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An Experimental Study of Microstructure and Mechanical Behavior of Alloy 625 Weld Overlay Deposited On ASTM A516 Grade 70

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Abstract

Background/Objectives: Surface modification for protection against corrosion is a critical field of research in the oil and gas industry. Alloy 625 is a superalloy with excellent resistance to pitting and corrosion. **Methods/Statistical Analysis:** Alloy 625 weld overlays were cladded through GTAW process on A516 carbon steel. The welding current ranging from 230 - 240 A the welding voltage 11 - 13 V; welding polarity EN (-). After welding, optical and SEM observations were conducted to determine the changes in the microstructure of base metal and clad. For examination of mechanical strength of claddings shear test was performed in accordance with ASTM A265 standard. **Results:** After Optical microscopy examinations, two different microstructures were observed in the HAZ zone. In the base metal, the grain size was reduced during the manufacturing process. The microstructure of weld metal was austenitic with dendritic structure. EDX observation showed that precipitates were mainly Niobium carbide (NbC). In the HAZ near the clad, microstructure included acicular ferrite, widmanstatten pattern, bainite, and pearlite. The tensile strength of a clad interface can be an important Consideration. For examination of mechanical strength of claddings shear test was performed in accordance with ASTM A265 standard. The minimum shear strength of different samples was 210 and 255 Mpa, which is higher than what it is stated in ASTM A265 standard. **Conclusion/Application:** The results showed that the manufacturing parameters in welding result in an appropriate mixing between base metal and clad material. The shear strength is higher than base metal and acceptable.

Keywords: Alloy 625, Carbon Steel, Microstructure, Shear Strength, Weld Overlay

1. Introduction

Superalloys are commonly used in parts that are subject to high temperature and require high strength, excellent high temperature creep resistance, fatigue life, phase stability, and oxidation and corrosion resistance. They are also used where corrosion by media would rule out stainless steel in acidic or saltwater environments[1]. The Alloy 625 is a family of austenitic nickel based superalloys with excellent resistance to pitting, crevice and corrosion cracking and it is highly resistant in a wide range of organic and mineral acids. It shows high temperature strength, ductility and toughness at low temperatures. However, its high cost makes it financially impossible in many applications. In order to solve this problem, cladding has been increasingly considered in industry because of its several benefits including reduction of material[2]. Many experimental studies have been conducted to analyze the changes of weld overlays due to the manufacturing parameters. The quality and properties of claddings depend on the chemical composition of cladding alloy and deposition process. The desirable characteristics of claddings are their higher strength and corrosion resistance. Achievement of sufficient metallurgical bond between the clad and substrate is required and shall be acquired[3]. For the mechanical strength of claddings shear test

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requirements are defined by ASTM A265 standard, and the shear test is the most commonly specified bond strength test[4].

In this study the welding technique is GTAW, which is a flexible method and results in low dilution because of high controllability of heat input. Heat input plays a significant role in dilution and can be achieved by proportionally varying the welding speed and the welding current[5,6].

2. Experimental

2.1 Materials

In this investigation, one layer and two layers of ER NiCrMo-3 weld metal was deposited on the A516 Grade 70 carbon steel plate. This is a carbon steel with specifications for pressure vessel plates and moderate or lower temperature service. A516 steel plate is intended primarily for service in welded pressure vessels where improved notch toughness is of great significance[7,8]. The chemical compositions of the filler metal and substrate can be reviewed in Table 1 and Table 2.

