

Characterization and Further Development of Austenitic Stainless Steel UNS S20910 towards New Industrial Applications

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ABSTRACT

UNS S20910 (XM-19) is an austenitic stainless steel with excellent corrosion resistance and high strength due to its high nitrogen content. In solution annealed condition, it exhibits better corrosion resistance than UNS S31603 and UNS S31703 while having approximately twice their yield strength at room temperature ($> 345 \text{ MPa}$ (50 ksi)). The tensile strength of UNS S20910 can be further increased by cold-working, which makes the material more versatile. This paper discusses the influence of strain hardening on the mechanical and corrosion properties of UNS S20910. The corrosion behavior was studied in terms of intergranular corrosion resistance, pitting corrosion and stress corrosion cracking susceptibility in chloride-containing solutions at different temperatures. UNS S20910 in strain hardened condition presents a fully austenitic microstructure with niobium-rich primary precipitates and Z-phase, a complex nitride. In addition, the material shows a yield strength and ultimate tensile strength higher than 890 MPa (129 ksi) and 1035 MPa (150 ksi), respectively, as well as an elongation above 20 %, and impact energy higher than 100 J (74 ft-lbs). Strain hardened material did not exhibit any sensitization; therefore, it retained its excellent pitting corrosion resistance in chloride-containing solutions, which decreases with increasing temperature, though. The material has also shown good resistance to stress corrosion cracking in brines at elevated temperature. It was confirmed that the strain-hardening process increases tensile strength without significantly affecting the corrosion properties of this stainless steel. Therefore, strain hardened UNS S20910 can be used in applications involving very aggressive environments where also high strength, good ductility and non-magnetic properties are required.

Key words: UNS S20910, austenitic stainless steel, strain hardening, mechanical properties, sensitization, pitting corrosion, stress corrosion cracking.

INTRODUCTION

UNS S20910 ¹, also known as XM-19 by ASTM A276 ², is a nitrogen-strengthened austenitic stainless steel with high strength and excellent corrosion resistance. Besides nitrogen (N) it also contains higher amounts of chromium (Cr), nickel (Ni), manganese (Mn), and a similar molybdenum (Mo) content compared with UNS S31603, as well as small additions of niobium (Nb) and vanadium (V). High contents of Cr, Mo and N confer this stainless steel high localized corrosion resistance. Mo, Mn and Cr increase the nitrogen solubility in iron alloys.³ On the other hand, Nb is added to increase the strength through Z-Phase precipitation. However, Nb can also be present in the microstructure as a primary carbonitride (Nb(C,N)) ⁴ and have a negative effect on the corrosion properties. Z-Phase is a complex nitride compound of N, Nb, Cr containing also small amounts of iron (Fe), V, Mo and Ni ^{5,6} that precipitates during the hot deformation process. The fine distribution of Z-phase precipitates in the austenitic matrix increases especially the yield strength, due to a precipitation hardening and solid solution mechanisms.⁶

The high N-content also helps to increase the strength in UNS S20910. In solution-annealed condition, UNS S20910 has a yield strength (YS) higher than 345 MPa (50 ksi), and ultimate tensile strength (UTS) higher than 690 MPa (100 ksi), both being considerably higher to the typical values obtained from UNS S31603.⁷ Additionally, it has good mechanical properties at elevated and sub-zero temperatures. In hot-rolled condition, YS and UTS are higher than 725 MPa (105 ksi) and 930 MPa (135 ksi), respectively, for small diameters up to 50.8 mm (2 inches) per ASTM A276.² Considerably less strengthening is specified for diameters up to 76.2 mm (3 inches). However, strength of all and especially larger diameters up to at least 203.2 mm (8 inches) can also be increased by strain hardening. YS and UTS can reach values over 800 MPa (116 ksi) and 950 MPa (138 ksi). In addition, material in strain-hardened condition shows impact energy values higher than 100 J (74 ft-lbs). Moreover, strain hardening does not affect the magnetic properties of UNS S20910; it remains non-magnetic even at high degrees of cold work.⁸

