

Paper No.
16654



Environmental Limits and Susceptibility of UNS S30403 to Environmentally Assisted Cracking in Thermal Oil Sand Operations.

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ABSTRACT

Environmental and material limits specified in ANSI/NACE MR0175/ISO15156-3:2015 restrict this use of austenitic stainless steel alloys under sour conditions typically encountered in thermal in-situ oil sand operations. This paper is a follow up study to one presented in 2016 (NACE-2016-7892), where C-ring testing was conducted to evaluate the susceptibility of austenitic stainless steels to conditions simulating a severe downhole environment; i.e. 230 °C, pH of 3.5, and variable chloride concentrations and H₂S partial pressures. Prior results indicated that after 720 hours of exposure, material did not show any cracking when tested at 10,000 mg/L Cl⁻ and 1,000 kPa pH₂S, and at 50,000 mg/L Cl⁻ and 100 kPa pH₂S.

In recent testing, three heats of UNS S30403 were tested under the same environmental conditions above and cracking was observed in some heats, suggesting borderline resistance to cracking under these severe conditions and unsuitability per ANSI/NACE MR0175/ISO15156-3:2015. Additional C-ring testing was performed in a less severe environment consisting of 230 °C, pH of 5, a chloride concentration of 10,000 mg/L and 100 kPa pH₂S, where the same three heats of UNS S30403 demonstrated no cracking.

Key words: environmentally assisted cracking, EAC, stainless steel, oil sands, thermal operations, stress corrosion cracking

INTRODUCTION

While carbon steel is the most commonly used material for in-situ facilities including gathering lines and plant piping; austenitic stainless steels (SS) have commonly, and effectively, been used in Alberta in-situ thermal operations for a variety of applications such as: valve trim, instrumentation, and vessel internals.¹ The nature of in-situ thermal processes routinely exposes these components to elevated temperatures (>200 °C), high chloride concentrations and varying H₂S levels. The aforementioned environmental conditions are known to promote environmental cracking (EC), such as chloride stress corrosion cracking (CSCC) and sulphide stress cracking (SSC). The potential for these conditions to cause cracking in stainless steel components must be evaluated during the material selection process to ensure the long-term integrity of these systems. Material guidelines such as ANSI⁽¹⁾/NACE MR0175/ISO⁽²⁾15156-3:2015 and EFC⁽³⁾ publications 16 and 17 offer recommendations for material selection; however, these guidelines cover only a limited range of environmental conditions and often fall short of those encountered in oil sands in-situ operations.^{2,3,4} For this reason, austenitic stainless steels have often been used by Canadian in-situ oil sand operators beyond the limits established by these standards, often without incident¹. Despite the performance of these materials in the field, in many cases it is difficult to establish a solid technical basis to challenge the established operating limits of these alloys due to a lack of well documented operating histories, and relevant laboratory testing. The track record of these materials, as well as experimental results show that some grades of stainless steel perform well beyond these recommended limits; suggesting that the current guidelines are overly conservative, and that these materials can potentially be used under more severe conditions without the need to resort to more expensive corrosion resistant alloys.⁵

Current boundaries for general use of austenitic stainless steels are limited to environments below 60 °C and 100 kPa (15 psi) partial pressure H₂S (pH₂S) or environments with chloride concentrations below 50 mg/L, as per ANSI/NACE MR0175/ISO15156-3:2015 (Table 1).² Expanded limits with regard to specific combinations of temperature, pH₂S, chloride concentration and pH have been issued for S31603, but do not address the use of other grades, such as S30403. Unrestricted use of austenitic stainless steels is permitted by ANSI/NACE MR0175/ISO15156:2015-3 for specific applications, such as instrumentation, control devices and various sub-surface components; however, there is also a cautionary remark that some combinations of temperature, pH₂S, chloride concentration and pH may not be appropriate, necessitating laboratory testing for specific applications.²