Table 3. Parameters of Cladding Process

Parameter	Value
Welding Current	230 - 240 A
Welding Voltage	11 - 13 V
Shielding Gas	Pure (99.99%) argon
Shielding Gas Flow Rate	12 L/min
Electrode Diameter	3.2 mm
Welding Speed	180 - 240 mm/min
Welding Polarity	EN(-)
Maximum Inter-Pass Temperature	150 °C
Heat Input	805 J/mm
Torch Angle	35°
Tip of the Electrode Angle	30°
Wire Angle	30°
Arc Length	13.8 mm

Table 1. Chemical composition of the base metal

ASTM	UNS	Fe %	C %	Mn %	P (max) %	S (max) %	Si %	Al %
A516 Gr. 70	K02700	Bal.	0.28	0.79 - 1.30	0.025	0.025	0.13 - 0.45	0.04

Table 2. Chemical composition of the filler metal

AWS	UNS	C %	Cr %	Fe %	Mn %	Ni %	Mo %	Si %	Nb %
ER NiCrMo- 3	N06625	0.10	20 - 23	4.0	0.5	Bal.	8 - 10	0.5	3.15 - 4.1

2.2 Welding Process

Before the process, the base metal surfaces were ground and washed with acetone to remove any contaminants. The welds were made through the GTAW process with a hot wire automatic feeding system. The cladding process was carried out in the flat 1G position. Before Overlaying, the plate was preheated to reach the minimum temperature of 150 °C. For heating the wire before overlaying, the current 70 A, and voltage 4.4 - 4.6 V were used. Other parameters for both cladding processes (see Table 3).

2.3 Examination of Microstructure

After welding, Optical and SEM observations were conducted to determine the changes in the microstructure of base metal and clad. Transverse sections of the substrate and welds were characterized after etching in Nital 2% solution and electrotching in 20% phosphoric acid. Surface chemical composition of weld overlays, cast and forged specimens were measured using a Scanning Electron Microscope (SEM) models TESCAN MIRA3, equipped with energy dispersive X-ray spectroscopy (EDS) systems.

2.4 Examination of Mechanical Properties

As it is mentioned before for examination of mechanical strength of claddings shear test can be conducted. These specifications do not define a through thickness clad tensile test. For most applications, the clad metal is simply too thin to produce a meaningful clad tensile specimen. The tensile properties shall be determined by a tension test of the composite plate for clad plates. Test specimen must be machined carefully to ensure accurate test results. Figure 1 shows the dimensions of the shear test specimens. As it is shown in Figure 2 test specimen were prepared using a wire cut machine in accordance with ASTM A265 standard. The interface area between Inconel 625 and base metal is 120.65 mm^2. As it is shown in Figure 3, using an apporopriate fixture the shear test was perforemed.

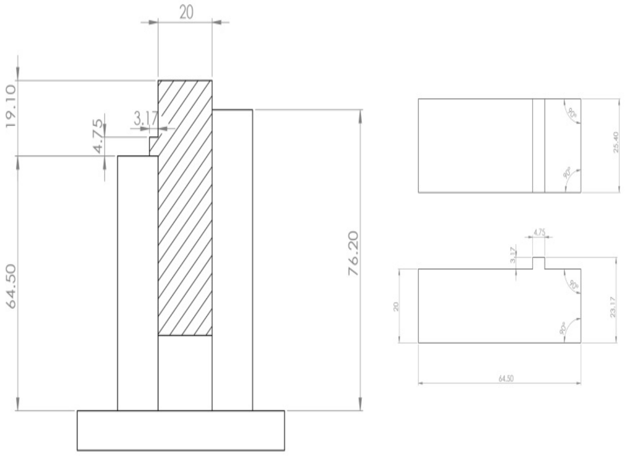


Figure 1. Schematic illustration of the shear test specimen in accordance with ASTM A265.

