Investigating the Effect of TIG and FSW Joint Design on the Mechanical Properties of the AA5083 Aluminum Alloy in Welding Processes

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Abstract

The 5083 aluminium alloy is one of the alloys of the 5xxx series that is widely used in defence and shipbuilding industries. In this study, the 5083 aluminium alloy plates were evaluated through two friction stir welding and tungsten inert gas welding (TIG) by a double groove weld with a 30° angle and a 2mm gap for TIG and a simple butt weld for FSW. In this study and in addition to examining the samples' mechanical properties, the microstructure changes and the hardness were also reviewed. The results show that the FSW weld has better mechanical properties than the TIG weld due to fast welding speed. However, by preparing the pieces, the mechanical properties of TIG get closer to those of FSW. In the FSW welding in the weld nugget, the grains have a fine and co-axial structure, and an increase in the advance rate will reduce the inlet heat and make the grains smaller. Nevertheless, in TIG welding at high speeds, the grains become more extensive with increased inlet heat.

1. Introduction

Nowadays, aluminum and composite sheets have a leading role in developing low-weight aircraft and hydrogen storing technologies [1-3]. Aluminum has Friction stir welding with many applications in welding homogenous and heterogeneous metals, especially in joining the aluminum of the 5xxx series with weak weldability. These alloys have practical applications and different ductility and are utilized in shipbuilding, automobile manufacturing, and aircraft manufacturing and military industries [4]. The 5xxx aluminum alloy is a non-precipitating alloy that enjoys various properties such as low cost, relatively high strength, and corrosion resistance [5]. The friction stir welding process (Figure 1) has been invented and registered by The Welding Institute (TWI) in 1991 [6] and is applicable in welding this alloy. In this method, a non-consumable rotating tool is employed for production in the workpiece. By pressing the joint work tool and resulting, the base metal gets heated and becomes soft and quickly transforms when it reaches its melting point at 80°. By keeping the rotating tool and moving it along the work joint, the pieces are joined together. The weld resulting from the friction stir welding (FSW) process consists of various parts shown in Figure 2.

1. Weld nugget zone
2. Thermomechanical zone
3. The heat-affected zone

Nevertheless, the tungsten inert gas welding, TIG (Figure 3), is a traditional fusion welding technology that establishes an electric arc between the tungsten electrode and the workpiece and the welding takes place by inserting a filler metal in the melt pool that is created due to low voltage and high current of the arc.

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Different researchers have studied the effect of different friction stir welding parameters on homogenous aluminum joints of the 5xxx series. Hattinge et al. [7] studied the effect of geometrical parameters of the tools on the force required for friction stir welding and the 5083 aluminum alloy's joint strength. Number, depth, and the thread angle of the pins with different designs were among the geometrical parameters they have studied. They concluded that optimizing the tools using threaded lifting pins with vertical grooves can help achieve a joint strength equal to 95-97% of the base metal's strength.

Hirata et al. [8] examined the effect of the inlet heat on the annealed alloy friction weld's microstructure and ductility. They concluded that by increasing the rotational speed to linear speed, the joints' strength and ductility decrease and the joint microstructure becomes larger in the weld nugget zone. Singh [9] et al. investigated the effect of various TIG welding parameters (ampere, voltage, gas flow, welding speed) on the mechanical properties of the 5083 alloy weld. They found that at optimal values of the welding parameters, increased welding speed will increase the tensile strength of the weld and improve the samples' mechanical properties. Singh et al. [10] also found that increasing the TIG parameters' optimal values will raise the penetration depth and weldability of the 5083 alloys.
2. Research Method

In the current study, a 5083 AA sheet with a 5m thickness has been used in FSW and TIG processes, such that a quantimeter has measured the chemical composition of this sheet like the following.

