

A New, Highly Stable Corrosion Resistant Alloy for Severe Oil & Gas and CPI Environments

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ABSTRACT

ATI has developed ATI 642^{TM†} alloy, a new Ni-Cr-Mo corrosion-resistant alloy that displays significant resistance to sensitization from the effects of hot-clad bonding and welding operations. The new alloy is unique because of its substantial Fe content, which gives it a significant cost advantage over Ni-based alloys of similar performance, while still containing enough Ni to provide SCC resistance superior to 6Mo stainless steels. It has a PREN value in excess of 40, which provides useful resistance to chloride environments such as seawater.

This paper will present the results of chloride stress-corrosion cracking (SCC), intergranular attack (IGA), and critical pitting temperature (CPT) corrosion tests, as well as results of tensile tests and Charpy impact energy tests. Testing was conducted in both the solution-annealed condition and following a sensitizing heat treatment that simulates typical exposure during the hot-clad bonding fabrication process. The microstructures of the new alloy in the solution-annealed, sensitization-heat-treated, and welded conditions will also be shown and discussed. The test results and microstructures will be compared to those of other alloys traditionally used by the oil and gas and chemical processing industries.

Keywords: Alloy 642, pitting corrosion, stress corrosion cracking, intergranular corrosion, phase stability, weldability, impact energy, clad pipe

INTRODUCTION

UNS⁽¹⁾ N06625 (alloy 625) is one of the most commonly used materials in the oil and gas (O&G) and chemical processing industries (CPI) because of its excellent corrosion resistance and its long history of reliable service. However, alloy 625 is relatively expensive because its chemical composition was designed to be suitable for a wide range of end uses in both high-temperature and aqueous corrosion-resistant applications. When less corrosion resistance is required, N08825 (alloy 825) is often used for similar applications. Although alloy 825 is less expensive than alloy 625, there are several environments where it is not a suitable replacement, such as in aqueous environments with high chloride contents at

[†] Trademark of ATI Properties LLC.

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elevated temperatures. This is because alloy 825 is more prone to pitting and crevice corrosion, and to stress corrosion cracking (SCC) under those conditions.

There are several Corrosion-Resistant Alloys (CRA) whose corrosion resistance properties are between those of alloys 625 and 825 in these environments. Some examples are N08904 (alloy 904L) and the 6% Mo superaustenitic alloys, and the super-duplex stainless steels. These alloys are often used in industrial applications such as in oil & gas and chemical processing, but there are some applications where they might not be appropriate choices. Hot-roll bonded pipe (HRBP) and bi-metallic process vessels are two such applications. These products are made by hot-roll bonding a CRA, such as alloy 625 or alloy 825, to a carbon steel substrate material. When hot rolling is used to bond the cladding material to the substrate, it is often necessary to heat treat the product afterwards to achieve a good combination of strength and ductility in the carbon steel substrate. This post-clad heat treatment (PCHT) is typically conducted in a sensitizing temperature range where carbides, nitrides and intermetallic phases such as sigma may form in the CRA used for cladding. Such phases are detrimental to the corrosion resistance and mechanical properties of the cladding layer, so the material chosen must be able to resist degradation of its properties during the PCHT. Alloys 625 and 825 are better at maintaining their properties following PCHT than superaustenitic and super-duplex alloys, which is why they are often used for hot-roll bonded products.

ATI has recently developed a new nickel-based alloy, generically known as alloy 642, that is less costly than alloy 625, has better resistance to pitting corrosion and chloride SCC than alloy 825, and has improved resistance to deleterious phase formation compared to superaustenitic and super-duplex alloys. This alloy may be considered as a cost-saving candidate to replace alloy 625 for aqueous environments with high chloride contents at elevated temperatures in applications where neither alloy 825 nor other lower-cost stainless steel alloys are suitable. Alloy 642 may also be considered as a replacement for alloy 825, superaustenitic, or super-duplex alloys in many applications where improved phase stability and SCC resistance combined with high pitting resistance are required.

This paper will present a comparison of corrosion and mechanical test results for alloy 642 with those performed on alloy 625, alloy 825 and a 6% Mo superaustenitic alloy (N08367).