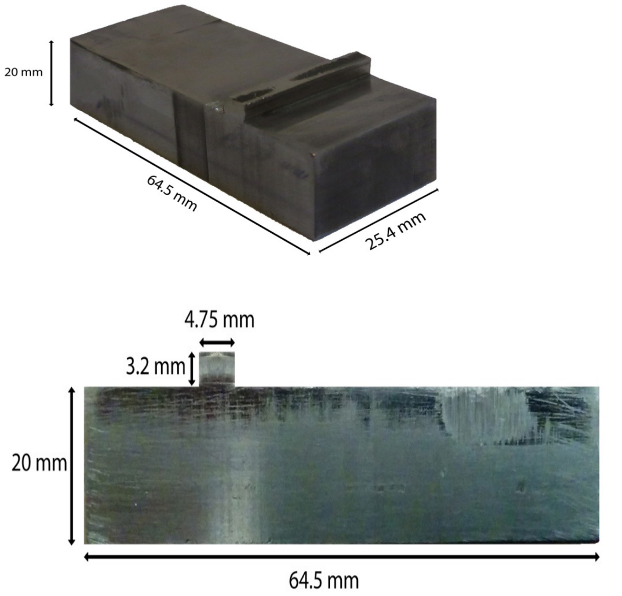


Figure 2. Test specimen were prepared using a wire cut machine in accordance with ASTM A265.

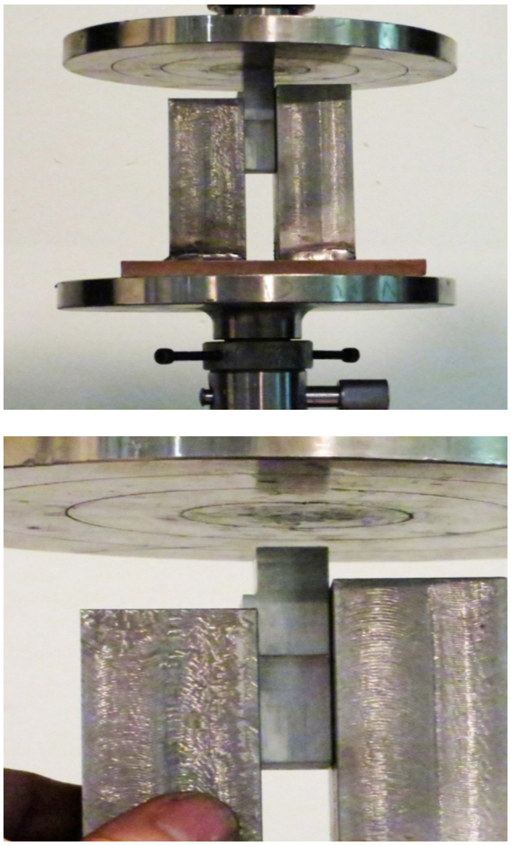
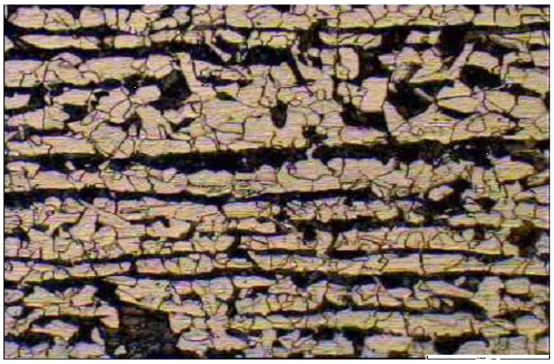


Figure 3. Test specimen in shear test fixture in accordance with ASTM A265.

