

Effect of heat input on microstructure and mechanical properties of dissimilar joints of AISI 316L steel and API X70 high-strength low-alloy steel

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ABSTRACT

The microstructure and mechanical properties of dissimilar joints of AISI 316L austenitic stainless steel and API X70 high-strength low-alloy steel were investigated. For this purpose, gas tungsten arc welding (GTAW) was used in three different heat inputs, including 0.73, 0.84, and 0.97 kJ/mm. The microstructural investigations of different zones including base metals, weld metal, heat-affected zones and interfaces were performed by optical microscopy and scanning electron microscopy. The mechanical properties were measured by microhardness, tensile and impact tests. It was found that with increasing heat input, the dendrite size and inter-dendritic spacing in the weld metal increased. Also, the amount of delta ferrite in the weld metal was reduced. Therefore, tensile strength and hardness were reduced and impact test energy was increased. The investigation of the interface between AISI 316L base metal and ER316L filler metal showed that increasing the heat input increases the size of austenite grains in the fusion boundary. A transition region was formed at the interface between API X70 steel and filler metals.

1. Introduction

Stainless steels are among the most extensively used special alloys that have been developed against corrosion. Austenitic stainless steels are the biggest group of stainless steels, and grades of AISI 316 and AISI 304 steel are the most commonly used austenitic stainless steels. These steels are generally considered to be very weldable. On the other hand, problems such as hot cracking and sensitization phenomena occur in these steels' weld metal and heat-affected zone. In order to solve these problems, a very low carbon grade like 316L and 304L has commonly been used^[1,2].

High-strength low-alloy (HSLA) steels are used extensively in oil and gas pipelines. Achieving high transmission efficiency becomes possible by constructing transmission pipelines using high-strength steels, which allow for high operating pressures and high rates of transmission. Owing to the economic benefits as well as the full advantage of the outstanding performance of two metals, such as strength and corrosion resistance, dissimilar welding is used extensively in the oil and gas industries^[3,4].

Some researchers have focused on the properties

of dissimilar welding, and a significant amount of research work has been carried out on the welding behavior and mechanical properties of dissimilar welding joints^[5-7]. Generally, the joining of dissimilar steels is more challenging than that of similar steels on account of several factors, such as the differences in chemical compositions and thermal expansion coefficients, which lead to different residual stress situations across the different regions of weldments as well as the migration of carbon elements from the steel with higher carbon content to the steel with relatively lower carbon content^[8-12]. Gas tungsten arc welding (GTAW) is widely employed in joining processes, especially in those dealing with structural and piping applications.

Lin and Hsieh^[13] studied the effect of Si content for 309L filler metal on the dissimilar welding of AISI 1017 and AISI 304L steels. The result showed that Si can increase the formation of δ -ferrite and the sigma phase in the weld metal.

Arivazhagan et al.^[14] investigated the effect of heat input on the microstructure and mechanical properties of dissimilar welding of 304 austenitic stainless steel and 4140 low alloy steel. It was found that as heat input increases, the micro-segregation

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of alloying elements increases, and also creates a chromium depletion zone in the grain boundaries; therefore, the mechanical properties of the joints are determinate.

Sadeghian et al.^[15] studied the effect of heat input on the microstructure and mechanical properties of a dissimilar welding joint of super-duplex stainless steel and high-strength low-alloy steel by gas tungsten arc welding. Results indicated that an increase in heat input leads to a decrease in ferrite percentage. Besides, there were no harmful secondary phases, neither carbides nor nitrides. It also indicated the bainite and ferrite phases formed in the heat-affected zone of HSLA base metal in low heat input. However, in high heat input, pearlite and ferrite phases formed.

Ramkumar et al.^[16] investigated the microstructure and mechanical properties of dissimilar UNS 32750/AISI 316L welded joint. They reported that microstructure studies revealed the presence of ferrite at the heat-affected zone of AISI316L and the fusion zone obviated the hot cracking tendency. Also, tensile studies showed that the strength of joint was sufficiently greater than that of parent metals and the impact toughness was slightly poor, due to the presence of large platelets of Widmanstatten ferrite

in the fusion zone.

The present work evaluates the effect of heat input on the microstructural development and the mechanical properties of dissimilar AISI 316L/API X70 steel joints prepared by GTAW.

2. Experimental Procedure

AISI 316L austenitic stainless steel and API X70 high-strength low-alloy steel were welded together in dimensions of 100 mm×70 mm×10 mm (Fig. 1) by GTAW. A 70-degree single V groove edge with a root face gap of 2 mm was employed before welding. Also, an ER316L welding rod was used and the welding was carried out in five passes to join AISI 316L to API X70 HSLA steel. The chemical compositions of base metals and filler metal are shown in Table 1, and welding parameters are shown in Table 2.

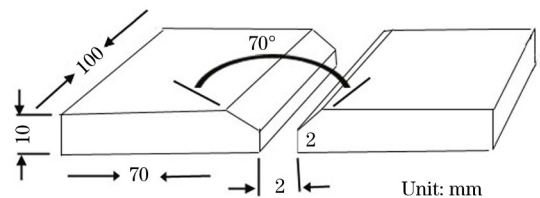


Fig. 1. Design of weldment.

Table 1

Chemical compositions of base metals and filler metals (wt.%)

Component	C	Si	Mn	P	S	Ni	Cr	Cu	Mo	Ti	Nb	Al
API X70	0.09	0.45	0.90	0.04	≤0.020	0.4	0.25	—	0.08	0.010	0.050	0.0300
AISI 316L	0.06	0.47	1.38	0.01	≤0.005	13.0	17.00	0.058	2.00	0.002	0.009	0.0036
ER316L	0.03	0.90	1.73	0.03	≤0.030	11.5	19.30	0.700	2.50	—	—	—

Table 2

Welding parameters

Current/ A	Voltage/ V	Speed/ (mm · s ⁻¹)	Heat input/ (kJ · mm ⁻¹)
160	13	1.69	0.73
180	14	1.78	0.84
200	15	1.85	0.97

Ferrite number measurement was also carried out by using Ferritescope FMP30 produced in Russia. The results of the Ferritescope are listed in Table 3.

In order to evaluate the mechanical properties, tensile test according to ASTM E8 standard, impact test according to ASTM E23 standard and microhardness test

Table 3

Result of Ferritescope

Heat input/(kJ · mm ⁻¹)	Ferrite/%	Austenite/%
0.73	5.2	94.8
0.84	3.3	96.7
0.97	2.1	97.9

according to ASTM E384 were performed. After the tensile test and impact test, all the fracture surfaces of the specimens were examined by using a field emission scanning electron microscope (FESEM). A microhardness test with force loading of 0.98 N for 10 s was conducted across the base metals, heat-affected zones and weld metals. The notch impact test specimens with dimensions of 55 mm×10 mm×10 mm and 2 mm notches with an angle of 45° were prepared, and the tests were conducted at room temperature and −5 °C. The weld metal was placed at the centers of the specimens. The Charpy impact test was performed on the specimen at room temperature.

Metallographic observation was carried out to study the microstructures of base metals, weld metal, heat-affected zones and microstructural changes. The specimens of API X70 steel were etched in nital (2 vol. % nitrate acid in alcohol) for 20 s; specimens of AISI 316L austenitic stainless steel were electro-etched in 60 vol. % nitric acid at 5 V for 60 s and specimens of austenitic stainless steel weld metal were etched by Marble's reagent (10 g CuSO₄+50 mL

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