UNS S20910 owns excellent corrosion resistance. Its Pitting Resistance Equivalent Number ($PREN = \%Cr + 3.3 \times \%Mo + 16 \times \%N$) ranges between 28 and 40 depending upon the actual chemical composition (Table 1). Gumpel et al.⁹ reported a Critical Pitting Temperature (CPT) and Critical Crevice Temperature (CCT) in 10% FeCl₃ · 6 H₂O solution equal to 45 °C (113 °F) and 20 °C (68 °F), respectively. These values are higher than some standard austenitic stainless steels like UNS S31603 and duplex stainless steel UNS S31803. Its excellent corrosion resistance in chloride environments and good performance in acidic environments have been demonstrated in the past.^{9,10} In addition, UNS S20910 was not susceptible to stress corrosion cracking (SCC) in boiling seawater after 1000 hours at a constant load beyond its corresponding YS. However, it was determined being prone to SCC in acidic high chloride bearing environments like boiling MgCl₂-solution.⁹

UNS S20910 is used in several industrial applications including marine, chemical industry, oil and gas, nuclear industry, and cryogenic industry due to its combination of high strength and excellent corrosion resistance. This paper discusses the influence of the strain-hardened condition on the mechanical properties and corrosion behavior of UNS S20910.

EXPERIMENTAL PROCEDURE

Material

The results discussed in this paper were obtained on samples of the austenitic stainless steel UNS S20910 (EN 1.3964, SAE XM-19) with the chemical composition reported in Table 1. In this study, UNS S20910 was characterized in two different metallurgical conditions: strain-hardened and after 10 minutes solution annealing at 1125 °C followed by water quenching (WQ).

Table 1
Nominal chemical composition of UNS S20910 in wt. %

C	Si	Mn	Cr	Mo	Ni	N	Nb	V	PREN
0.03	0.4	5.0	21.8	2.3	12.5	0.5	0.2	0.2	37

Test methods

Specimens were taken in longitudinal direction from a 166 mm (6.5 inches) diameter rod at mid-radius, and for assessing the mechanical properties in strain hardened condition also at 25.4 mm below the surface. Optical microscopy and scanning electron microscopy (SEM) were used to study the microstructure. The mechanical properties were evaluated according to ASTM A370¹¹ at room temperature (RT).

The corrosion behavior of UNS S20910 in strain hardened condition was studied with different methods. Intergranular corrosion resistance was assessed using ASTM A262 Practice A and E.¹² The material was tested without and with a sensitization treatment at 675 °C for 1 hour. According to ASTM A262 practice E, the rectangular specimens were bent 180° after 15 hours of exposure in a boiling solution of copper-copper sulfate and 16 % sulfuric acid.

Pitting resistance was tested per ASTM G48 Method A.¹³ The specimens were exposed to ferric chloride solution for 72 hours at RT and 50 °C. At least three tests were run for each metallurgical condition. The CPT was determined according to ASTM G48 Method C.¹³ Tests were conducted in acidified ferric chloride solution for 72 hours at different temperatures. The starting temperature was estimated by Equation 1¹³ minus 10 °C. The bath temperature was increased until pitting was observed.

$$\text{CPT (}^{\circ}\text{C)} = 2.5\%\text{Cr} + 7.6\%\text{Mo} + 31.9\%\text{N} - 41 \quad (1)$$

Pitting corrosion resistance was also evaluated using cyclic potentiodynamic polarization measurements according to ASTM G61.¹⁴ Test environments were 0.63 M Cl⁻ (3.5 wt. % NaCl) solution at RT, and 2.25 M Cl⁻ containing solution at RT and 75 °C. The pH of the last solution was 12 at RT. A three-electrode configuration was used for the electrochemical measurements. The specimen of UNS S20910 was used as working electrode, while a platinum sheet and a KCl-saturated Ag/AgCl were used as counter and reference electrode, respectively. The open-circuit potential (OCP) was monitored and recorded for 60 minutes before the specimen was polarized. The pitting (E_{pit}) and repassivation potentials (E_{rp}) were determined at 100 $\mu\text{A}/\text{cm}^2$.¹⁵

The SCC resistance of strain hardened UNS S20910 was investigated by using uniaxial tensile specimens with a gauge diameter of 4 mm (0.17 inches). Three constant load tests were conducted in saturated NaCl (6 M Cl⁻ containing) using a constant load of 310 MPa for 1000 hours. In addition, constant load tests were performed in 2.25 M Cl⁻ containing solution at 105 °C applying a constant tensile load of 350 and 450 MPa for 200 hours. After the test, the specimens were inspected visually and by optical microscopy for cracks or pits.

