The purpose of this study was to discuss the change in microstructures and hardness values in fusion zone (FZ) and heat-affected zone (HAZ) of austenitic stainless steel and carbon steel welds. By comparison, the morphology of δ – Ferrite which formed in the fusion zone of single-pass and multi-pass welding was analyzed. The columnar dendritic shape can be seen as features extending from the fusion line of a weld pass toward the subsequent passes. Furthermore, the δ-Ferrite morphology changed from fine cellular to columnar dendrite or equiaxed dendrite. The recrystallization phenomenon was only observed in the HAZ carbon steel side of multi-pass welding. This zone was divided into HAZ-1 (grain-refining region) and HAZ-2 (partial grain-refining region). The hardness values in each zone were measured with the highest value was on fusion boundary of carbon steel side. Transverse tensile was carried out.

**KEYWORDS**

Dissimilar metal weld, HAZ, Weld metal, Austenite stainless steel, Carbon steel

**1. INTRODUCTION**

When welding two different materials, consideration should be given to the diffusion of carbon at the melting boundary between the base metal and the electrode metal. There is a difference in the chemical composition of the alloying elements that form the gradient of the energy and promote the diffusion of the carbon from the low side to the element's higher alloys. Many studies have shown that this diffusion phenomenon can occur when the carbon content on both sides is approximately equal (no component gradients). Diffusion of carbon has a significant effect on the formation of carbide phases during welding [1,2]. At the specified location (usually at the grain boundary), when the alloying elements and carbon reach a certain level, they will form carbonates (e.g. M23C6, M7C3, M2C) [3,4]. For welding of two different materials, specifically here we consider welding between stainless steel and carbon steel, the microstructure more complex weld metal, especially at the border between carbon steel and electrode. Around the boundary of this molten road, there is a mix of base metal and base metal that leads to the formation of areas of continuous chemical composition from solid base metal to weld metal. In liquid state [5]. This area is called an incomplete fluid flow.

![Figure 1: Different areas of weld](image)

The mechanical of the weld depends on the microstructure, the phase transformation, the process of producing the carbide particles that form in the melting zone and the heat-sensitive region of the weld. In other words, to study about the mechanism as well as to learn methods to improve the quality of welds, we first have to understand the thermodynamic processes that occur during welding (phase diagram and transfer variable). During arc welding, the process of thermodynamics is more complex than that of conventional casting [6-8]. It consists of transformations that take place in both liquid and solid states. For melting regions, because the metal is present in a completely liquid state, the region occurs crystallization from a liquid state to solid state and to subsequent phase transformations occurrence after welding (e.g from austenite to ferrite in carbon steel welding) [9-11]. For the zone of thermal effect (HAZ), the change and phase change in the solid state.

Dissimilar metal welds (DMW) between austenitic stainless steel and carbon steel are generally used for the fabrication and joining of engineering components. However, control of the microstructures and properties of the weld metal and heat – affected zone is a challenge. Differences in physical and mechanical and metallurgical properties between the weld metal and base metals will almost certainly exist [12-14]. For example, differences in the coefficient of thermal expansion may result in locally high stresses that can promote service failures, particularly due to thermal cycling from low to high temperatures. The corrosion resistance may also vary locally in both the weld metal and the transition region, due to differences in composition and microstructure [15]. In most of the DMW components, the plates were welded by using multi-pass welding methods. The characteristics of a multi-pass weld were more complex than single-pass weld due to the thermal cycles of subsequent passes which affected on the microstructure, hardness, mechanical properties and the residual stresses after cooling to room temperature [16]. Therefore, the study on the thermal process, residual stress distributions can be used to explain the phase transformation and chemical properties in the different zones of welds [17-20].
Based on the previous study, this paper will focus on the microstructure, recrystallization and mechanical properties in the HAZ and the fusion zone of dissimilar welds between low carbon steel and austenitic stainless steel 304. The differences in microstructure of single - pass and multi - pass weld will be discussed in the following section.

2. MATERIALS AND METHODS

The base metals used in the experiments were austenitic stainless steel (304) and low carbon steel with 3mm and 19 mm thick. These samples were welded by means of gas tungsten arc (GTAW) for the root pass and shielded metal arc (SMAW) for subsequent passes of the multi-pass welding and SMAW method of the single-pass welding. The chemical composition of the base metals and the filler are listed in Table 1. Figure 1 shows the weld preparation. The welding parameters are presented in Table 2 and Table 3.

