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EFFECT OF FILLER METALS ON THE MECHANICAL PROPERTIES OF DISSIMILAR WELDING OF STAINLESS STEEL 316L AND CARBON STEEL A516 GR 70

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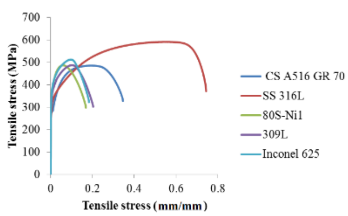
Graphical abstract



Abstract

This paper describes an investigation on the effect of using three different filler metals to weld two dissimilar metals namely, stainless steel 316L and low alloy carbon steel A516 gr 70. Manual Gas Tungsten Arc welding (GTAW) with three filler metals including ER 80S-Ni1, ER309L, ER NiCrMo-3 were selected to weld the two metals. Radiography and penetrant tests were performed on the welded metals to ensure the surface and internal soundness of the welds based on the tensile tests results, all the specimens failed at the carbon steel A516 gr 70 base metals with fully ductile fracture mode (cup and cone). Welded samples using Inconel 615 filler metal has the highest strength of 512 MPa while other samples show almost similar strength of 481 and 487 MPa. The tensile strength of all the welded samples is found to be in between the tensile strength of the base metals. Micro-hardness test showed that ER80S-Ni1weld has the highest hardness, meanwhile hardness profile of ER309L presented a sharp drop in the stainless steel side and ER NiCrMo-3 weld metal illustrated hardness above the two base metals with fewer variations across the weld metal.

Keywords: Gas tungsten arc welding, mechanical properties, tensile test, micro-hardness test

Abstrak

Kertas penyelidikan ini menghuraikan suatu kajian ke atas kesan penggunaan tiga logam penambah yang berbeza untuk mengimpal dua logam yang berlainan iaitu, keluli tahan karat 316L dan aloi keluli rendah karbon A516 gr 70. Menggunakan kimpalan gas arka tungsten (GTAW) dengan tiga logam pengisi iaitu ER 80S-Ni1, ER309L, ER NiCrMo-3 telah dipilih untuk mengimpal dua logam tersebut. Ujian radiografi dan penusuk telah dilakukan ke atas logam dikimpal untuk memastikan permukaan dan kekuatan dalaman kimpalan, berdasarkan keputusan ujian tegangan, semua spesimen gagal pada keluli karbon A516 gr 70 logam asas dengan mod patah mulur sepenuhnya (cup dan cone). Sampel yang dikimpal menggunakan Inconel 615 logam penambah mempunyai kekuatan tertinggi iaitu 512 MPa manakala sampel lain menunjukkan kekuatan hampir sama 481 dan 487 MPa. Kekuatan tegangan semua sampel dikimpal didapati di antara kekuatan tegangan daripada logam asas. Ujian mikro kekerasan menunjukkan ER80S-Ni1weld mempunyai kekerasan yang tinggi, sementara itu profil kekerasan ER309L menunjukkan penurunan mendadak dibahagian keluli tahan karat dan ER NiCrMo-3 kimpalan logam mengambarkan kekerasan di atas kedua-dua logam asas dengan variasi yang kurang di sepanjang logam kimpal.

Kata kunci: Kimpalan arka gas tungsten, ciri mekanikal, ujian tegangan, ujian kekerasan-mikro