| Element | Si   | Fe  | Cu  | Mn  | Mg  | Cr  | Ni  | Pb  | Zn  | Ti  | AL  |
|---------|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Percentage (wt%) | 0.116 | 0.452 | 0.0268 | 0.722 | 4.38 | 0.0935 | 0.005 | 0.417 | 0.25 | 0.0194 | remained |

To remove the oxide layer on the surface of the samples, the pieces were washed using sodium hydroxide solution for 10 to 15 seconds and then dried by dry wind pressure. The welding samples with the dimension of 220 × 300 mm and a 5mm thickness were utilized for butt FSW welding in optimal conditions [11] and double groove TIG welding with a 30° angle and a 2mm gap. The characteristics related to friction welding are shown in Tables 2 to 5.

| Pin type (AISI) | Shoulder diameter (mm) | Pin diameter (mm) | Pin height (mm) |
|----------------|------------------------|------------------|-----------------|
| H13 Steel      | 95.29                  | 72.5             | 85.4            |

Table 3 – FSW welding parameters [7]

| Weld code | rotational speed (rpm) | Pin deviation angle (°) | advance rate (mm/min) |
|-----------|------------------------|------------------------|-----------------------|
| F5        | 1100                   | 1                      | 100                   |

Table 4. TIG weld parameters

| Polarity | AC                      |
|----------|-------------------------|
| Electrode type | 5356 AA with an electrode diameter of 2mm |
| Tungsten type | Pure tungsten or green tip characteristic |
| Gas type | Pure Ar – Gas flow of 15 L/min |
| Ampere for assembly | 161 amp |
| Ampere for welding | 95 amp |

Table 5. Chemical formula (wt%) of the filler metal in AA5356

| Element | Percentage (wt%) | Element | Percentage (wt%) |
|---------|-----------------|---------|-----------------|
| Mg      | 5/5-5/4         | Cu      | 10/0            |
| Ti      | 0006/0020       | Si      | 24/0            |
| Mn      | 20-0005/0       | Zn      | 10/0            |
| Cr      | 20-0005/0       | Fe      | 40/0            |
| Be      | 0008/0          | -       | -               |

3. Results and Discussion

3.1. Hardness Test

To examine the hardness of different welding spots, four samples (F1, F2, F3, and F4) of TIG and one sample (F5) of FSW welded under optimal conditions were subjected to a 10kg load and the following results in Figure 4 were obtained.
Results of the hardness experiments show that in the TIG process, the hardness decreases from the base metal toward the reinforcement which can be due to the destruction of the rolled structure because of the high heat of Welding 2 and the unlocking of the dislocations or due to the formation of a coarse structure because of the boiling zone melting. While the hardness in the weld zone in the FSW process is reduced from the base metal to the reinforcement, which can be due to the dissolution of the second phase particles and the unlocking of the dislocations the loss of hardness strain resulting from the rolling structure. In general, the hardness in both welded samples has been reduced by moving from the base metal to the reinforcement, and the hardness in the TIG process is less than that in the FSW process [11-13].

3.2. Investigating the Mechanical Features of TIG and FSW

According to Part 2 of the DIN 50120 Standard, all tensile test samples were prepared transversely as shown in Figure 5 and the properties listed in Table 6.

| Dimensions and size (mm) | Sign | Details                  |
|--------------------------|------|--------------------------|
| 50                       | Ls   | Length of the welded sample |
| 25                       | b1   | Sample width             |
| 5/12                     | b    | Sample internal width    |
| 70                       | Lc   | Parallel length          |
| 5/12                     | r    | Radius                   |
| 150                      | Lt   | Sample length            |

Figure 5. Tensile test sample
Tensile testing was performed at a 1mm/min speed, an ambient temperature of 25 oC for all the welds. The experimental results are shown in Figure 7.

