-the-art knowledge covering experiences in the application of Corrosion-Resistant Alloys (CRAs) and issues of welding, fabrication, surface, finishes, 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 also provides a collection of reported successful uses and failure history of specific CRAs used in oil field environments.

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, pitting, under-deposit 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.

1.2 Coverage of Report

This report covers a wide range of corrosion mechanisms, including uniform corrosion, localized corrosion, i.e., pitting and crevice corrosion, and environmentally assisted cracking (EAC) i.e. stress corrosion cracking (SCC), forms of hydrogen embrittlement (HE), and liquid metal embrittlement (LME) and corrosion fatigue. The oil and gas industry is witnessing the emergence of increasingly challenging wells characterized by corrosive reservoir conditions. There is a growing demand for unattended or unmanned assets to minimize the need for frequent inspections and maintenance. Moreover, the imperative for energy transition and circular economy has prompted several new adaptive modifications to the oil and gas processing streams and their effluents. These evolving requirements further necessitate the utilization of CRAs instead of carbon steels. Owners and operators perform life cycle cost analyses to strike a balance between capital expenditures (CAPEX) and operational expenditures (OPEX) while ensuring the integrity of assets and equipment. 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.

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.