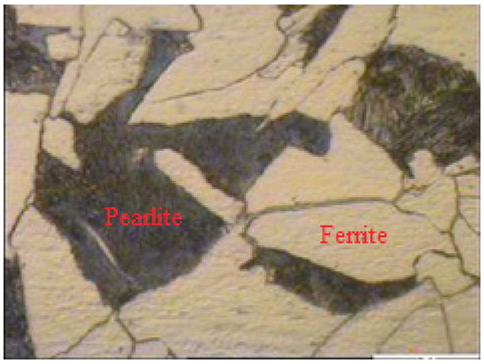
3. Results and Discussion

3.1 The Microstructural Characterization of the Base Metals

After Optical microscopy examinations two different microstructure were observed in the HAZ zone. Figure 4 and Figure 5 show the first microstructure of HAZ near the base metal before and after cladding respectively. The grain size of ferrite (light phase) and pearlite (dark phase) were reduced during cooling in the manufacturing process. The smaller grain size increases the strength and results in higher shear strength in the mechanical tests. In the HAZ near the clad different microstructure was observed, which included acicular ferrite, widmanstatten pattern, bainite, and pearlite (Figure 6). The Microstructure of weld metal is shown in Figure 7, which is austenitic with dendritic structure. Both continuous and non-continuous dendritic structures were found in microstructure of alloy 625 weld overlay. Niobium and molybdenum contents in Inconel 625 filler metal are 4% and 9%, respectively. Nb and Mo are elements that show strong segregation during solidification of the weld metal[9]. It should also be noted that carbon can diffuse from base metal to the clad. Studies show that carbon has a high penetration rate in nickel. Cieslak et al.[10] also reported that the equilibrium distribution coefficient of Carbon in Inconel 625 is less than one (kC = 0.21 in IN-625). Therefore, there is high possibility of the diffusion and segregation of carbon to react with other elements in the weld metal. These are the main explanations for the formation of various carbide phases during the solidification.



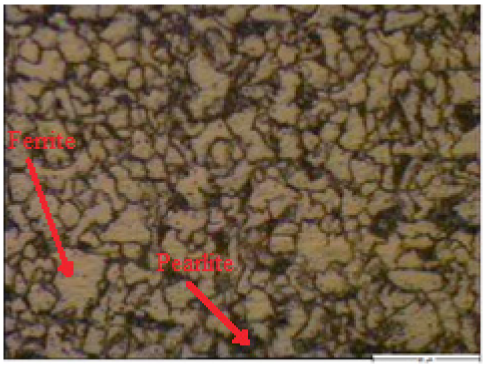
(a) 100x



(b) 500x

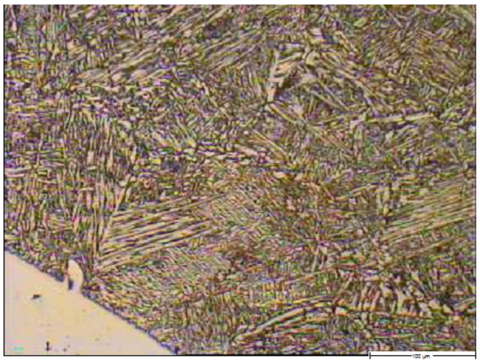
Figure 4. Microstructure of HAZ near the base metal before cladding with ferrite, and pearlite phases.

(a) 100x



(b) 500x

Figure 5. Microstructure of HAZ near the base metal after cladding with reduced grain size ferrite, and pearlite phases.



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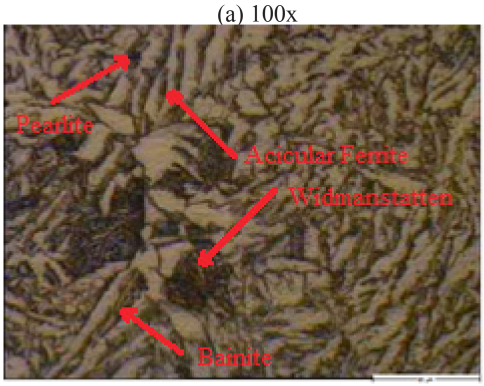
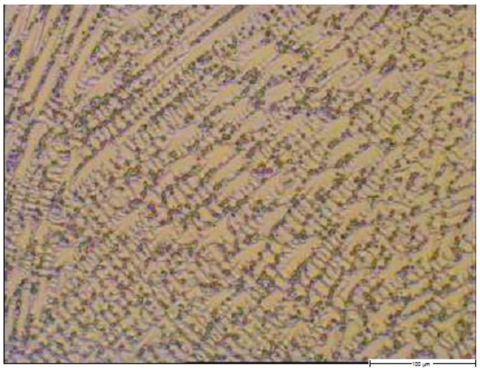


