

Alloy UNS N08827: a New and Advanced Version of Alloy UNS N08825 with Better Corrosion and Hot Cracking Resistance

Julia Botinha
VDM Metals International GmbH
Kleffstrasse 23
58762 Altena, Germany

Martin Wolf
VDM Metals International GmbH
Kleffstrasse 23
58762 Altena, Germany

Bodo Gehrman
VDM Metals International GmbH
Kleffstrasse 23
58762 Altena, Germany

Helena Alves
VDM Metals International GmbH
Kleffstrasse 23
58762 Altena, Germany

ABSTRACT

Alloy UNS⁽¹⁾ N08827, herein called Alloy 825 CTP, is a nickel-iron-chromium alloy with additions of molybdenum and copper. It was recently designed as a further development of the standard Alloy 825 (UNS N08825) for applications in the chemical process industry as well as in the oil and gas industry, where resistance to pitting and crevice corrosion in chloride environments is required.

Because of its high nickel content, alloy 825 CTP shows an outstanding resistance to stress corrosion cracking in aqueous and acidic chloride-containing solutions. Furthermore, as showed by previous tests, its increased molybdenum content of around 6% leads to an increased critical pitting temperature in comparison to standard alloy 825.

In combination with the ameliorated corrosion resistance of Alloy 825 CTP, in particular the absence of titanium in its chemical composition promotes a reduction of its susceptibility to hot cracking during fusion welding. The improvement of weldability is shown in the present study theoretically, through thermodynamical modeling of the solidification process and confirmed hereafter experimentally, through Modified Varestraint Transvarestraint (MVT) hot cracking tests.

Plasma arc welding (PAW) trials simulating component weldments were additionally carried out to test the weldability of Alloy 825 CTP under nearly practical conditions. These weldments were evaluated by metallographic examinations and corrosion tests like ASTM⁽²⁾ G28 A and ASTM G48 A, C and D.

Key words: Nickel Alloys, Alloy UNS N08825, Alloy UNS N08827, Alloy 825 CTP, Crevice corrosion, Pitting corrosion, weldability

⁽¹⁾ Unified Numbering System

⁽²⁾ American Society for Testing and Materials (ASTM), West Conshohocken, Pennsylvania, US

INTRODUCTION

The standard alloy UNS N08825 is a titanium-stabilized fully austenitic nickel-iron-chromium alloy with additions of copper and molybdenum¹. This combination of elements grant to the alloy resistance to corrosion under both oxidizing and reducing conditions, what leads to a great variety of applications in the chemical industry, oil and gas producing and processing, maritime applications among others. Nevertheless, alloy UNS N08825 has only a limited resistance to chloride-induced localized corrosion, which is a common corrosion type in the oil and gas industry.²

In order to improve resistance to chloride-induced localized corrosion, the chemical composition of Alloy UNS N08827 (herein called Alloy 825 CTP) has been optimized by increasing the molybdenum content from around 3 wt.-% in the alloy UNS N08825 to around 6 wt.-% in the alloy 825 CTP. By increasing the molybdenum content, the PREN (Pitting Resistance Equivalent Number), given by formula (1), is increased from 33 to 42, giving the first indication of improved corrosion resistance. The improved corrosion resistance was confirmed experimentally by an increase of the Critical Pitting Temperature (CPT) from 30 °C (86 °F)² in alloy UNS N08825 to around 55 °C (131 °F)³⁻⁵ in Alloy 825 CTP.

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

Additionally, Alloy UNS N08825 is well known to be highly prone to hot cracking during welding, which can occur in the Heat Affected Zone (HAZ) or in the weld metal itself, representing an intergranular mode of failure.

In order to evaluate the hot cracking susceptibility of a material, the solidification temperature range (solidus-liquidus difference value, ΔT) is usually used as a first assessment. Higher ΔT leads to residual liquid phase distributed along grain boundaries and interdendritic regions, leading to a loss of grain boundary ductility during cooling shrinkage and, consequently, hot cracking can take place.^{6,7} Experimentally, the hot cracking susceptibility can be evaluated by means of Modified Varestraint-Transverstraint (MVT) Tests. MVT tests are used as an “universal” weldability test, designed to permit independent control of the welding parameters and mechanical loading, which allows the evaluation and comparison of materials by number of hot cracks and hot crack length on welded samples.

The elements titanium and niobium are usually added to alloys to stabilize the carbon and to prevent the precipitation of chromium carbides at the grain boundaries that may cause intergranular corrosion. On the other side, in the welding point of view, it is known that titanium has a potent influence on the material's weldability,⁷ but limited information regarding this aspect of titanium is available in the literature.

Shankar et al. verified a general high titanium enrichment along cracks and interdendritic regions of Ti-Stabilized austenitic stainless steels weldments. According to him, higher titanium contents result in increased segregation to the grain boundaries, what lead to the formation of more detrimental secondary phases in these regions that may later contribute to the formation of cracks.

Additionally, titanium and other partitioning elements are known to enrich the grain and subgrain boundaries during solidification. These elements, when partitioned to the boundaries area act to significantly depress the effective solidification temperature range at these sites.⁸

Another flaw of titanium as an alloying element is its unpredictable oxidation behavior during arc welding, which may lead to a depletion of interstitial titanium – thus reducing its stabilizing effect - in conjunction with the occurrence of titanium oxides in the weld metal.

Since the recently developed Alloy 825 CTP can achieve very low carbon contents through advanced secondary metallurgical production processes, titanium addition is not required with the purpose of

controlling the corrosion susceptibility of the material by the precipitation of titanium carbides as described above. In this context, the production of a titanium-free material with good intergranular corrosion resistance is possible.