Table 1: The chemical composition

| Alloys | Stainless steel | Carbon steel | Filler |
|--------|-----------------|--------------|--------|
| C      | 0.09            | 0.1          | 0.08   |
| Mn     | 1.54            | 0.62         | 0.7    |
| Si     | 0.49            | 0.02         | 0.8    |
| S      | <0.005          | 0.04         | <0.005 |
| P      | 0.055           | 0.05         | <0.003 |
| Cr     | 18.3            | 0.02         | 19.7   |
| Ni     | 7.56            | 0.08         | 11.8   |
| Mo     | 0.13            | 0.005        | 0.1    |
| V      | 0.11            | 0.01         | 0.09   |

Table 2: The welding parameters of the multi-pass welding

| Pass No. | I(A) | U (V) | V (mm/min) | T (°C) | VGAS (l/min) |
|----------|------|-------|------------|--------|--------------|
| 1        | 92   | 50    | 16.7       | 60     | 12           |
| 2        | 119  | 54    | 70         | 63     | 12           |
| 3.1      | 98   | 22    | 44         | 58     | N/A          |
| 4.1      | 99   | 24    | 41         | 72     | N/A          |
| 4.2      | 110  | 24    | 55         | 55     | N/A          |
| 5.1      | 112  | 25    | 56         | 57     | N/A          |
| 5.2      | 114  | 25    | 47         | 65     | N/A          |
| 6.1      | 113  | 24    | 56         | 79     | N/A          |
| 6.2      | 112  | 24    | 63         | 88     | N/A          |
| 6.3      | 113  | 25    | 42         | 60     | N/A          |
| 7.1      | 114  | 24    | 54         | 72     | N/A          |
| 7.2      | 113  | 25    | 57         | 86     | N/A          |
| 7.3      | 112  | 24    | 56         | 88     | N/A          |
| 7.4      | 113  | 25    | 43         | 97     | N/A          |
| 7.5      | 110  | 25    | 43         | 105    | N/A          |

Table 3: The welding parameters of the single-pass welding

| Pass No. | I(A) | U (V) | V (mm/min) | T (°C) | VGAS (l/min) |
|----------|------|-------|------------|--------|--------------|
| 1        | 100  | 25    | 12.0       | 25     | N/A          |

3. RESULTS AND DISCUSSIONS

3.1 Macrostructure of the dissimilar welds

The base metals in the experiments are austenitic stainless steel and carbon steel. Typical microstructure of carbon steel is composed of Ferrite and small regions of Pearlite (Figure 4a); whereas Austenite phases can be observed in austenitic stainless steel (Figure 4b). Figure 3 shows the macrostructure of the single – pass and multi-pass welding. Overall, the microstructure of the welds changed significantly in three different regions: fusion zone, HAZ and base metal. The grains size in the HAZ in single – pass welding was larger than in multi-pass welding and reduced dramatically from the fusion line to the base metal. In contrast, the recrystallization was observed in the HAZ in the multi-pass welding that can be divided into HAZ-1 (grain-refining region) and HAZ-2 (partial grain-refining region). In both cases, δ – Ferrite phases were formed in the weld metal zone and its morphology indicated the fine cellular to columnar dendritic transition.
3.2 The microstructure in the fusion zone

The variation of δ-Ferrite morphology in the fusion zone during single-pass welding (Figure 5) and multi-pass welding (Figure 6) can be observed. In the single-pass welding, the δ-Ferrite phases transformed from fine cellular or lathy along the fusion line to the columnar dendritic and the equiaxed dendritic in the middle of weld metal. These can be explained both on the solidification behavior, subsequent solid-state transformations and cooling rate. Following the compositions and the relationship of solidification type to the pseudobinary phase diagram (Figure 5d), type FA and AF solidification modes were applied for the austenitic stainless steel boundary and the carbon steel boundary, respectively. Besides, the cooling rate that reduced from the fusion line to the center leaded changing δ-Ferrite morphology.