EXPERIMENTAL PROCEDURE

Testing was performed on samples of alloys 642, 625, 825, and the 6 Mo alloy (N08367). Data presented for alloy 904L were obtained from ATI's historical production data. The nominal compositions of these alloys are shown in Table 1.

Table 1: Nominal Compositions of Alloy 642 and Comparative Alloys

	Alloy 642	Alloy 825	Alloy 904L	6Mo Alloy	Alloy 625
UNS	N08XXX	N08825	N08904	N08367	N06625
Ni	43	39	24.5	23	63
Cr	22	22	20.5	20.5	21
Mo	5.7	3.3	4.5	6.2	9
N	0.05	0.01	0.01	0.2	0.01
Other	Co, Cu	Cu, Ti	Cu	-	Nb
Fe	Balance	Balance	Balance	Balance	Balance
PREN ⁽²⁾	42	33	35	44	50

⁽²⁾ PREN = Cr + 3.3Mo + 16N

Cold rolled and annealed 0.060" (1.5 mm) sheets were used for all testing except for the Charpy impact testing, which used hot rolled and annealed 0.270" (6.85 mm) plates. All material was solution annealed (SA) at 2100°F (1150°C) after hot and cold rolling for times commensurate with thickness. Some of the material was also given a simulated post clad heat treatment (PCHT) which consisted of one stage at 1750°F (954°C) followed by a second stage at 1100°F (593°C). Testing was performed on samples in both the SA and PCHT conditions.

Mechanical Testing

Charpy impact testing was performed per ASTM⁽³⁾ E23¹. Half-size (0.197" [5 mm]) Charpy samples were machined from 0.270" plates and tested at -58°F (-50°C). Two samples were tested for each alloy in both the solution annealed and PCHT conditions. Samples were made in the transverse (T-L) orientation. Following the tests, absorbed impact energy, lateral expansion, and percent shear fracture were reported.

Tensile testing was performed at room temperature according to ASTM E8². Standard 2" (50.8 mm) gage length tensile samples were made from 0.060" (1.5 mm) material in the longitudinal direction. Triplicate samples were tested for each alloy in each condition, and the 0.2% offset yield strength, ultimate tensile strength, and the % elongation were determined.

Corrosion Testing

The critical pitting temperature (CPT) for each alloy was measured by testing coupons per ASTM G48³ Method C. Test coupons approximately 1" x 2" (25mm x 50mm) were sheared from 0.060" sheets. Sheared edges were ground and deburred, finishing with a 240 grit paper. Coupons were cleaned in distilled water and acetone and duplicate coupons were tested at each temperature. Coupons were immersed in an acidified ferric chloride solution and the test was repeated after increasing the solution temperature in increments of 5°C (9°F) until the CPT was reached. The CPT is defined as the lowest temperature at which pits are formed that are 0.001" (0.025 mm) or greater in depth.

Intergranular corrosion resistance was measured using ASTM G28⁴ Method A. Duplicate test coupons approximately 1" x 2" (25mm x 50mm) were sheared from 0.060" sheets. Sheared edges were ground and deburred, finishing with a 240 grit paper. Coupons were cleaned in distilled water and acetone and immersed in the boiling ferric sulfate-sulfuric acid solution. Tests were run for 120 hours and the weight loss of each coupon was determined.

Stress corrosion cracking resistance was determined in a boiling magnesium chloride solution per ASTM G36⁵. Duplicate 1" x 4" (25.4 x 101.6 mm) test samples were sheared from 0.060" (1.5 mm) sheets of each alloy. The sheared edges were ground and deburred, finishing with a 240 grit paper. Two holes were drilled 0.5" (12.7 mm) from each end, then the samples were immersed in a solution of 20% HNO₃ at 130°F (54°C) for ten minutes to remove contaminants then rinsed in distilled water. The samples were then bent around a 1" (25.4 mm) diameter to form a U-shape, which creates a stress state similar to that commonly experienced in the field as a result of equipment manufacturing (welding, forming), installation, and operation (temperature gradients). The ends of the U-bend sample were then bolted to maintain a leg separation of 1" (25.4 mm), using plastic washers to insulate the sample from the bolt. The assembly was ultrasonically cleaned prior to being immersed in 155°C (311°F) boiling 45% MgCl₂. The U-bend samples were checked periodically for the presence of cracks, and the tests were run until cracks appeared or until the immersion time reached 1,008 hours.

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