| Weld code | Ultimate strength (Mpa) | Yield strength (Mpa) | Elongation percentage | Fracture path                  |
|-----------|-------------------------|----------------------|-----------------------|--------------------------------|
| B.M       | 330                     | 283                  | 7.14                  | -                              |
| F1        | 228                     | 196                  | 5.7                   | HAZ                            |
| F2        | 248                     | 219                  | 9.7                   | HAZ                            |
| F3        | 278                     | 248                  | 2.11                  | HAZ                            |
| F4        | 290                     | 258                  | 7.13                  | HAZ                            |
| F5        | 290                     | 258                  | 7.13                  | Tip of the weld center at a 3-4 mm distance from the surface |

The obtained results show that the welds’ mechanical properties become closer to those of base metal with the increase in the advance rate. That is why the tensile properties of the welds depend on the welding speed, such that the mechanical properties of the welding samples improve with increased welding speed. The FSW processes’ speed has been steadier than in the TIG process; thus, the mechanical properties of the FSW at the selected optimal speed are improved. On the other hand, and given the microhardness test results, it can be observed that the fracture occurs in a zone with the least hardness.

3.3. Microstructure Review

To review the cross-sectional microstructure of different welding zones and determine the grain size number, the samples were first prepared perpendicular to the welding direction. They were then sanded by 200, 100, 400, 600, and 800 emeries and were then electro etched in a 30% nitric acid and methanol solution for 3 minutes with a voltage of 7.5. The welded structure was reviewed using an optical microscope. Microscopic examinations show that the TIG samples’ fracture occurs in the HAZ zone, which is since this zone is coarser than the welding metal. The size of the sub-grains increases with increasing inlet heat during welding, as a result of which the grains become larger with increasing inlet heat [7-9]. Welding structure in Figure 6-b shows that the grains in the reinforcement are formed as co-axial dendritic grains with different grain sizes due to the high heat of welding, and the hardened working structure of the base metal is wholly destroyed. In Figure 6-c in the HAZ zone, the recrystallized grains are coarse and co-axial due to the high heat received from the fusion welding process and the low cooling rate due to the vastness of this zone, which provides sufficient time for grain growth in the affected zone.

Figure 6. Microscopic pictures from different welding zones in the TIG and FSW processes with a magnification of 10. a) Microscopic picture of the base metal. b) microscopic picture of the reinforcement in the TIG process, c) microscopic picture of the HAZ zone of the TIG process, d) microscopic picture of the reinforcement in the FSW process, e) microscopic picture of the HAZ zone of FSW.
Whereas in Fig d-6 and the friction stir welds in the weld nugget zone, the grains are completely co-axial and the grain size is smaller than the base metal grains and indicates dynamic recrystallization in this zone they become smaller as the inlet heat decreases. However, in the case of the thermomechanical zone of the grains stretched on the side of the material flow, the prominent feature of this zone is that despite severe plastic deformation, dynamic recrystallization has not occurred in this zone; therefore, the grains have still retained their elongated shape. In the HAZ zone in Figure e-6, it is observed that the grain size is smaller than the HAZ in the TIG process [14, 15].

4. Conclusions

In the FSW welding and in the weld nugget zone, the grains have a fine structure and are co-axial. The inlet heat decreases with increased advance velocity, and the grains become smaller. However, high-speed welding is not possible in TIG welding, and thus the grains become larger with the increase in inlet heat.

Microstructure of the reinforcement in the FSW process is shaped like onion rings, and fine co-axial and recrystallized grains compose its morphology. Whereas the weld nugget's microstructure in the TIG process is dendritic and its morphology is composed of large grains.

Grains in HAZ have better growth in the TIG process than in the FSW process.

Tensile properties of the welds depend on the welding speed, such that the mechanical properties of the samples improve with increased welding speed. In the FSW process, the advance rate is much steadier than in the TIG process. Therefore, the FSW sample's mechanical properties improve with increasing speed, but by preparing the parts by double groove welding because of welding on both sides of the sample, TIG welding metal's mechanical properties become closer to those of FSW welding metal.

The hardness in both welded samples is reduced by moving from the base metal to the weld, and the hardness in the TIG process is less than the hardness in the FSW process.

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