The Effect of Welding Parameters on Joining Dissimilar Low Carbon Steel and 3CR12 Ferritic Stainless Steel by GTAW with ER308L Filler Metal

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Abstract. The effect of welding parameters on GTAW (gas tungsten arc welding) between low carbon steel and 3CR12 ferritic stainless steel with ER308L filler metal was investigated with regard to microstructure and mechanical properties. The welded metal presented good configuration. The microstructure of weldment was found to be of Widmanstätten austenite, acicular ferrite and martensite. Martensite and Cr-rich carbide precipitated particles formed under certain conditions in weldment produced results of both better hardness values and tensile strength. The results indicated that influence of these welding parameters have significant effects on microstructure and mechanical properties in welded metal.

1. Introduction
Nowadays, sugar processing equipment requires the fabrication of low pressure vessels. Dissimilar metal has been selected in sugar processing equipment. Low carbon steel, and 3CR12 ferritic stainless steel is selected instead of austenitic stainless steel because of low cost price and good mechanical properties. Most fabrications use GTAW due to facile device, high penetration for weld metal [1,2]. Ferrite stainless steel is various corrosion resistance properties like stress corrosion cracking, corrosion resistance in chloride environment and atmospheric corrosion resistance [3].

Research papers have studied dissimilar metal welding that are challenging and interesting, the dissimilar metal have difference of chemical composition, mechanical properties and metallurgy [4], including a difference of thermal expansion and thermal conductivity [5]. Khorrami et al. [4] studied the effect on microstructure and mechanical properties of dissimilar metal welds of low carbon steel to ferritic stainless steel, they found that using a filler metal produced better mechanical properties than autogenous welding.

The aims of this paper were to study the effect of GTA parameters for joining dissimilar metals of low carbon steel and 3CR12 ferritic stainless steel with ER308L filler metal, this area of research is interesting at the present moment and for the future, due to the requirement of good mechanical properties and predominantly a low cost material. This paper can inform selection of welding process for low pressure vessel and structure fabrication work in order to improve quality of weld for dissimilar metals such as low carbon steel to ferritic stainless steel.
2. Materials and experimental procedure
Low carbon steel and 3CR12 ferritic stainless steel specimens were cut to dimensions of 80 mm \(\times\) 50 mm \(\times\) 4.5 mm. ER308L filler metal was used to produce welding. A chemical composition analysis was verified by SPECTROLAB M10 for 3CR12 ferritic stainless steel, as SPECTROLAB Model: Lavm12 for low carbon steel, these data of chemical compositions are provided in Table 1 to include data of ER308L filler metal as a mill certificate report. Welding process was operated by GTAW with filler metal and welding conditions were used as following parameters in Table 2. Weld joint configuration was prepared as a single-V butt joint of 60° internal angle, 3 mm root gap, 1 mm root face.

**Table 1.** Chemical composition of the base metals and filler metal.

| Alloy   | C     | Cr   | Ni   | Mo   | Mn   | Si   | N   | Cu   | Cr\_eq/Ni\_eq |
|---------|-------|------|------|------|------|------|-----|------|----------------|
| 3CR12   | 0.021 | 11.2 | 0.38 | -    | 0.54 | 0.7  | 0.025| -    | 6.935          |
| LCS     | 0.121 | 0.01 | 0.025| 0.001| 0.45 | 0.009| -   | 0.008| 0.003          |
| ER308L  | 0.02  | 19.62| 9.56 | 0.08 | 1.84 | 0.34 | 0.038| 0.16 | 1.781          |

**Table 2.** The welding parameters and heat input of low carbon steel to 3CR12 ferritic stainless steel.

| Filler metal | Name   | Pass | Current (A) | Voltage (V) | Welding speed (mm/min) | HI (kJ/mm) | Dilution (%) of base metal |
|--------------|--------|------|-------------|-------------|------------------------|------------|---------------------------|
| ER308L       | S1     | Root | 100         | 12.5        | 57.84                  | 1.30       | 21                        |
|              | Face   | 70   | 9.9         | 35.04       | 1.19                   |            |                           |
|              | S2     | Root | 100         | 12.3        | 53.34                  | 1.38       | 23                        |
|              | Face   | 100  | 11.8        | 60.78       | 1.16                   |            |                           |
|              | S3     | Root | 100         | 12.4        | 55.8                   | 1.33       | 24                        |
|              | Face   | 130  | 13.3        | 90.54       | 1.15                   |            |                           |

The welded metal was studied for microstructure by optical microscopy, and scanning electron microscopy (SEM, JEOL, JSM-6510LV). The chemical composition in weldment was verified by an energy dispersive spectroscopy (EDS, OXFORD, X-MAX IE-350). The welded metal was etched by immersion in a Glycerregia reagent according to ASTM E407 standard. Mechanical properties were studied by tensile and hardness test. A tensile specimen prepared according to ASTM E8M standard, which was tested by tensile test machine (ZWICK/ROELL Z100) using a crosshead speed at 1 mm/min at room temperature. A hardness value was tested by the vickers microhardness machine (WILSON HARDNESS, TUKON 1102), with a load of 200 gf, and duration of 15 s.

3. Results and discussion

3.1. The microstructures of a weldment
Figure 1 shows a microstructure using 70A to face pass. The microstructure exhibited a widmanstatten austenite. The microstructure of widmanstatten austenite occurred due to continuous cooling [6] within the weldment. Figure 2 shows a microstructure of the weldment using 100A to face pass. The microstructure exhibited an acicular ferrite and a lath martensite. The lath martensite was widely dispersed.
Figure 1. The optical micrograph of the weldment using 70A to face pass.