1.0 INTRODUCTION

Dissimilar welding between austenitic stainless steel and ferritic steel are widely utilized in many industries such as petrochemical and power generation industries in fabrication of pressure vessel, heat exchanger and joining of stainless steel piping and low alloy steel nozzles1, 2. There are three different welding process categories to carry out weld namely; fusion welding, low dilution welding and non-fusion welding as presented in Figure 1. Low dilution and non-fusion methods are often utilized for special purposes in which alloying level between the dissimilar materials must be minimized. In oil, gas and power industries fusion welding is widely used for joining of dissimilar metals3. Generally, the consumables with different chemical composition than both base materials are used in dissimilar welding. The additives in austenitic and ferritic dissimilar welding are normally austenitic filler metals containing specific amount of ferrite. However, Nickel-based fillers are used in a variety of joints involving carbon steel, stainless steel, nickel base alloy, and overlaying welding due to their high corrosion resistance properties4, 5. Dissimilar welding problems are associated with physical and chemical properties of base metals. So that, thermal expansion coefficient and crystal structure result in weld thermal/mechanical constraint and formation of intermetallic phases during welding respectively. Lack of ductility, high cracking and corrosion susceptibility are some negative effects of intermetallic phases. Heat affected zone in the austenitic and ferritic dissimilar welding encounter more problems such as, carbon migration, dilution and frequent failure on the carbon steel side6, 7. Several studies have been done to improve mechanical properties of dissimilar welding by using different consumables.

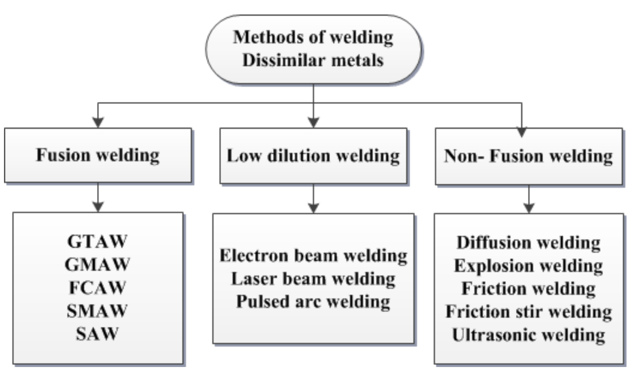


Figure 1 Dissimilar welding methods

Mechanical properties of 9Cr±1Mo ferritic carbon steel and Alloy 800 nickel based austenitic steel dissimilar welds, studied by Sireesha *et al.*, using Inconel and stainless filler metals, showed that Inconel additives has a superior mechanical properties. Recently, Haitao Wang *et al.* have studied the local mechanical properties of A508 ferritic Steel and 316L Stainless Steel welded by Alloy 52M filler metal. He found that inhomogeneous mechanical properties results from different microstructure can result in macroscopic fracture mechanics parameter, local crack initiation and growth behavior8, 9.

In this study, mechanical properties of A516 gr 70 ferritic low carbons steel and 316L stainless steel were studied by using different filler metals. Tensile and micro hardness tests were applied to discuss about the properties.

2.0 EXPERIMENTAL

In this study two base materials of carbon steel A516 gr 70 and stainless steel 316L were cut to form a plate with dimension of 300 x 150 x 12 mm. Three different filler metals of 2.4 mm in diameter were used namely, ER80-Ni1, ER309l and ER NiCrMO-3 (Inconel 625). Their typical chemical compositions are presented in Table 1. Direct-Current Electrode Negative manual Gas Tungsten Arc Welding (GTAW-DCEN) processes with argon gas shield of 99.99% purity was used to join the samples with single V bevel prepared edges.

Table 1 The chemical composition of base metals and filler metals (%wt)

Element	C	Cr	Ni	Mo	Si	Ti
A516 Gr 70	0.2	0.02	0.02	0.005	0. 3	0.01
316L	0.27	17.8	9.8	2	0.25	0.01
ER80S-Ni1	0.12	0.15	0.96	0.3	0.6	-
ER309L	0.02	23.7	13.8	0.04	0.51	-
ERCrNiMo-3	0.1	23.4	57.7	10	0.5	0.02

Maximum interpass temperature was held at 150 C° for ER309L and 100C° for ERCrNiMo-3 and root pass for these two welding was purged by argon gas so as to prevent root oxidization. Welding parameters and calculated heat input for passes presented in Table 2. All parameters except for the filler metals were kept constant. Dye penetrant and radiographic test was performed according to ASME Sec. V in order to detect the surface and internal defects respectively. The tensile test was carried out on the base and welded samples (by three different fillers). For the welded samples transverse test method were applied. The tensile strength of each sample was determined from their corresponding stress-strain curve. The tensile test specimens were prepared in accordance to AWS B4.0 and ASTM A370 standards. Micro-hardness tests on welds was determined using Schimadzu micro-hardness tester.

