Effect of Shielding Gas and Filler Metal to Microstructure of Dissimilar Welded Joint Between Austenitic Stainless Steel and Low Carbon Steel

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Abstract: Welding of dissimilar metals involves different types of metals which have different chemical composition, mechanical and thermal properties. This paper presents a study on dissimilar metal weld between type 304 stainless steel and SS400 carbon steel. The steel plates were welded by using different filler metals (solid wire, flux-cored wire) and different shielding gases (100%CO₂, 90%Ar+10%CO₂). Then the weldments were observed by optical microscope, scanning electron microscope and EDX analysis. It seems that the weldments which were welded by using 100%CO₂ shielding gas have significant amount of inclusions in weld metal compared to 90%Ar+10%CO₂ shielding gas mixture. The EDX analysis shown the inclusions are oxides which consist of some elements (C, Si, Cr, Mn) with O. The weldment which was welded by using 90%Ar+10%CO₂ shielding gas mixture and solid wire has much less inclusions in weld metal.

Keywords: dissimilar metal weld (DMW), 304 stainless steel, SS400 carbon steel, microstructure, inclusions

1. Introduction

Dissimilar metal weld (DMW) which applied for joining of low carbon steels to austenitic stainless steels is frequently applied in the automobile, nuclear plants, petroleum and petrochemical industries. A serious concern is noticeable in recent years where DMW joints indicated a small-localized zones near fusion boundary which show high hardness region [1]. The difference in chemistry, mechanical and thermal properties of metals influence complexity of DMW, so DMW is challenging and need more attention compared to similar metal weld [2, 3].

Fusion welding is generally applied for joining of similar and dissimilar metals. Gas–tungsten arc welding (GTAW) is preferred for similar or dissimilar metals weld consider good quality result and good appearance of workpiece. However, to achieve good quality joints, DMW requires proper selection of welding parameters, filler metal, shielding gas, welding method, etc. Austenitic stainless steel has an excellent combination of corrosion resistance and mechanical properties that often used in petrochemical, power plant, automotive, oil and gas industries [2].

DMWs are made from two metals which have significant different in chemical composition and mechanical properties. When dissimilar metals are joined by an arc welding process, mixing of parent metal and filler metal in the fusion zone produce different mechanical properties and this phenomenon
influence the distribution of residual stress after welding [4]. Gas metal arc welding (GMAW) method is commonly applied in steel fabrication for both similar and dissimilar metal welding, on the other hand GTAW method usually is selected to achieve high quality welds in a various metals, but it does not usually used in thick metals due to its low deposition rate so that poor productivity. In fusion welding operation, welding parameters such as voltage, current, welding speed, polarity, filler metal, shielding gas and gas flow rate have all a significantly influence on weld quality [5].

Interaction factor of filler metal, welding speed, and current have affected the mechanical properties of DMW between stainless steel (AISI 304) and carbon steel. The results of ultimate tensile strength and elongation for DMW between AISI 304 stainless steel and carbon steel showed there was significant different due to interaction factor of filler metal, welding speed, and current [3].

Specification of filler metal has significant affect to weldment. From the study of the various experiments for DMW between 316LN austenitic stainless steel and alloy 800, selection of the nickel-based consumables show better tensile strength and improved thermal stability compared to 316 austenitic steel welding wire [6].

Research of weldability of AISI 4140 and AISI 316 by GTAW method with and without filler metal (autogeneous) have been reported by Madduru et al. [7]. Carbides was found at the heat affected zone (HAZ) of AISI 316 side when GTAW method without filler metal (autogeneous) was performed. It would be probably occurred due to carbon element diffused from AISI 4140 low alloy steel to AISI 316 stainless steel. Hardness distribution of GTAW steel weldments with and without filler metal show clearly that the highest hardness was measured at the HAZ of AISI 4140 in autogeneous GTA weldments [7].

