Welding of ferritic stainless steel plate using austenitic stainless steel electrode

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Abstract. In this study, microstructure and phase transformation of ferritic stainless steel plate 405 using austenitic stainless steel 309-16L electrode was explained. Shielded Metal Arc Welding SMAW was used. Optical microscopy OM and scanning electron microscopy SEM were conducted to evaluate the morphology and structure of weld metal and heat-affected zone. X-ray diffraction also used to determine the crystal structure that developed during welding of bcc crystal structure and fcc crystal structure. Energy-dispersive X-ray spectroscopy EDS was used to evaluate the chemistry of the element. Microhardness was conducted in this research to determine the effect of alloying element on the mechanical properties of the joint.

1. Introduction: -
Austenitic stainless steels are a very common alloy that used extensively in lots industrial applications for example, chemical and petrochemical, thermal, and nuclear industries due to their ability for high corrosion resistance and acceptable mechanical properties at high temperatures. Ferritic stainless steels alloys exhibit more resistance to stress corrosion cracking than austenitic stainless steels. Furthermore, they are a less expensive alternative to austenitic stainless steels alloys in aqueous, corrosion-related applications. Moreover, ferritic stainless steel alloys are very suitable for use in welding especially in heat exchanger tubing this is because of their high thermal conductivity and also low thermal expansion [1]. Austenitic stainless steels show a good weldability through ordinary fusion welding processes, and welding methods for them are well established [2]. In the ferritic stainless steel phase diagram, the alloy shows no phase transformation from the liquid to solid at room temperature which lead to present coarse grain in the heat affected zone HAZ and melting zone MZ. However, there are only two methods that could be used to control the grain size: controlling the heat input and through grain refining methods. while the welding of austenitic and ferritic stainless steel has been studied widely as a similar metals, the increased demand of these type of steels will need a better understanding of the concerns associated with welding of dissimilar stainless steels as dissimilar metal weld joints are usually used in industry. The use of dissimilar metal joints is important for the different requirements of various physical and mechanical properties, also may result in large savings of novel and expensive materials, reducing product cost.

many of industrial applications such as defense, chemical, and petrochemical industries have no choice other than to join dissimilar metals together in one product to achieve design requirements. Because dissimilar metals have different mechanical, metallurgical and physical properties when they
are welded together, they are usually showed many of issues. Further, difficulty arises with the addition of filler metals, which is a common practice in fusion welding. It is necessary to produce high quality joints between two different metals to take full advantage of the properties of them. For dissimilar metal joints it is common practice that mechanical properties of the joints should not be less than those of the weaker base metal in the combination. In addition, the weld should have corrosion resistance equal to the least resistant base metal being joined. This study was designed to provide some insight into the microstructure property relationships in fusion and solid-state welding of ferritic-austenitic stainless steel combinations. Also, this paper focuses on the introducing duplex stainless steel.

2. Experimental procedures
The materials selected for these studies are AISI 405 Ferritic stainless steel as a plate and AISI 309-16L austenitic stainless steel as an electrode. Their chemical composition properties are given in table 1, using the Chemical Analysis test, and table 2 according to AWS A5.4/A5.4M:2006, ASME SFA-A5. Austenitic stainless steel. exhibits higher strength, ductility, and impact toughness than ferritic stainless steel. Using diffusion welding procedure ferritic st. st. as base metal 12-mm thickness and Austnitic st. st. as filler metal. Preparation of Materials Cutting off the parent metal using stainless steel cutter as shown in Figure 1, Prepare the joint design by chamfer as (V) with angle (60) by using milling machine according to ASME Code as shown in Figure 2, welding the joints using (MMA) AC current using Austenitic st. st. Electrodes Type (309L-16), as shown in table 3.

