Mechanical Properties and Microstructure of the Repeated Weld-Repairs of Austenitic Stainless Steel Plates

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Abstract. Joining Most of the repair weld of parts and components cannot be avoided in any manufacturing industry. Weld procedure is commonly used to ensure the welded parts can be useful and safe. Weld repairs have to be carried out with suitable care and avoid premature failures of the weld components. The weld repairs often occur repeatedly on welded parts. Hence the investigation was done to evaluate the effects of repeated weld-repairs of austenitic stainless steels plates on both mechanical and microstructural properties. Weld samples were joined using gas tungsten arc welding (GTAW) with several numbers of weld repairs. The first weld was performed to join metal plates and assigned as 0R. The weld bead was then ground away and followed by the first weld repair using the same GTAW (designated as 1R). This repair process was continual until five times (identified as 5R). All specimen was characterized by the chemical composition test, the microstructure observation, and the mechanical tests. It was found that the HAZ hardness of repeated weld repair decreased when the number of repairs increased. The tensile test results of the repeated weld repair had a few effects on tensile strength. However, the result of the impact test on repeated weld repairs shows a substantial reduction in the toughness properties as the repeated number of weld repairs. The repeated weld repair influenced the mechanical properties of austenitic stainless steel plates and showed a tremendous decrease compared with the type of 304L stainless steel as the repeated numbers of weld repairs.

1 Introduction

Stainless steels are mostly in use for many engineering applications because of superior corrosion resistance together with the great mechanical properties. The austenitic stainless steel is high alloy steel that contained the equal or more than 12% chromium. This steel was first developed in chemical and power plant [1]. Repair welding is one of the critical maintenance and repair processes. A recognized code, standard fabrication and welding practice need to construct the engineering components or parts such as the pressure vessel. Unwanted premature failures can happen due to any reasons such as faulty design, the incorrectly selected material of construction, and the incorrect welding techniques in an early service period. Damage to components is due to the changes in the working parameters, the improperly operation, the base metal defects. Once failure has been identified, the parts have to be carefully reviewed to assess the presence of an impairment, the requirement for reparation and the technique of repair. Several welding codes, for instance, API-1104 [2] and ASME IX [3], have no limit to the number of weld repairs as stated in the welding procedures. However, the welding codes such as DNV, IPS-CPI, and GB50236-98 standards have limitation to the numbers of weld repairs. For examples, DNV standard stated that the repair weld joints could only be done for just two times at the similar locations. Also, it is only one time to repair weld joints based on the IPS-CPI standard. Moreover, the weld repair can only be done twice in the same location according to the GB50236-98 rules [4]. Many investigators study the repeated weld repair on the stainless steels type 304L and 316L, affected by alloying, temperature treatments and joining techniques on microstructures, high temperature and cyclic properties [5–6]. Some researchers were focusing on the residual stress after weld repair and very few studies on the influence of weld repair on mechanical behavior. Vega et al. study the various weld repairs of pi ple at the same location, and it is possible the four times of weld repair [7]. Lin et al. [8] studied the properties on stainless steel 304L due to the influence of repeated weld repair. It was found that the toughness has no significant change due to the repeated weld repair, but the fracture behavior was affected. Investigation of the influence of heat input on austenitic stainless steel 316L properties using E309MoL-16 electrode showed that the corrosion rate of austenitic stainless steel 316L decrease by increasing the heat input. [9] The investigation of the influence of several weld repairs on a clad plate of stainless steel showed that the repeated weld repair resulted decreased the longitudinal and transverse residual stress. It was due to the content of small ferrite was increased, and the increased the hardness in the surface layer due to the diffusion of Fe and C into the
layer. Since the layer should be removed to avoid the crack, the clad plate should be repaired no more than twice. [10]. Thus, in the present study, the repeated number of repaired weldment was evaluated by the comparative study on microstructure and mechanical properties such as tensile strength, toughness, and hardness to avoid several short-term repairs or replacements.

2 Research Methodology

Two types of austenitic stainless steels plates (304L and 316L) were used as a base material (BM) and prepared with a size of 125 mm x 100 mm x 12 mm thickness. The chemical compositions of both plates of steel are listed in Table 1 and Table 2. Both filler wires ER308L and ER316L of 1.2 mm diameter were consumed to weld the test plates, and their wire composition of the ER308L and ER316L are given in Table 3 and Table 4 respectively.