Table 2 The welding procedures and the heat input in root, filling and cover passes

	Welding parameters				
	Pass No	Current (A)	Volt (V)	Welding speed (mm s^{-1})	Heat input (KJ mm^{-1})
Root	1	110	12	1.1	0.72
Hot	2-3	120	12	1.2	0.72
Filler	4-15	130	11	1.1	0.78
Cap	16-20	140	11	1.3	0.71

3.0 RESULTS AND DISCUSSION

3.1 NDT Results

Penetrant and radiography testing as NDT methods show neither surface nor internal flaws in the welds. Figures 2 and 3 present radiography and dye penetrant test results for all welded joints, respectively. All welds were found to be defect-free.

Figure 2 Radiography results of welds of (A) 80S-Ni1 (B) 309L (C) Inconel 625

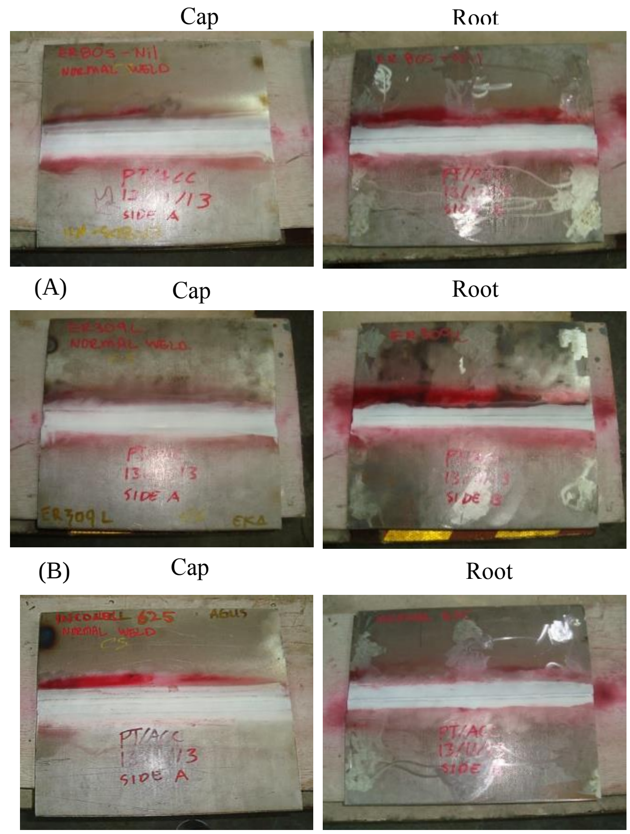
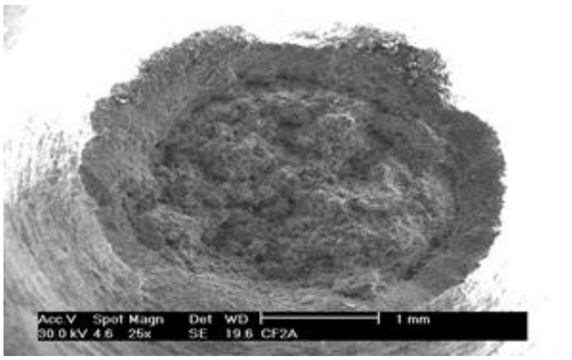


Figure 3 The dye penetrant test results of the cap and root surfaces of the welds; (A) welded by 80S-Ni1 filler metal (B) welded by 309L filler metal (C) welded by Inco 625 filler metal

