Nickel Content Limits for API 5CT Sour Service Products

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Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue NW, Suite 1100, Washington, DC 20001, standards@api.org.

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Introduction

Many studies have been performed regarding the effect of nickel content on sulfide stress cracking (SSC) of low-alloy steels. The results of these studies, however, have not been conclusive. As a result, API 5CT:2018 [1] restricts the maximum nickel (Ni) content in some grades—such as Q125—but not for others—such as P110. NACE MR0175-2021/ISO 15156-2:2020, which provides guidelines for SSC resistance and selection criteria for use of carbon and low-alloy steels (LAS) in sour service, does restrict the maximum Ni-content to <1 for low-hardness steels (in Section A.2.1.2) [2]. These two documents have dissuaded the oil and gas industry from using higher nickel (1 % or greater) steels in sour service. A review of these studies, however, suggests that Ni-content may not restrict SSC resistance of steels, and the underlying microstructure obtained from processing, such as heat treatment and mechanical processing, plays a more important role instead.

With this background, limited testing was performed to compare AISI 4140 (low Ni-content) and AISI 4340 (high Ni-content) steels for their SSC resistance when heat treated to a similar yield strength. The yield strength selected was close to the upper limit of API 5CT [3] grade P110, which also overlaps with the yield strength range of API 5CT:2018 grade Q125. This study showed that AISI 4340 could have higher SSC resistance relative to 4140 at similar strength levels, again suggesting that Ni-content may not restrict SSC resistance. With API assistance, a more detailed study on steels of different Ni-contents is recommended to understand how nickel affects microstructure and cracking resistance. Chemical compositions for API 5CT grades and NACE MR0175 could then be suitably modified.

Low-alloy steels have been traditionally restricted by NACE MR0175/ISO 15156 to Ni-contents below 1 % on the assumption that higher nickel concentrations could negatively affect SSC resistance. For components manufactured to API 5CT grade P110, the use of commercial Ni-containing grades with better hardenability, such as UNS G43XX alloys, could enable heavier wall thicknesses with better toughness to meet API 5CT requirements.

NACE MR0175-2021/ISO 15156-2:2020 Section A.2.1.2 states that "Carbon and low-alloy steels are acceptable at 22 HRC maximum hardness provided they contain less than 1 % mass fraction nickel". Similarly, API 5CT:2018 Table E.4 does not restrict nickel content for grades below 80 ksi SMYS (specified minimum yield strength). However, nickel content is restricted for L80, C90, T95, and Q125 to 0.99 % maximum, whereas the P110 grade has no restrictions on nickel content.

The limitation in NACE MR0175/ISO 15156 was mostly based on a body of research conducted during the 1960s and 1970s. In their pioneering work, R. S. Treseder and T. M. Swanson [4] and A. K. Dunlop [5], found that LAS with more than 1.0 wt% nickel were more susceptible to SSC under similar loading and environmental conditions. Treseder and Swanson also reported that steels with a Ni-content higher than 1.0 wt% were susceptible to SSC even if hardness was kept under 235-BHN, which is equivalent to the 22-HRC limit now adopted by NACE MR0175/ISO 15156.

This limitation has created some challenges for HPHT applications that require strengths above 552 MPa (80 ksi) SMYS and hardness above 22 HRC. Commercial nickel-containing grades—such as UNS G43XX—may be needed to meet the hardenability and toughness requirements for heavy section components that some non-nickel-containing low-alloy steels would not meet. While early research suggested 43XX grades at lower hardness of 22 HRC max (552 MPa/80 ksi SMYS) may have lower SSC resistance than low nickel-containing steels with similar hardness limits, the performance of 43XX-type grades at higher strengths of 758 MPa/110 ksi SMYS or 862 MPa/125 ksi SMYS compared with that of P110 or Q125 equivalents with lower Ni-content had not been considered. This study is a step in that direction.

There is a commercial benefit for HPHT reservoirs to qualify nickel-containing LAS for use in API 5CT and NACE MR0175/ISO 15156 service, especially at higher temperatures. Heavy-wall accessories in particular are designed to withstand higher loads and tend to require P110 or Q125 grades. Due to the hardenability limitations of grades typically used (i.e., AISI 4130/4140), higher Ni-content grades (i.e., AISI 4330/4340) would be useful for such components. Although API 5CT:2018 grades P110 or Q125 are not "sour grades," their use in elevated temperatures in sour service is allowed by NACE MR0175/ISO 15156, enabling a reliability and availability for those applications.

Nickel Content Limits for API 5CT Sour Service Products

1 Scope

This technical report is a review of the literature and subsequent corrosion testing performed to explore if the limits on nickel (Ni)-content in low-alloy steels (LAS) can be revised.

There exists a legacy limitation on the Ni-content in LAS for deployment in sour service due to a perception on significantly reduced resistance to sulfide stress cracking (SSC) when nickel contents above 1 wt% are present. NACE MR0175-2021/ISO 15156-2:2020 contains an explicit limit of maximum 1 wt% Ni for low-hardness steels, and API 5CT:2018 enforced this limit on sour grades and grade Q125. This 1 wt% maximum Ni limitation for LAS may hinder development of HPHT reservoirs by prohibiting grades that may be suitable for heavy-wall, high-strength applications.

The outcome of the study suggests that Ni-content may not restrict SSC resistance of LAS and the underlying microstructure obtained from processing, such as heat treatment and mechanical processing, plays a more important role instead.

2 Normative References

There are no normative references for this document.

3 Terms and Definitions

There are no terms and definitions for this document.

4 Literature Review

4.1 General

Regardless of the actual cracking mechanism, research indicates that the SSC resistance of both Ni-free and Ni-bearing low-alloy steels is contingent on the interdependency of heat treatment, microstructure, and strength/hardness. In this regard, fully tempered martensite showed the best sour service performance, followed by lower bainite [6]. In contrast, presence of untempered martensite and upper bainite reduces SSC resistance significantly. Below are summaries of some of these studies.

4.2 OTC 3509-MS [7]

The effect of nickel on SSC resistance is presented in OTC 3509-MS for AISI 4130-type steels and for a medium carbon alloy steel (0.22 % C, 2.00 % Cr, 0.60 % Mo, 0.20 % V), respectively. As OTC 3509-MS shows, Ni-contents up to ~1.0 wt% have no effect on SSC resistance, but above ~1.0 wt% did cause SSC resistance to decrease. The tests used a survival stress level statistically determined (designated as σ_{50}), representing a median failure stress level as a way to assess cracking resistance.

4.3 Metallurgical Transactions A, Vol. 17, No. 9, p. 1601–1610 [8]

The objective of this study was to compare the performance of selected nickel containing low-alloy steels in a standard H_2S environment with that of nominally nickel-free AISI 4130 steel at comparable strength and hardness levels (yield strength (YS) ≈ 690 MPa (100 ksi), HRC ≤ 22).

Five commercial low-alloy steels with nominal Ni-contents ranging from 0 %–3 % were selected. These were quenched and tempered to the desired hardness. In addition, five different tempering treatments were used for one of the steels (AISI 4330) to establish the effect of minor microstructural changes on the SSC cracking susceptibility.