RESULTS AND DISCUSSION

Mechanical Properties

Table 2 shows the mechanical properties obtained from UNS S20910 in both metallurgical conditions. Strain hardening was capable to increase the ultimate tensile and yield strength of the material to values beyond 890 MPa (129 ksi), and 1035 MPa (150 ksi), respectively. Correspondingly, the hardness of the material also increased. These values are considerably higher compared to those obtained in the solution annealed condition. Even though the elongation (A4) and Charpy V-notched (CVN) impact energy decreased significantly after strain hardening, the ductility (elongation and reduction of area, RoA) as

well as the impact toughness of the material in this condition can be considered as appropriate for demanding applications.

Table 2

Mechanical properties of UNS S20910 in strain hardened and solution annealed condition.

Condition		YS in MPa (ksi)	UTS in MPa (ksi)	A4 in %	RoA in %	Hardness HRC	CVN Impact in J (ft-lb)
Strain hardened	mid radius	893 (130)	1035 (150)	19	62	30	177 (131)
	25.4 mm below the surface	947 (137)	1048 (152)	19	61	34	129 (95)
Solution annealed (10 min @ 1125 °C+WQ)		407 (59)	779 (113)	47	74	20	433 (319)

Microstructure

After strain-hardening, UNS S20910 shows a fully austenitic microstructure with primary precipitates, most likely of type Nb(C,N) (Figure 1). Nb-primary precipitates are formed during the solidification process and are inhomogeneously distributed in the microstructure. Fine precipitates can be observed inside the austenitic grains. These precipitates are rich in Cr, Nb, Ni and N (Figure 2). The precipitation of this phase occurs at temperature below 1300 °C (2372 °F) and can be identified as Z-Phase according to Thermocalc®* simulation, Version 2021a, Database TCFE11, (Figure 3). These two phases are typically found in UNS S20910 and haven been already reported in the past.^{4,5} No indications of sigma phase or other detrimental phases like δ -Ferrite, $M_{23}C_6$ and M_2N were detected.

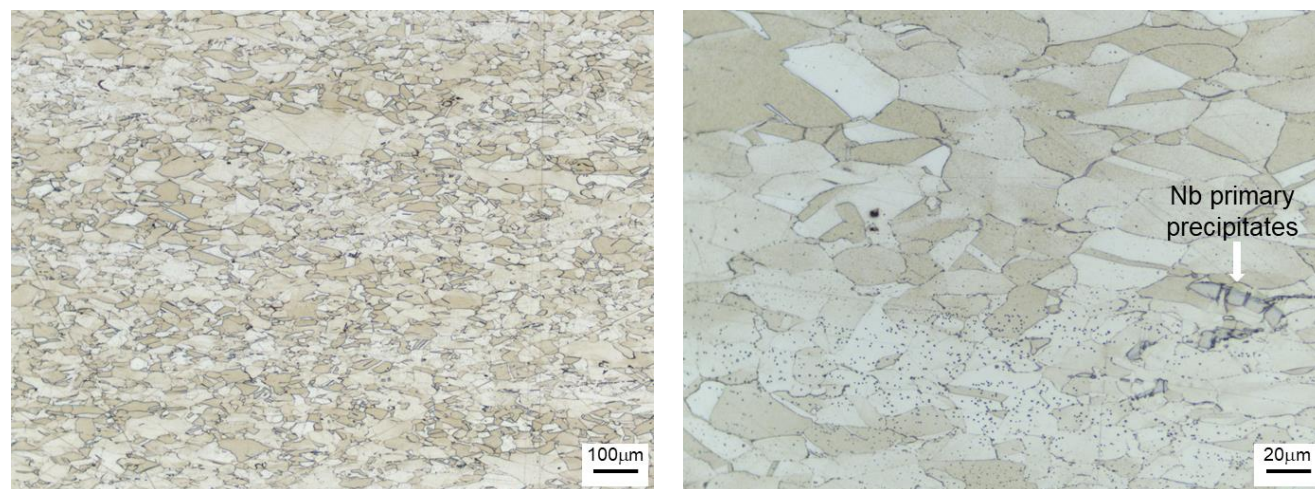


Figure 1: Microstructure of UNS S20910 in strain-hardened condition

* Trade Name

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