EXPERIMENTAL PROCEDURE

Material

Heats A, B and C are plate material from Alloy 825 CTP with 5 mm (0.08-in) and 16 mm (0.25-in) thickness. These heats were melted by an open melting process followed by continuous casting. After hot rolling, the plates were annealed in atmospheric industrial furnace. Heat D is plate material from Alloy UNS N08825 used in this study as a reference for standard material properties. **Table 1** shows the main chemical composition of all heats. Note that titanium is not intentionally added to Alloy 825 CTP.

Table 1
Main chemical composition of heats A, B and C of Alloy 825 CTP and heat D of Alloy UNS N08825 in wt.%

Heat	Alloy	Cr	Ni	Fe (balance)	Cu	Mo	Ti
A	Alloy 825 CTP	22.59	39.28	28.59	2.1	5.66	0.07
B	Alloy 825 CTP	22.28	39.19	29.02	2.05	5.88	0.06
C	Alloy 825 CTP	22.31	39.19	29.32	1.95	5.66	0.07
D	UNS N08825	22.53	38.37	31.48	1.86	3.27	0.81

Mechanical Testing / Metallography

Tensile testing and microstructural inspection were carried out to verify the material properties.

Microstructure

Microstructural investigations were performed on mechanically polished and chemically etched specimens. For etching, a pickling solution containing 100 mL H₂O, 100 mL HCl, and 10 mL HNO₃ was used. Evaluation of the microstructure was performed using light optical microscopy techniques. The grain sizes were measured according to DIN⁽³⁾/ISO 643-2013⁹.

Tensile Testing

Tensile testing was conducted according to DIN/ISO 6892-1¹⁰ at room temperature. Smooth specimens in the transversal direction were machined and tested at room temperature, 175 °C (347 °F), and 205 °C (401 °F).

Corrosion testing

The corrosion testing program was established to meet the requirements of NACE⁽⁴⁾ MR0175 / ISO⁽⁵⁾ 15156-3¹¹ for qualification of Corrosion Resistant Alloys (CRAs) for H₂S-service, taking Sulfide

⁽³⁾ German Institut for Standardization (DIN) e. V., Am DIN-Platz, Burggrafenstraße 6 10787 Berlin, Germany

⁽⁴⁾ National Association of Corrosion Engineers (NACE) International, 15835 Park Ten Place, Houston, TX 77084

⁽⁵⁾ International Organization for Standardization (ISO), 7 ch. De la Voie-Creuse, Case Postale 56, Geneva, Switzerland

Stress Cracking (SSC), Galvanically Induced Hydrogen Stress Cracking (GHSC) and Stress Corrosion Cracking (SCC) into account. All corrosion testing on solution annealed material according to the requirements of NACE MR0175 / ISO 15156-3 for qualification of CRAs was performed at the Salzgitter Mannesmann Research Institute. Corrosion testing of welded material was carried out at the laboratories of VDM Metals GmbH.

Pitting and crevice corrosion

Corrosion test according to ASTM G48¹² Method C was carried out to determine the critical pitting temperature (CTP) in acidified ferric chloride solution. ASTM G48 Method D was used to assess the critical crevice temperature (CCT) in the same solution.

Sulfide Stress Cracking (SSC) Resistance

SSC testing according to NACE TM0177¹³ Method A was performed at $24\text{ }^{\circ}\text{C} \pm 3\text{ }^{\circ}\text{C}$ ($75\text{ }^{\circ}\text{F} \pm 5\text{ }^{\circ}\text{F}$) on triplicate smooth round specimens with a gauge diameter of 6.35 mm (0.25 inch) and a gauge length of 25.4 mm (1 inch). The testing was carried out in Solution A saturated with 100 kPa (14.5 psi) H_2S , resulting in an initial pH of 2.7; the final pH was measured and was less than 4.0. Stress level of 90 % AYS was applied by deflection of the proof ring. Test duration was 720 h (30 d).

Galvanically Induced Hydrogen Stress Cracking (GHSC) Resistance

GHSC testing was performed in accordance with the previously conditions for SSC testing. In addition, the tested specimens were electrically coupled by platinum wire to carbon steel, which was fully immersed in the test solution.

Stress Corrosion Cracking (SCC) Resistance

SCC testing was performed according to NACE TM0177 Method C (C-ring test). The material was tested under Level VI and Level VII test conditions as specified by NACE MR0175 / ISO 15156-3, Table E.1. SCC testing was conducted on triplicate C-ring specimens at 100 % of AYS at the test temperature. Four C-ring specimens were machined from each heat with an outer diameter (OD) of 40 mm (1.57 inch). For each set of four specimens, one C-ring was strain gauged to determine the necessary deflection corresponding to 100 % AYS at test temperature. The determined data was then used to deflect the tested triplicate set of specimens. SCC testing was carried out in autoclaves made of corrosion resistant material. After placing the specimens in the vessel, the test solution was added, so that all specimens were completely immersed in the liquid phase. Temperature was daily monitored. Separate specimens were used for 3 months testing at Level VI and 1 month testing at Level VII. After exposure to the corrosive environment, C-ring specimens were rinsed with distilled water and photographed. Examination for evidence of cracking was performed visually at 10x magnification.

Hot Cracking Susceptibility

Solidification Temperature Range

With the use of the software JMatPro⁽⁶⁾, using the NiSuperalloy data base, solidus and liquidus temperatures at different cooling rates were calculated in order to get the solidification intervals with the aim of having a first assessment of the hot cracking susceptibility of Alloy 825 CTP. The same calculations were carried out for standard compositions of alloys UNS N08825 and UNS N06625, well known alloys in the market and literature, in terms of comparison.

⁽⁶⁾ Trade name. Java-based Materials Properties.