(b) 500x

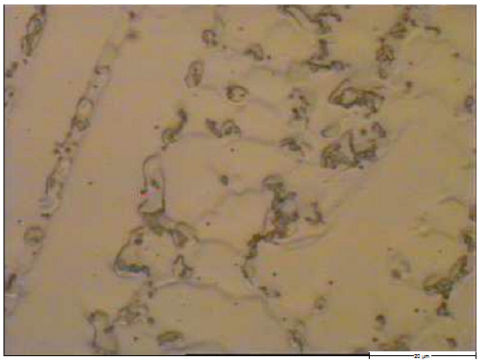
Figure 6. Microstructure of HAZ near the alloy 625 clad with acicular ferrite, widmanstatten pattern, bainite, and pearlite phases.

3.2 Mechanical Strength

Figure 8 illustrates the stress-strain diagram which is the result of the shear test. The minimum shear strength of the cladding and base metals shall be 20 000 psi (140 MPa)[11]. The minimum shear strength of sample 1, and sample 2 were respectively 210 and 255 Mpa, which is higher than what it is mentioned in the standard. This shows that the



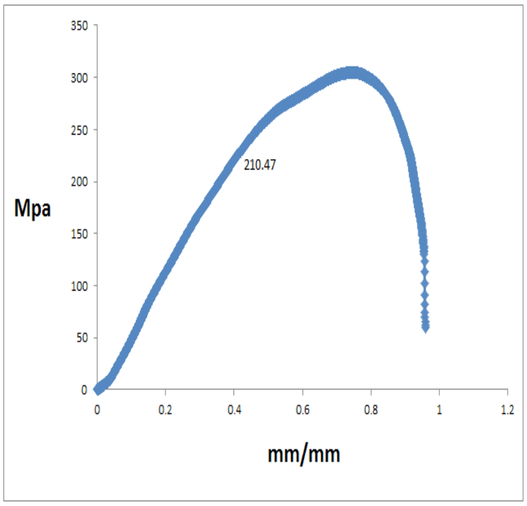
(a) 100x



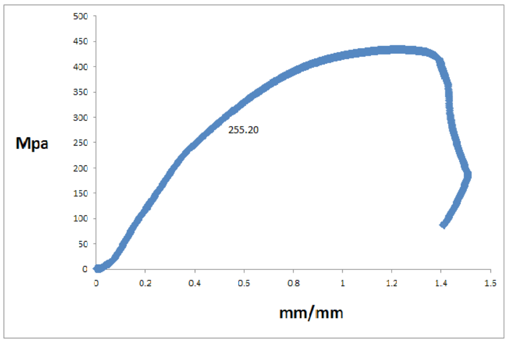
(b) 500x

Figure 7. Microstructure of Alloy 625 with both continuous and non-continuous dendritic structures.

manufacturing parameters in GTAW welding result in an appropriate mixing between base metal and clad material. As it is shown in Figure 9 the interface of substrate and Inconel 625 had an acceptable toughness and after the yield point a plastic behavior was observed.



(a)



(b)

Figure 8. (a) sample 1, and (b) sample 2 stress-strain diagram of shear test.

Figure 9. Shear test specimen after ASTM A265 test.

4. Conclusion

Based on the results presented in this study, concerning the microstructure and mechanical properties of the nickel-based Alloy 625 weld overlays deposited with by GTAW process and Alloy 625 cast and forge forms, the followings are concluded:

- Optical and SEM observations showed two different microstructures in the HAZ zone. In the base metal, the grain size was reduced during cooling in the manufacturing process. In the HAZ near the clad, microstructure included acicular ferrite, widmanstatten pattern, bainite, and pearlite. The Microstructure of weld metal is austenitic with both continuous and non-continuous dendritic structure. EDX observations show that precipitates are mainly Niobium carbide (NbC) and laves phase Fe_2Nb.

- The average shear strength of test specimens was 232.5 Mpa, which is higher than what it is stated in ASTM A265 standard. This proves that the manufacturing process with the mentioned welding parameters results in an appropriate mixing between the carbon steel substrate and Alloy 625 clad.

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