Figure 2. The optical micrograph of the weldment using 100A to face pass.

Figure 3. The optical micrograph of the weldment using 130A to face pass.

Figure 4. The optical micrograph of the weldment using 100A to root pass.

Figure 5. SEM images of the weldment using 130A to face pass with dimensions (a) 31.2 µm and (b) 17.2 µm.

Figure 6. (a) SEM image and (b) EDS analysis of Cr-rich carbide precipitated cluster using 130A to face pass.

Figure 3 shows a microstructure of the weldment using 130A to face pass. The microstructure exhibited a lath martensite with a higher amount of martensite. Cr-rich carbide particles have precipitated in grain boundary ferrite and martensite. There are two characteristics of Cr-rich carbide particles which either formed very fine particles or particle clusters. The different dimensions of Cr-rich carbide clusters are measured approximately at 31.2 µm as in Figure 5(a) and 17.2 µm as in Figure 5(b).

Figure 4 shows a microstructure of the weldment using 100A to root pass. The microstructure exhibited an acicular ferrite and a lath martensite.

The results present a microstructure of Widmanstatten austenite and acicular ferrite as shown in Figure 1, 2 and 4, the value of Cr<sub>eq</sub>/Ni<sub>eq</sub> ratio is shown in Table 1 a high ratio. As mentioned, a high possibility that in these cases demonstrated F solidification mode.

Accordingly, pseudo-binary diagram of the Fe-Cr-Ni phase diagram with 21, 23 and 24% dilution as shown in Table 2 that possible the position of line on Cr-rich side in pseudo-binary diagram, it transformed as the liquid through the solidification a path as following L → L+δ → δ → δ+γ [7]. It must be cooled down within δ+γ region of the solidus boundary and characteristics of the final dual structure, δ-ferrite and partially transform to γ-austenite at the Ac1 temperature.

The martensite is formed due to enough the dilution of 23 and 24% and enough rapid cooling rate as shown in Table 2. The solid state ferrite transforms to austenite which rapidly cooled austenite transforms to martensite at temperature below Ms temperature, while in Figure 1 the martensite is not formed due to the slowest cooling rate and not enough austenite transforms to martensite. The results indicate that both the dilution and the cooling rate were revealed to have a significant influence on the martensite formation. The martensite structure has an effect on decreased ductility and toughness, best strength [8] in weldment.
Figure 6 shows cluster of Cr-rich carbide precipitated particles and EDS analysis is found that it contained alloying elements of Fe, Cr, Ni, C, Mn and Si. This case formed carbide due to the delta ferrite content decreases within weldment. The delta ferrite can dissolve the solid solution of carbon, the maximum solubility of carbon is 0.09 wt% at 1,495°C [9] that results appeared excess carbon. The nature of Cr alloying element behavior has a greater affinity for C therefore could be precipitated in weldment.

4. Mechanical properties

4.1. Hardness

Figure 7, 8 and 9 show a hardness profile of welded metal, the hardness values of both base metals lower than hardness values of weldment. The weldment of 130A to face pass is indicated the highest hardness with values of 311.4, 321 and 285.1HV0.2. This was due to martensite formation and Cr-rich carbide precipitated particles in weldment. The weldment of 100A to face pass values of 278.3, 274.2 and 266.4 HV0.2 to achieve a lower hardness than using 130A. This was due to only martensite formation in weldment. In the case of 70A weld, hardness values of 175.4, 182.5 and 180.9 HV0.2 were the lowest hardness values compared to the other conditions. This is likely due to not martensite or Cr-rich carbide particles formation.

Hardness profiles at roots pass, all conditions, these cases are indicated a similar hardness values and to give better hardness values than hardness values of the face pass. This was due to the martensite strengthening. Microstructures have the influence on indentation dimension as shown in Figure 10.
4.2. Tensile properties

Figure 11(a), (b) show tensile specimens before and after test. The breaking area is presented at low carbon steel side of all tensile welded metals, as shown in Figure 11(b). The tensile strength was 388, 411 and 401 MPa of S1, S2 and S3, respectively, as in Figure 11(c). The maximum tensile strength reached 411 MPa of S2 specimen and, the lowest tensile strength to reach 388 MPa of S1 specimen.

All welded conditions, gave a satisfied tensile strength to occur due to tensile strength of all welded metals higher than base metal of low carbon steel side and results presented that martensite strengthening could improve tensile strength [8]. The percentage elongation of welded metal S1, S2 and S3 were 20, 24 and 22, respectively that these values corresponding with significant tensile strength.

5. Conclusions

Dissimilar metals of low carbon steel and 3CR12 ferritic stainless steel were welded by GTAW with ER308L filler metal. The conclusions are summarized as follows.

All welding parameters demonstrated good configuration of welded metal. The microstructure of weldment consisted widmanstatten austenite, acicular ferrite and martensite. Martensite was formed in weldments above welding current of 70A to face pass. Cr-rich carbide precipitated particles was formed only welding current of 130A. The hardness values of both base metals lower than weldments. The maximum hardness values of face pass reached 311.4, 321 and 285.1HV of 130A welding current. The tensile strength of all welded metal higher than low carbon steel side indicated a welded joint efficiency. The maximum tensile strength reached 411 MPa of S2 specimen.

6. References

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