Table 1. The chemical composition of 304L (in wt. %)

| C    | Si  | Mn  | P   | S   | Cr  | Mo  |
|------|-----|-----|-----|-----|-----|-----|
| 0.028| 0.235| 1.82| 0.009| 0.005| 18.6| 0.325|
| Ni   | Al  | Cu  | Nb  | Ti  | V   | Fe  |
| 8.80 | 0.004| 0.464| 0.018| 0.004| 0.091| Bal. |

Table 2. The chemical composition of 316L (in wt. %)

| C    | Si  | Mn  | P   | S   | Cr  | Mo  |
|------|-----|-----|-----|-----|-----|-----|
| 0.032| 0.418| 1.33| 0.01| 0.005| 16.8| 2.05|
| Ni   | Al  | Cu  | Nb  | Ti  | V   | Fe  |
| 11.0 | 0.003| 0.269| 0.021| 0.009| 0.082| Bal. |

Table 3. The chemical composition of the weld metal of ER308L electrode (wt. %)

| C     | Cr  | Ni  | Mo  | Mn  |
|-------|-----|-----|-----|-----|
| 0.02  | 20.2| 9.2 | 0.03| 1.6 |
| Si    | P   | S   | Cu  | Others|
| 0.44  | 0.02| 0.02| 0.11| 0.03|

Table 4. The chemical composition of the weld metal of ER316L electrode (wt. %)

| C     | Cr  | Ni  | Mo  | Mn  |
|-------|-----|-----|-----|-----|
| 0.02  | 20.2| 9.2 | 0.03| 1.6 |
| Si    | P   | S   | Cu  | Others|
| 0.44  | 0.02| 0.02| 0.11| 0.03|

2.1 Welding Parameters

The TIG welding was used as a method for joining and repairing stainless steel plates. A skilled welder conducted the joining process and then the removing of the weld bead to produce several repaired weldments. The WPS including parameters is shown in Table 5.

Table 5. Welding Procedure Specification (WPS)

| Pass | Current (A) | Voltage (V) | Welding speed (mm/min) | Heat Input (kJ/mm) |
|------|-------------|-------------|------------------------|-------------------|
| 1    | 100-110     | 15-20       | 40-50                  | 2.015             |
| 2    | 110-120     | 15-20       | 100-135                | 0.841             |
| 3    | 130-160     | 15-20       | 100-180                | 1.133             |
| 4    | 130-160     | 15-20       | 100-180                | 1.151             |
| 5    | 125-150     | 15-20       | 120-140                | 1.047             |
| 6    | 125-150     | 15-20       | 120-140                | 0.871             |

2.2 Preparation of Weld Samples

Welding of the stainless plate was prepared by using the V-grooved butt welds with dimension as seen in Fig. 1(a). A milling machine used to remove the weld bead after welding done. The weld metal and fusion line were entirely removed before weld repairs done. The first weld samples welded is assigned as 0R and specimen which was the first weld repair noticeable as 1R and the next weld repairs. Therefore, all samples consisting of the main weld plate and with a various number of weld repairs: 0R, 1R, 2R, 5R were set.

2.3 Weld Characterization and Testing

The several weld repairs were mechanical testing such as tensile test, impact test, and Vickers-hardness test. Metallographic observations by OM and SEM was also carried out to evaluate the microstructure. The tensile testing was performed at room temperature in line with ISO 4136. Tensile of weld specimens were prepared using the sub-size dimension as shown in Fig. 1(b). The impact specimens were tested at a room temperature of 25°C according to ASTM: E-23 (Fig. 2(a)). The microhardness measurement was carried out using Vickers hardness by ASTM: E-384. The location of the micro Vickers test was shown in Fig. 2(b). Numerous cross-section samples were cut from welds of various repaired weldments for metallographic analysis. Standard metallographic techniques were also used using the electrochemical etchants of 15 % oxalic acid. The spot test of element distribution was examined using energy dispersive spectrometry. The HAZ grain size measurement was conducted based on ASTM E-112. The assessment of volume fraction of δ-ferrite on HAZ was carried out using an OM equipped with a images analyzer.
3 Results and Discussion

3.1 Microstructure analysis

Micrographs of optical microscopy (OM) of the base metal stainless steel plates (BM), and the HAZ repaired weld of 0R, 1R, 2R, and 5R samples are shown in Fig.3 and Fig 4.
The BM and HAZ microstructure can be seen in Figs. 3 and 4, it shows a matrix of austenite, delta ferrite precipitates, and dark carbide particles, this is similar to that observed by Agha Ali et al. [4]. The base metal (BM) of both steel plates is a fully austenitic phase with twinning grains as seen in Fig. 3a and 3b. The shape of δ-ferrite was changed with the repeated weld repairs. The microstructure of HAZ exposed to the first weld repairs (R0) showed the finer lathy shaped delta ferrite compared with the HAZ of the higher weld repair (1R to 4R). Also, the black carbide precipitates were present in HAZ of repeated weld repairs, and the numbers of carbide precipitates increased with increasing weld repairs numbers as can be seen in Figure 3(c) to 3(e) and Figure 4(a) to 4(e). Some investigation on repeated weld repair on austenitic stainless steels explained that the grain size of stainless steel was correlated to the weld repairs number. The recrystallization of new grain firstly starts the mechanism of microstructural change due to the heat of the welding. Hence the number of grain is increased. Repeating the process of welding repair, the coarse grain occurred. Fig. 5 and Fig. 6 shows the SEM images of the 304L and 316L stainless steel of the 1R and 5R specimens, respectively.

