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# A comparison study between friction stir welding and metal inert gas welding in joining similar Al-Al strips

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**Keywords:** Friction stir welding; similar joints; Heat affected zone ; Weld nugget; metal inert gas.

**Abstract.** In this study, two sets of pure aluminum strips 3 mm in thickness were friction stir welding (FSW) together in a regular Butt joint pattern. Two rotational speeds of 1750 RPM and 2720 RPM were utilized to perform the welding process. The transverse speed and the axial load were kept constant at 45 mm/min and 6.5 kN respectively. As a welding tool, cylindrical shoulder and pin geometry was selected. For comparison purposes other similar strip pair sets were butt welded using the conventional metal inert gas arc welding technique (MIGAW). The welding quality, power input, microstructure, macrostructure and the mechanical properties of the weld joints yielded from these two welding techniques were examined. The types of the fumes and the amount of the released gases during these two welding processes were measured and compared. The results proved that the solid state friction stir welding is clean, cost effective and environment friendly process as opposed to the conventional metal inert gas arc welding.

## Introduction

FSW is a green, environment friendly and non harmful process as it is not accompanied arc formation, radiation and toxic gas emission [1]. FSW is a solid state welding process which can afford high quality welds even for unmanageable materials for conventional welding such as aluminum. As a solid state joining process, FSW gives several privileges for joining various alloys, especially aluminum alloys. Aluminum alloys are used in wide applications; these include aerospace, automotive industries and ship building. Since the introduction of FSW, this welding technique has been widely utilized in welding of low melting alloys which are difficult to be joined by any other conventional fusion weld [2]. The FSW process leads to the appearance of thermo-mechanically affected zone (TMAZ), heat affected zone (HAZ) and a nugget zone (NZ) which is also known as the stir zone (SZ) in the central part of the TMAZ. The main parameters of the FSW process that determine the quality of the welded joint are ; the tool plunge force, the tool rotational speed, the tool geometry and the transverse speed [3]. Gas metal arc welding (GMAW) is an example of a conventional arc welding process that employs a continuous consumable solid filler wire electrode and an externally supplied inert shielding gas [4]. In GMAW, the arc generated between the continuously fed filler wire electrode and the metal pair body melts the filler completely and slightly the sides of the metal pairs and join them together. The power needed for GMAW can be calculated using the following formula [5]:

$$\text{Power} = \text{Voltage} \times \text{Current} \qquad (1)$$

Other than that, GMAW as a fusion welding process is done at a temperature higher than the melting temperature of the metal to be welded. High temperature process can induce lots of defects to the welded joint, such as distortion, cracking and higher residual stress which results in lower mechanical strength. High temperature process also indicates that the power consumed to perform the welding is higher [5]. The aim of this article was to study the impact of FSW and GMAW on the microstructure, mechanical properties and quality of the weld joints and to assess their cost effectiveness and influence on the environment.

**Experimental Work**

The executed weld joints for the FSW and GMAW were Butt joint typed. The FSW schematic representation and the tool geometry are shown in Fig.1. Medium carbon steel, heat treated and quenched to Rockwell (RC) 56 was used to fabricate the tool. Vertical milling machine used to execute the FSW process. It was of 3hp or 2237 watt.

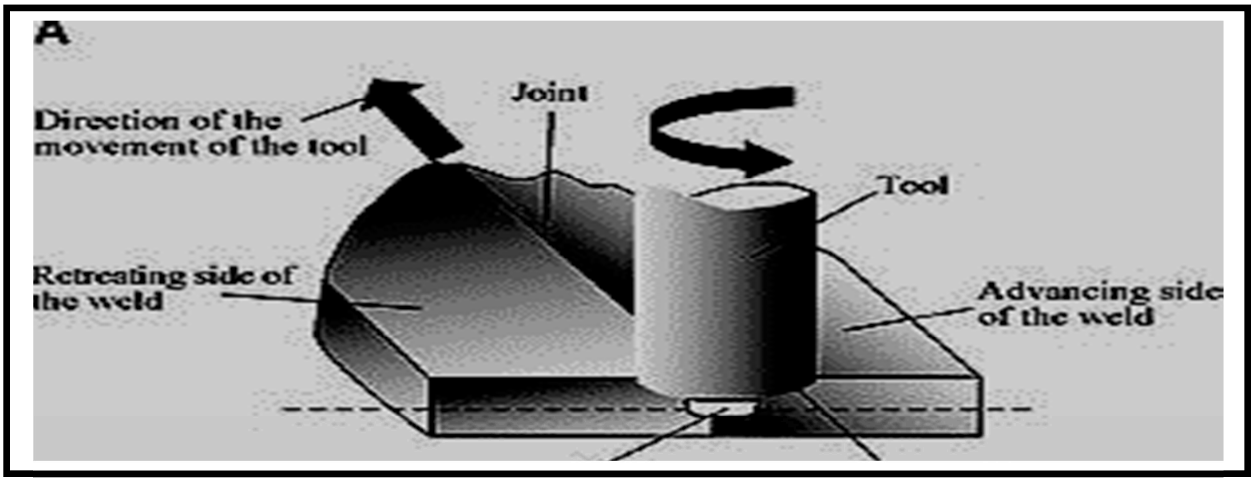


Fig. 1: Schematic representation of the FSW process.