The objective of this test program was to develop sufficient data to support the use of austenitic stainless steels in thermal in-situ operations, thereby expanding the current limits set in ANSI/NACE MR0175/ISO15156-3:2015. Laboratory testing was completed using S30403 with the intent that successful testing of S30403 would also permit the use S31603. Initial testing was performed using triplicate specimens exposed to numerous environmental conditions, probing for a boundary where environmental cracking occurs. All test specimens originated from a single heat in order to limit the number of tests and associated costs for this exploratory exercise. Results demonstrated a significant expansion in environmental limits, to those reaching 230 °C, pH of 3.5, chloride concentration of 10,000 mg/L and pH₂S of 1000 kPa. It was also found that the chloride concentration could be increased to 50,000 mg/L if the pH₂S was reduced to 100 kPa.⁶

To fully satisfy laboratory test requirements of ANSI/NACE MR0175/ISO15156-3:2015, an additional three heats of UNS S30403 were tested under the same environmental conditions above. Cracking was observed in some heats, suggesting S30403 has borderline resistance to cracking under these severe conditions and cannot be safely used in these environments. Additional C-ring testing was then performed in a less severe environment that still exceeds the severity of most thermal in-situ

¹ American National Standards Institute (ANSI). (25 West 43rd Street, New York, NY 10036).

² International Organization for Standardization (ISO). (Chemin de Blandonnet 8, 1214 Vernier, Geneva Switzerland).

³ European Federation of Corrosion (EFC). (Institute of Materials, London)

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environments (with exception to steam generator blowdown or other streams where concentration of dissolved solids occurs). The environmental conditions of this test are summarized as below:

- Temperature: 230 °C (446 °F)
- H₂S partial pressure: 100 kPa (14.5 psi)
- Chloride concentration: 10,000 mg/L
- pH: 5

The primary cracking mechanism of S30403 is stress corrosion cracking (SCC), which requires testing at the maximum intended service temperature, i.e., 230 °C (446 °F). S30403 is also susceptible to secondary cracking mechanisms including sulfide stress cracking (SSC) and galvanically induced hydrogen stress cracking (GHSC). Both secondary cracking mechanisms require testing at 24 ± 3 °C (75 ± 5 °F); however, S30403 is already permitted for any equipment or component for temperatures below 60°C (140 °F) for environments containing up to 100 kPa pH₂S, irrespective of chloride concentration and pH. Therefore, additional SSC and GHSC testing were deemed unnecessary.

Table 1: Environmental and materials limits for austenitic stainless steels used for any equipment or components as per ANSI/NACE MR0175/ISO15156-3:2015⁽²⁾

Materials type/individual alloy UNS number	Temperature max °C (°F)	Partial pressure H ₂ S pH ₂ S max kPa (psi)	Chloride conc. max mg/L	pH	Sulfur-resistant?	Remarks
Austenitic stainless steel from materials type described in A.2 ^a	60 (140)	100 (15)	See “Remarks”	See “Remarks”	No	Any combination of chloride concentration and <i>in-situ</i> pH occurring in production environments is acceptable
	See “Remarks”	See “Remarks”	50	See “Remarks”	No	Have been used without restrictions on temperature pH ₂ S or <i>in-situ</i> pH in production environments. No limits on individual parameters are set but some combinations of the values of these parameters might not be acceptable
S31603 ^b	60 (140)	1000 (145)	50,000	≥4.5	NDS	
	90 (194)	1000 (145)	1,000	≥3.5	NDS	
	90 (194)	1 (0.145)	50,000	≥4.5	NDS	
	93 (200)	10.2 (1.5)	5,000	≥5.0	NDS	
	120 (248)	100 (14.5)	1,000	≥3.5	NDS	
	149 (300)	10.2 (1.5)	1,000	≥4.0	NDS	
S20910	66 (150)	100 (15)	See “Remarks”	See “Remarks”	No	Any combination of chloride concentration and <i>in-situ</i> pH occurring in production environments is acceptable

NDS: No data submitted