| Elements | C% | Si% | Mn% | P% | S% | Cr% | Fe% |
|----------|----|-----|-----|----|----|-----|-----|
| Nominal composition | 0.08 | 1.0 | 1.0 | 0.04 | 0.03 | 13 | 85 |
| Actual composition | 0.02 | 0.241 | 0.843 | 0.02 | 0.0005 | 12.75 | Bal. |

| Elements | C% | Cr% | Cu% | Mn% | Mo% | Ni% | P% | Si% | S% |
|----------|----|-----|-----|-----|-----|-----|----|-----|----|
| Nominal Composition | 0.04 | 23.5 | 0.75 | 1.80 | 0.75 | 13 | 0.04 | 1.0 | 0.03 |

| Welding current (A) | No. of passes | Electrode | Electrode diameter (mm) | Arc voltage (V) | Preheat |
|---------------------|--------------|-----------|------------------------|----------------|---------|
| 140                 | 5            | 309L-16   | 4, 2.5                 | 25             | None    |

Figure 1. Cutting off the parent metal using stainless steel cutter.

Figure 2. Prepare the joint design [1].
Will use Optical microstructure (OM) to see the microstructure of the BM, FZ, HAZ, WM, either we done mechanical grinding to the work piece with different grades of emery paper, ASTM grit (400,600,800,1000,1200 and 1400) and polishing with special cloth and (0.3 µm)alumina, and then etching using (3 parts HCl, 2 parts acetic acid, 2 parts HNO₃) the samples then cleaned with water and alcohol and dried, scheffler diagram in all cases DMW used to predict weld metal composition by calculating Cr eq. and Ni eq. for both base metal and weld metal and draw both percent in scheffler diagram Figure 3, using the Cr and Ni equations to predict stainless steel microstructure of welded zone and either to predict the crack that may be cause by the welding of dissimilar metals, and either will use X-ray diffraction (XRD) test for weld metal (WM) and base metal (BM) to see the phases, and either use. (Micro hardness) test for the same regions to determine the strength of the materials, and Scanning electron microscopy (SEM) test to see the compositions of the alloys in the BM, WM, HAZ, FZ, and then we will discuss the results of this analyses.

3. Results and discussion
3.1 Microhardness
We noticed that the hardness of the HAZ near the fusion line was noticeably higher than that of the other parts in the weldments, whereas on the BM and the WM zone the hardness changes were very small, the reason is that at the HAZ their be making duplex stainless steel from the fusion at the HAZ its has a two phase microstructure around 50% of ferrite phase and 50% of austenite phase as shown in Figure 3, and the other reason in difference the values is the differ chemical compositions and mechanical properties, and may be because of martensite formation, or may be because of presence carbides Dual phase prevents grain growth during annealing and a much higher strength can be achieved after strain hardening compared to ordinary austenitic stainless steel. Duplex stainless steels are unique in its kind of combining super high strength with excellent ductility and elongation. Even at very high strength levels. Duplex stainless steel is equally good or has a better elongation than other type of stainless steel. at the weldment there is no duplex just austenite that is higher tensile strength and elongation than the ferritic stainless steel but lower yield strength.

Figure 3. Microhardness versus distance of the whole sample, showing the high hardness values at HAZ due to coarse grains of austenite phase. Also, moderate hardness value at the weld metal zone due to duplex phase of ferrite and austenite.

3.2 Microstructure
The weld microstructure depends significantly on kinetic factors such as cooling rate and epitaxial growth rates so the structures differences from region to region in the work piece. The effect of the temperature gradient $G$ and the growth rate $R$ dominate the solidification microstructure. the ratio $G/R$ determines the mode of solidification while the product $GR$ governs the size of the solidification structure. $(G/R \geq \Delta T/\Delta L)$ [10], the 405 ferritic stainless steel welded using austenitic stainless steel filler wire, it is observed that, the coarsening and elongated grains of weld metal structure increases with increase in heat input, and the HAZ region has fine grains because low heat effecting. Composition of the 309L weld metal is designed to have Columnar dendritic and porosity as shown in Figure 6, using (OM) 10x magnification, and either noticed that the appearance of the weld metal...
duplex stainless steel and large grains, difference from the HAZ Cellular grains and as shown in Figure 7, using 10x magnification. The ferritic stainless steel 405 as shown in Figure 4, has equiaxied grains, but the austenite stainless steel has elongated grains as shown in Figures 6 and 8, the reason may be due to the difference in the thermal conductivity characters of the two martials. Ferritic stainless steel conductivity being higher, Austenitic stainless steel has lower thermal conductivity and greater hardness at higher temperatures compared to ferritic stainless steels. When used schaffler diagram and calculate the Cr and Ni equivalent for both base metal and weld metal with dilution percentage that was 30%. Noticed that obtained phase was (A+F) phases as shown at the scheffler diagram that 18% ferrite and the retained austenite structure this means that we have(B) phase crack and embrittlement crack that can relief by preheating.