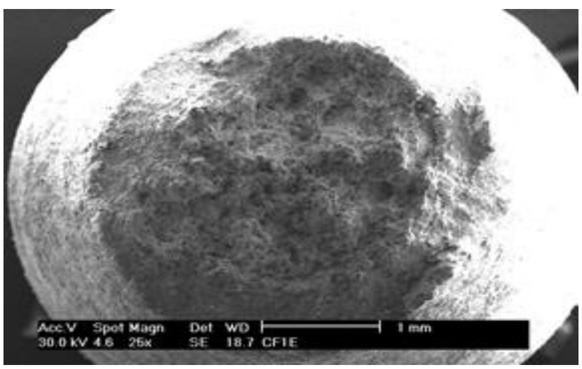
3.2 Tensile Test

The tensile strength of base and welded metals has been evaluated at room temperature. For the transverse tensile tests, all welded joints failed at the weaker parent metal, carbon steel A516 gr 70. This fracture surface consists of cup and cone form which show failure in a ductile manner (Figure 4, 5). Tensile strength of welded joints was found to be in between the two base metals, carbon steel A516 gr 70 and stainless steel 316L which was higher than carbon steel but lower than stainless steel. Among the welded joints, the one which was welded by Inconel 625 filler metal has higher tensile strength compared with the two other joints. Tensile stress vs tensile strain curves for all welded joints are presented in Figure 6. Furthermore, this figure shows welded joints have lower toughness compare to base metals meanwhile, joints welded by Inconel 625 and 309L have better toughness than 80S-Ni1 joint.

Figure 4 Photograph of fractured tensile specimens of the base metal and welded specimens



(A)



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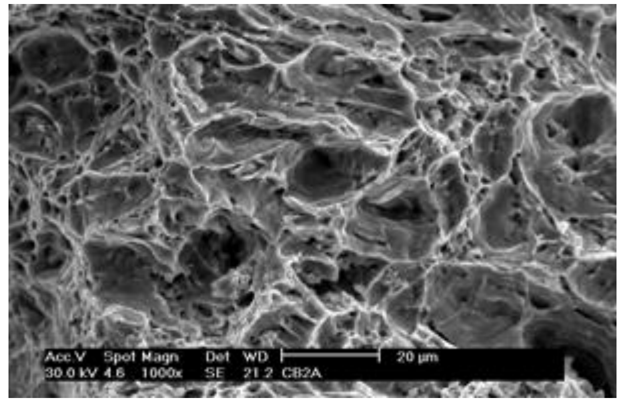
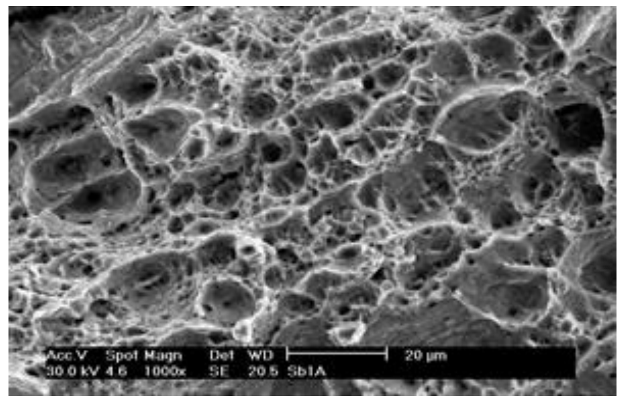


(C)



(D)

Figure 5 Tensile fractographs of test specimens which were failed on carbon steel side (A) cup (B) cone which shows ductile fracture. (C) carbon steel A516 gr 70 (D) stainless steel 316L

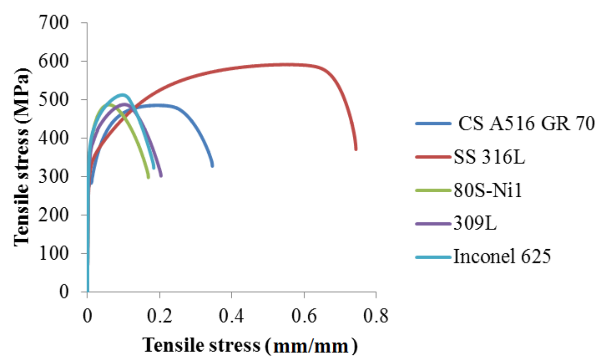


Figure 6 Tensile curves of transverse specimens at room temperature for carbon steel A516 gr 70, stainless steel 316L, dissimilar metal welded by 80S-Ni1, dissimilar metal welded by 309L and dissimilar metal welded by Inconel 625.

