

Development of the High Strength Cold Worked Super Austenitic Stainless Steel UNS N08034 for Challenging Oilfield Environments

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ABSTRACT

Corrosion resistant alloys are used in oilfield applications where carbon and low-alloy steels are expected to be affected by corrosion, and they often represent a cost-effective alternative to chemical treatment, or where specific application-driven requirements are required. Several alloys from 13% chromium stainless steel up to highly-alloyed nickel and cobalt alloys have been successfully used in drilling, completion, production as well as offshore oilfield equipment, where corrosion resistance is of concern. Many drilling technology components, for example, require non-magnetic austenitic stainless steels. In demanding production environments involving very corrosive fluids at elevated temperatures, on the other hand, nickel alloys are preferred. While one of the disadvantages of stainless steels concerns their limited resistance to localized corrosion and stress corrosion cracking in halide-containing environments, nickel alloys, particularly those that are precipitation hardenable, might be susceptible to hydrogen-stress-induced cracking (HISC).

Due to its excellent resistance to localized corrosion and environmentally assisted cracking at elevated temperatures as well as high resilience to hydrogen-assisted cracking mechanisms, UNS⁽¹⁾ N08034 – a

⁽¹⁾ Unified Numbering System

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superaustenitic stainless steel with increased nickel content and balanced additions of nitrogen and manganese – is a promising candidate for oil and gas applications. Its refined chemical composition improves manufacturing characteristics to allow the fabrication of large components, including good machinability and weldability. Its non-magnetic nature enables the use in directional drilling and reservoir characterization tools. Since one limitation of austenitic stainless steels is their strength, cold working has been used to increase the yield strength of UNS N08034 to values higher than 120 ksi (827 MPa). In this study, a manufacturing process was developed based on thermodynamic and laboratory studies and subsequently applied to mill production trials. This paper reports the results from mechanical testing as well as microstructural investigations and corrosion testing conducted on strain-hardened UNS N08034.

Key words: UNS N08034, Strain-hardening, High Strength Super Austenitic Stainless Steel, Pitting Corrosion, oil and gas exploration, non-magnetic

INTRODUCTION

Wells in oil, gas and geothermal production experience a broad spectrum of operating conditions in terms of temperature, depth, pressure and production environments, which govern material selection. For severe environments, where high strength and toughness combined with excellent corrosion and cracking resistance are required, a new superaustenitic stainless steel has been recently developed. Aiming for a minimum yield strength of at least 120 ksi (827 MPa), strain hardening enables the desired mechanical properties, allowing users to avoid well known but HISC susceptible and less cost effective precipitation hardened (PH) nickel alloys.

UNS N08034, commercially known as Alloy 31 Plus⁽²⁾, is a Nickel-Iron-Chromium-Molybdenum alloy, situated between the high-alloyed stainless steels and the Nickel-Chromium-Molybdenum alloys in terms of chemistry. UNS N08034 has controlled additions of nitrogen and optimized nickel content in comparison to its predecessor Alloy 31 (UNS N08031). The addition of nitrogen provides not only an increase in strength, but also an increase in the pitting corrosion resistance,¹ as expressed by its high Pitting Resistance Equivalent Number (PREN),² which is calculated at 54 according to Equation 1. A comparison of the corrosion resistance of UNS N08034 with other well-known solid solution alloys is published elsewhere.³

$$PREN = \% Cr + (3.3 \times \% Mo) + (16 \times \% N) \quad (\text{Eq. 1})$$

While nitrogen improves the strength and the corrosion resistance, the higher nickel content improves the metallurgical stability of the alloy. High-alloyed 6-Mo-stainless steels including UNS N08034 are usually prone to the precipitation of the detrimental tetragonal intermetallic sigma-phase, a chromium, molybdenum, nickel and iron containing phase which lowers environmental cracking resistance and toughness. An increase of about 3 % nickel in comparison to UNS N08031 is essential to the fabrication of large components of UNS N08034. It reduces the sigma-solvus temperature, allowing a solution annealing at 1140-1160 °C, and retards significantly the formation of sigma-phase, allowing the alloy a longer soak under critical temperatures before this detrimental phase precipitates. This makes UNS N08034 more convenient for manufacturing than UNS N08031, which requires higher heat treatment temperatures and faster cooling rates.¹ This feature is of great relevance mainly if heavy section products are to be manufactured, taking in consideration the limitations in terms of cooling rates after heat treatment.

Thus, UNS N08034 combines the advantages of high chromium and molybdenum containing materials, that is the high resistance to localized corrosion, allowing to create a highly corrosion resistant material

⁽²⁾ Trade name. Alloy 31 Plus and Alloy 31 are proprietary alloys of VDM Metals International GmbH

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using only small amounts of expensive alloying elements.⁴ In addition to its exceptional pitting and crevice corrosion resistance, high strength and high toughness can be achieved through strain hardening processes, which allows the alloy to be used in several applications including those relevant to the oil and gas industry, e.g. completions and production tools, subsea and wellhead equipment and, especially, directional drilling and reservoir characterization tools.

EXPERIMENTAL PROCEDURES FOLLOWED

Thermodynamic calculations

Thermodynamic calculations were carried out using the software Thermocalc⁽³⁾ Version 2021a, Data base TCFe 9 in order to define manufacturing temperature windows, to avoid an unwanted precipitation of detrimental phases. A nominal chemical composition of UNS N08034 was used for the calculations.

Material

Four heats of UNS N08034 within the nominal chemical composition given in **Table 1** were used for the investigation program. The heats were melted in an electric furnace, followed by vacuum degassing and electro-slag-remelting (ESR). The ESR process removes macrosegregation, ensuring a cleaner and more homogeneous ingot, with fewer non-metallic inclusions compared to a cast product.⁵

Table 1
Nominal chemical composition (in wt.%) of Alloy UNS N08034

	Ni	Cr	Fe	S	Si	Mn	P	Mo	Cu	N	C	Al
Min	33.5	26.0	Bal.			1.0		6.0	0.5	0.10		
Max	35.0	27.0		0.01	0.1	4.0	0.02	7.0	1.5	0.25	0.01	0.30

The ESR ingots were pre-forged at high temperature to achieve the desired diameters of pre material. After forging, the ingots were solution annealed followed by rapid cooling in a water bath in order to avoid sigma-phase precipitation. The transport from heat treatment furnace to water quenching is critical and must be conducted quickly. After annealing, the billets were peeled and then strain-hardened through a rotary forging process at a controlled temperature.

Heats A, B, C and D were forged to different and increasing cold work ratios, in which heat A was subjected to the lowest amount of cold work and heat D to the highest amount.

After final surface preparation, the bars had diameters of about 200 mm (7.9").

Mechanical Properties and Microstructure

Specimens for hardness, tensile and impact energy tests were taken in the center, at mid-radius and at 1" (25.4 mm) below surface from both the top and the bottom of the bars.

⁽³⁾ Tradename.