3.3 The microstructure of the HAZ of carbon steel side

During the first pass welding or single-pass welding, the HAZ in the carbon steel can be related to the Fe-C phase diagram (The grain size changed gradually from the fusion line to the base metal. Next to the fusion line, the average grain size was the largest (position D) and reduced to the base metal (position A). Widmanstatten Ferrite can be formed along grain boundaries. Furthermore, because of the differences of peak temperature and cooling rate, Austenite transformed to Martensite or Bainite. Figure 8 presents the microstructure in the different positions in HAZ of carbon steel.
Figure 7: Carbon steel weld (a) HAZ; (b) Phase diagram [19]

Figure 8: The change in microstructure in the HAZ of single-pass welding; (a) position D, (b) position C, (c) position B

However, the recrystallization can be seen in HAZ after second pass welding. Figure 9 shows the recrystallization during multi-pass welding which was divided into HAZ-1, HAZ-2. It can be clearly seen that grain – refining sizes were formed in the HAZ-1 (Figure 9a). These were much finer than single-pass welding. This region was heated well above the effective upper critical temperature Ac3, allowing form fully Austenite phase. Thus, Austenite phase decomposed into Martensite or Bainite or Pearlite and Ferrite during the cooling process. However, the peak temperature of this zone was still above Ac3 and reduced gradually in the subsequent pass, allowing Austenite grains were formed finer and finer nucleate, then it decompose into smaller Pearlite and Ferrite (no Martensite and Bainite). The HAZ-2 was the partial grain-refining region by the extremely fine grains of Pearlite and Ferrite. This zone was subjected to a peak temperature just above the effective lower critical temperature, Ac1.

3.4 The mechanical properties of the HAZ of carbon steel side

The hardness values in the different zones of multi-pass welding are shown in Figure 10. The hardness distribution profile of the multi-pass welding is higher than that of the single-pass welding. The hardness value in the HAZ carbon steel, fusion zone and HAZ stainless steel were unchanged by nearly 194HV, 208HV, 200 HV, respectively for multi-pass welding and 152HV, 172HV, 180HV respectively for single-pass welding. In both cases, the hardness value of the fusion line of carbon steel side was the highest by 344HV of the multi-pass welding.

The average hardness value of multi-pass welding is higher than that of single-pass welding. This is explained that when the multi-pass welding process is performed, the heat energy of the second pass will provide to the first process, so the crystallization process takes place slower than case of the single-pass welding - there is no subsequent heat supply. Furthermore, with such provided-heat process, the carbides formed will contribute to increasing the hardness value of the material. At the zone of HAZ carbon steel and fusion zone, the hardness is the highest. This is explained by the high content of the elemental alloy, the carbides form more and more. However, at this zone, more carbides will be more likely to damage the weld, so further research is needed on the heat treatment of this zone.
respectively. Single-pass and multi-pass welds were 442 MPa and 525 MPa, weakest in the weld metal with the tensile strength values of fusion line by 344HV. The HAZ of carbon steel was the single-pass weld. The highest hardness value was documented at the grain – refining region and the partial grain-refining region. The recrystallization in the HAZ carbon steel side caused forming the a weld pass toward the subsequent passes. The microstructure in the fusion zone of the multi-pass welds consisted of the bead welds with the columnar dendritic shape extended from the fusion line of the HAZ and fusion zone were investigated during austenitic stainless steel welded dissimilar joints of mild steel and stainless steel. De Gruyter, doi: 10.2478/adms-2014-0002.

The results of strength test reflect clearly the as-analyzed microstructure. However, both samples will be destroyed at the HAZ. The structure at HAZ changes with the accumulation of stresses causing destruction. Analysis of the microstructure of the destruction zone during the tensile test shows that there is a break in the bonding between the metal particles causing the destruction of the material in the HAZ.

4. CONCLUSIONS

The microstructure, recrystallization and mechanical properties of the HAZ and fusion zone were investigated during austenitic stainless and carbon steel welds. The following conclusions can be drawn: The differences in microstructure between the multi-pass and the single-pass were analyzed. The microstructure in the fusion zone of the multi-pass welds consisted of the bead welds with the columnar dendritic shape extended from the fusion line of a weld pass toward the subsequent passes. The recrystallization in the HAZ carbon steel side caused forming the grain – refining region and the partial grain-refining region. The hardness values in the multi-pass weld were higher than the single-pass weld. The highest hardness value was documented at the fusion line by 344HV. The HAZ of carbon steel was the weakest in the weld metal with the tensile strength values of single-pass and multi-pass welds were 442 MPa and 525 MPa, respectively.

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