M.T. Liao et al. [8] reported that the microstructure evolution of stainless steel weldment are influenced by the shielding gas which used to protect the weld pool from atmospheric gas such as nitrogen and oxygen. The shielding gas type not only influence microstructure of the weldment but also influence the shape and weld penetration. During welding, the shielding gas also interacts with the filler metal to produce microstructure evolutions which influence mechanical properties and corrosion resistance of particular weld deposits. The spatter rates increase and ferrite number decreases with increasing the CO₂ percentage of the Ar+CO₂ shielding gas mixture from 2 to 20%. The increase of CO₂ percentage will raise carbon content in the weld deposits, therefore the ferrite number will decrease and nickel equivalent become larger. Also, the increase of CO₂ content will speed up the consumption of Cr and Si elements due to oxidation effect and make the Cr equivalent smaller [8].

D. Katherasan et al. [9] studied a 316L stainless steel which was welded by flux-cored arc welding (FCAW) method with various shielding gases. Impact toughness and ferrite amount of the weld metals tend to decreased by increasing the CO₂ in shielding gas mixtures, when impact test was performed at temperatures of 25 °C, -100 °C and -196 °C. The average values of impact toughness decreased with decreasing test temperatures and increasing the CO₂ percentage in shielding gas mixtures [9]. On the other hand, the CO₂ percentage in the shielding gas mixtures has significantly influenced on the size of undercut weld defects. The width, length and volume of undercut weld defects decreased with increasing CO₂ percentage. When the CO₂ percentage was more than 20%, welding spatters deteriorated the weld bead appearance [10].

During welding operation, the weld pool is protected by the shielding gas from direct contact to the atmospheric gas. Proper selection of the shielding gas influence welding quality. Argon is widely used for shielding gas, argon often mixed with some other gases that can be inert such as helium, or active gas such as CO₂, O₂ or H₂ [5].

Gasem et al. [1] suggested that the fusion boundary on the carbon steel side is the problem area of DMWs joint, because the hard zones present along the fusion boundary. These hard zones are very thin and noncontinuous layers (typically 0.025 mm wide) with a hard phase. Microscopic observation by using Energy Dispersive X-Ray Spectrometry (EDS) on some different DMWs revealed that the hard zones containing 3-5% chromium and 2-3% nickel [1]. Microstructure analysis and EDS observation indicated that these hard zones containing chromium carbides in a martensite matrix. Filler metals which containing chromium element will produce a similar hard zone in the fusion boundary, it explains why E309 (austenitic filler metal with 24 wt% Cr) resulting welds with high amount of hard zone, and hence susceptible to sulfide stress cracking compared to Inco 182 (Ni-base filler metal with 15 wt %Cr) [1].
In this study, the effects of various filler metal and shielding gases on the microstructure of weldments were investigated. The specimens were observed with optical microscope and scanning electron microscope.

2. Materials and Methods

In these experiments, 304 austenitic stainless steel and SS400 low carbon steel plates were used as the base metals. The chemical composition of both 304 and SS400 steel plates are provided in Table 1 and 2.

Eight samples of 304 austenitic stainless steel plates were cut with the dimension of 90 x 50 x 3 mm. And another eight samples of SS400 low carbon steel plates were cut with the dimension of 120 x 80 x 6 mm. Those plates 304 austenitic stainless steel and SS400 low carbon steel were fillet welded as shown in Figure 1.

| Specimen | Welding method | Filler metals | Diameter of filler metal (mm) | Shielding gas |
|----------|----------------|---------------|-------------------------------|---------------|
| S1       | GMAW           | ER309LSi      | 0.9                           | 100% CO₂      |
| S2       | GMAW           | ER309LSi      | 0.9                           | 90%Ar+10%CO₂  |
| S3       | FCAW           | E316L         | 1.2                           | 100% CO₂      |
| S4       | FCAW           | E316L         | 1.2                           | 90%Ar+10%CO₂  |
| S5       | FCAW           | E308L         | 1.2                           | 100% CO₂      |
| S6       | FCAW           | E308L         | 1.2                           | 90%Ar+10%CO₂  |
| S7       | FCAW           | E309L         | 1.2                           | 100% CO₂      |
| S8       | FCAW           | E309L         | 1.2                           | 90%Ar+10%CO₂  |
3. Results and Discussions

The microstructures were observed on each specimens using optical microscope. The observation regions including BM, HAZ, and WM.