3.3 Micro-hardness

Variations of hardness across the welds are shown in Figure 7. In all the samples investigated, the weld metals exhibited higher hardness values than carbon steel A516 gr 70 base metal except for cap pass by 309L filler metal. The 80S-Ni weld metal shows highest hardness value than other welds. This is probably due to residual stress developed as a result of the completely different microstructure evolution from the filler metal such as martensite and upper bainite. The Inconel 625 weld used show better hardness distribution in the base and in the filler metals compared with the other weld metals.

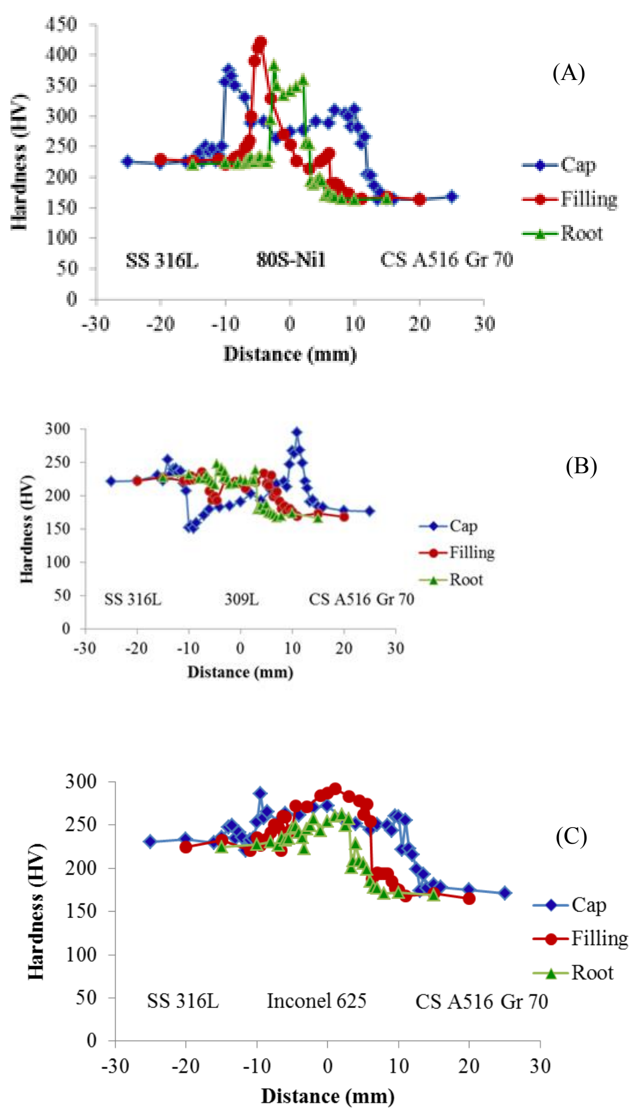


Figure 7 Micrograph for the welds joined by (A) 80S-Ni1 (B) 309L (C) Inconel 625 filler metals

4.0 CONCLUSION

In this paper, the dissimilar welding of A516 gr 70 carbon steel plates and 316L stainless steel welded by Gas Tungsten Arc Welding (GTAW) process with single V groove edge design with three different filler metals namely; 80S-Ni1, 309L and Inconel 625 was described. Based on the experimental results and analysis, the following conclusions can be drawn;

1 - The tensile strength of the welded dissimilar metal joints is higher than the carbon steel A516 gr 70 base metal but lower than stainless steel 316L base metal. In other words, the tensile strength of the welded dissimilar metal is in between the tensile strength of both base metals.

2 - The dissimilar metal welded by Inconel 625 filler metal has the highest tensile strength and better hardness distribution compared with other dissimilar metals welded with ER80-Ni1and ER309L filler metals.

3 - The filler metal most suitable for dissimilar welding of carbon steel A516 gr 70 and stainless steel 316L is Inconel 625

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