Fig. 4. Microstructure photographs by Optical Microscopy of 304L and 316L stainless steel (a) 1R HAZ 316L (b) 2R HAZ 304L (c) 2R HAZ 316L (d) 5R HAZ 304L (e) 5R HAZ 316L

Fig. 5. The size and number of delta-ferrite on 304L HAZ observed by SEM (a) 2R and (b) 5R
Fig. 6. The size and number of delta-ferrite on 316L HAZ observed by SEM (a) 2R and (b) 5R

Fig 5 and Fig 6 showed that the percentage of delta ferrite decline with the increase in the welding repairs numbers. The percentage of delta ferrite on HAZ have the relation to the level of welding heat input given. According to Silva et al., the decreased portion of delta ferrite had been ascribed to a reduced cooling rate due to the heat input increased. [9]

Moreover, this was also found by the investigator that the cooling rate has a substantial effect on phase transformations during the welding for stainless steel containing δ-ferrite above 14% [11].

The prolonged phase transformation from δ to γ occurred when the cooling rates decreased, hence the increasing percentage of δ-ferrite transformed into austenite. Fig 7 shows that the percentage of delta (δ) ferrite tend to drop with the rising weld repairs number.

Fig. 7. The percentage of delta (δ) ferrite as a function of weld-repair numbers

The effect of grain size on the repeated numbers of weld repairs is shown in Fig 8. The grain size assessment on HAZ was conducted based on ASTM E-112. It was revealed that the size of grain number (G) on the HAZ decreased with decreasing the number of welding repair. In other words, the grain size becomes coarser as the increasing weld repair as can be seen in Fig 8.

Fig. 8. The weld-repairs is the function of the grain size number (G)

3.2 Microhardness test evaluation

Microhardness results are shown in Table 6. The value of weld metal hardness is higher than the HAZ and base metal as seen in Table 6. This difference of hardness value was due to the level percentage of alloying elements distributed along the weldments. Table 6 shows the level of HAZ hardness has the relation to the number of welding repair. The result revealed that the increasing weld repairs tend to decrease the hardness of HAZ of repaired weldments as can be seen in Table 6. According to Vega et al. [7], it was found that the increasing weld repairs increased the grain growth as well as the reduction of delta ferrite occurred.
3.3 Tensile tests evaluation

The tensile tests results are shown in Table 7. The tensile test properties of repaired welds show that the ultimate tensile strength (UTS) have a few reduced with adding the weld repairs. The decreasing of tensile strength is due to the effect of HAZ grain growth as in Fig. 8. The alteration in the percentage of elongation has a similar trend with the tensile strength.

3.4 Impact properties analysis

The results of the impact test are revealed in Fig. 9. It shows that the impact strength has a few decreased as the increasing weld repairs numbers in the stainless steel of 304L plates. However, the impact strength of 316L stainless steel plates has a significantly declined as-as the rising weld repairs number.

Table 6 Microhardness value of repaired welds on different weld locations

| Samples | Weld Metal | HAZ | Base Metal |
|---------|-----------|-----|-----------|
|         | 0 - 8 mm  | 10 - 18 mm | 20 - 28 mm | 30 - 40 mm | Average |
| 304L-0R | 234       | 228 | 205       | 197       | 201     |
| 304L-1R | 223       | 209 | 205       | 201       | 203     |
| 304L-2R | 201       | 201 | 201       | 181       | 191     |
| 304L-5R | 201       | 197 | 185       | 193       | 189     |
| 316L-0R | 244       | 234 | 201       | 185       | 193     |
| 316L-1R | 234       | 228 | 193       | 201       | 193     |
| 316L-2R | 234       | 228 | 185       | 209       | 197     |
| 316L-5R | 214       | 209 | 178       | 178       | 178     |

Table 7 The tensile tests results for the different weld repair.

| Material: SS 304L | BM | 0R | 1R | 2R | 5R |
|-------------------|----|----|----|----|----|
| Max. tensile strength, MPa | 581 | 613 | 611 | 610 | 609 |
| Yield strength, MPa | 290 | -  | -  | -  | -  |
| Maximum elongation, % | 47.1 | 45.9 | 44.9 | 38.1 | 37.6 |
| Broken location | Base metal | Base metal | Base metal | Base metal | Base metal |

| Material : SS 316L | BM | 0R | 1R | 2R | 5R |
|-------------------|----|----|----|----|----|
| Max. tensile strength, MPa | 583.4 | 597.6 | 593.6 | 591.4 | 586.4 |
| Yield strength, MPa | 333 | -  | -  | -  | -  |
| Maximum elongation, % | 44.9 | 43.6 | 43.2 | 41.2 | 40.7 |
| Broken location | Base metal | Base metal | Base metal | Base metal | Base metal |
5 Conclusion

1. The HAZ weld repair microstructures consisted of a matrix of austenite, delta ferrite precipitates, and dark carbide particles. The structure and total of delta ferrite changes as a result of the welding heat input. The increasing number of weld repairs decrease the percentage of delta ferrite and produces the fine short ferrite precipitates.

2. The tensile strength of weldments has a few declines with the repeated weld repairs number. The HAZ microhardness reduced with a repeated weld repair number. The impact strength of stainless steel plates have a significantly reduced as the repeated weld repairs number in 316L plates, but a few decreased in the 304L plates.

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