Microstructure observation of the BM revealed that SS400 carbon steel was composed of ferrite (light region) and pearlite (dark region), and 304 stainless steel was composed of austenitic grains as shown in Figure 4.

The HAZ of SS 400 side consist of martensite and coarse grain heat affected zone (CGHAZ) as shown in Figure 5. The microstructure in the fusion boundary have a partially mixed zone, that is a narrow region where the composition gradually changes from the WM to the BM.
FIGURE 5. Optical microscope images on specimen S1 at the HAZ of SS400 side

FIGURE 6. Optical microscope images on specimens S1 to S8 at weld metal (WM)
Each specimens were observed using optical microscope and scanning electron microscope. The microstructure of WM was observed with optical microscope using 500X magnification for all specimens S1 to S8 and the results are shown in Figure 6. Specimens which were welded using 100% CO\textsubscript{2} as shielding gas (S1, S3, S5, S7) show more inclusions than specimens which were welded using mixture gas 90%Ar+10%CO\textsubscript{2} (S2, S4, S6, S8). It seems the usage of mixture gas 90%Ar+10%CO\textsubscript{2} as shielding provided better protection from the atmospheric gas compared to CO\textsubscript{2} shielding gas. The inclusions were found in the weld metal may came from the CO\textsubscript{2} of shielding gas which was decomposed at high temperature during welding.

The area fractions that quantitatively measured by image analyzer show specimen S2 (0.17%), S4 (0.42%), S6 (0.34%) and S8 (0.24%) which welded with 90%Ar+10%CO\textsubscript{2} mixture gas have less inclusions than other specimens using 100% CO\textsubscript{2} (0.59 to 0.75%).

Specimen S2 which welded by combination of GMAW method and mixture gas 90%Ar+10%CO\textsubscript{2} has much less inclusions than other specimens. It would be probably the shielding gas used more effectively protect the weld pool from contact with the atmospheric gas during welding operation. Solid wire that using in this GMAW may contributed to reduce inclusions as well.

Figure 6 show that size and volume of inclusions tend to increase with increasing CO\textsubscript{2} content of the shielding gas. These are probably oxide inclusions such as silicon oxides or manganese oxides. The EDX analysis confirmed the inclusions likely combination of (C, Si, Cr, Mn) with O. The oxides present in WM may caused decomposition of CO\textsubscript{2} to carbon and oxygen in the WM, and oxygen interact with filler metal at high temperature during welding operation.

FIGURE 7. EDX analysis of specimen S5 showing inclusion elements in the weld metal

From 316L WM to SS400 BM side, Cr & Ni tend to decreased as shown in Figure 8. It could be probably due to Cr & Ni diffuse towards SS400 BM from 316L WM.
From 309L WM to SS400 BM, Cr & Ni tend to decreased as shown in Figure 9. It could be probably due to Cr & Ni diffuse towards SS400 BM from 309L WM.

4. Conclusions

The conclusions of this DMW study can be summarized as follows.

1. Effect of different types of filler metal and shielding gas has significantly influenced the microstructure of WM for DMW of 304 stainless steel and SS400 low carbon steel.
2. DMWs that use 100% CO\textsubscript{2} shielding gas produced more inclusions than 90%Ar + 10%CO\textsubscript{2} mixture gas. The inclusions were found oxides such as silicon oxides or manganese oxides. It may caused decomposition of CO\textsubscript{2} to carbon and oxygen in the WM, and oxygen interact with filler metal at high temperature during welding operation.
3. Chromium and nickel content in the WM tend to decreased towards the SS400 BM. It could be probably due to Cr & Ni diffuse towards Carbon Steel BM from Stainless Steel WM.
5. References

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