**Figure 4.** Optical microstructure showing the base metal of ferritic stainless steel with fine grains of bcc-iron phase

**Figure 5.** Optical microstructure showing the weld metal of austenitic stainless steel with fine grains of fcc-iron phase.

**Figure 6.** Optical microstructure showing the base metal, HAZ and weld metal. It is clearly that the diffusion of alloying elements through HAZ and formed fcc-Fe structure with coarse grains.

**Figure 7.** Optical microstructure showing the weld metal of austenitic stainless steel with dendritic structure.
Figure 8. Optical microstructure showing the fusion line between fcc and bcc structures.

Figure 9. Schaeffler diagram [5].

3.3 X-Ray Diffraction

X-ray diffraction analysis is the method by which multiple beams of x-ray create a three-dimensional picture of the density of electrons of any crystalline structure. The purpose is to identify with a high degree of certainty the composition of the molecules, on an atomic scale. This makes it the most reliable method to determine the composition of zeolite. The weld metal is austenite phase with (fcc) with the presence of α-ferrite (bcc) at the austenite interface where there is mixing, a mixture of ferrite and austenite phases was identified, but only ferrite peak was observed at the austenite-weld interface. In order to resolve this ambiguity and clearly identify the phases, SEM analysis was carried out at this
interface was confirmed by X-ray diffraction experiment which that solidification of SS316L is expected to occur through formation of primary austenite+ delta ferrite as shown in XRD test for weld metal that has α-ferrite (h-k-l) (2 0 0) at 2θ (65) and 2θ (84) (h-k-l) (2 1 1), so we have 50 percent γ and 50 percent α, so we have duplex structure. Since there is the base metal α-ferrite does not undergo any mixing, thereby there is no change in chemistry as well as crystal structure, which has (bcc) as shown in xrd result for base metal.

![X-ray diffraction patterns of weld metal showing the two structures of fcc and bcc (duplex stainless steel).](image)

**Figure 10.** X-ray diffraction patterns of weld metal showing the two structures of fcc and bcc (duplex stainless steel).

### 3.4 Scanning Electron Microscopy SEM and EDS

Scanning electron microscopy (SEM) is performed at high magnifications, generates high-resolution images and precisely measures very small features and objects and determine the compositions of the elements as shown below.
Figure 11. X-ray diffraction patterns of base metal showing the one structure of bcc phase (ferritic stainless steel).

Figure 12. SEM high magnification image

Figure 13. SEM image showing the fusion line and dendritic structure of fcc-structure.
Figure 14. SEM low magnification image.

| Result Type | Spectrum Label | Weight % |
|-------------|----------------|----------|
|              | Cr  | Mn  | Fe   | Ni   | Total |
| 1) Spectrum 1 | 12.99 | 1.00 | 84.96 | 1.05 | 100.00 |
| 2) Spectrum 2 | 20.73 | 0.95 | 68.26 | 10.06 | 100.00 |

Figure 15. EDS spectrum showing the quantity and chemistry of sample in two different zones (weld metal and HAZ).
4. Conclusions
- The effects of the welding process on the microstructure of dissimilar metal combinations of ferritic and austenitic stainless steels have been studied.
- The hardness of the HAZ near the fusion line was noticeably higher than that of the other parts in the weldments.
- The cooling rate was affected to the structures of the metals.

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