For GMAW, the welding current was a DC electropositive current and the shielding gas used was pure argon. The welding current and the welding voltage were 120A and 20V respectively. According to Eq. 1, the average power consumed in the GMAW to conduct one joint was about 2400 watts. Sample preparation for metallography testing was done according to the ASTM E3 (Standard Guide of Metallographic Specimens standard) [6]. Hardness test specimens were etched according to the ASTM E407 (Standard Practice for Microetching Metals and Alloys) [7].

**Results and Discussion:**

Indoor Air Quality Pro device was used to detect and measure the emission and the amount of carbon dioxide and carbon monoxide during welding. Table 1, shows the measured amounts of the carbon dioxide and carbon monoxide in a certain volume confined to the welding place. Fig. 2 (a) reveals the FSW weld morphology, it can be seen that the top of the welded strips is not smooth and spattered. This was due to insufficient heat generated by the shoulder rubbing action. In Fig. 2 (b) the lack of root penetration and an incomplete filled groove are evident. This is attributed to the shortness of the pin which resulted in insufficient heat flow necessary to deform, plasticize and fuse the bottom sides together. Fig. 3 (a) depicts the weld profile at a rotational speed 2720 RPM.

Table 1: The amounts of the carbon dioxide and the carbon monoxide exist at welding area.

| Welding Technique | GMAW | | FSW | |
|---|---|---|---|---|
| Gases Volume / Number of test | Carbon monoxide [ppm] | Carbon dioxide [ppm] | Carbon monoxide [ppm] | Carbon dioxide [ppm] |
| 1 | 1.3 | 361 | 0.0 | 197 |
| 2 | 1.0 | 354 | 0.0 | 241 |
| 3 | 1.2 | 344 | 0.0 | 196 |
| 4 | 0.8 | 338 | 0.0 | 201 |
| 5 | 0.7 | 333 | 0.0 | 223 |

It reveals smoother surface than that conducted at 1750 RPM that shown in Fig. 2. Fig. 3 (b), shows the bottom side of the welded strips. Defects free profile is evident. This was due to the proper heat received at the top and bottom sides of the strips. The heat generated was enough to plastizie the metal at the strip edges and join them together.

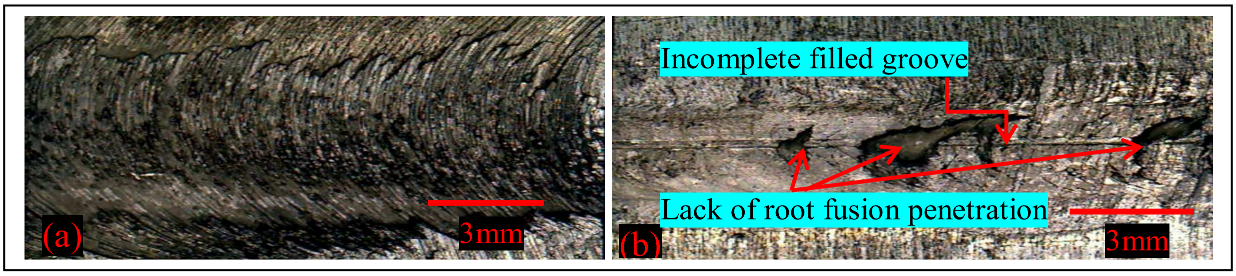


Fig.2: The weld profile of the Al-Al FSW joint at a rotational speed of 1750 RPM (a) the top side (b) the bottom side.

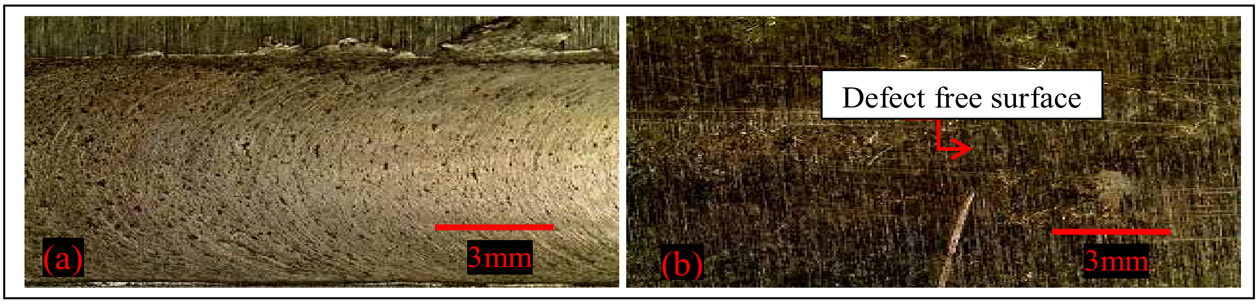


Fig. 3: The weld profile of the Al-Al FSW joint at a rotational speed of 2720 RPM (a) top side (b) bottom side.

Fig.4 (a), shows the weld profile of the Al-Al GMAW welded joint on its top side. Spatters around the welded metals are evident. This might caused by the excessive current, arc blow, damp electrode. Fig. 4(b), clearly shows that there are lack of root fusion and lack of penetration at the bottom of the welded strips. This probably caused by the high welding speed. Fig. 5(a) shows different weld regions of the Al-Al GMAW welded joint. Fig. 5(b), shows the microstructure of different weld regions of the Al–Al FSW joint at a rotational speed of 2720 RPM. The microstructure of the base metals in Fig. 5(a) and (b), showed the elongated grain structure reflecting the original cold rolling process on the as received base metal. During FSW, the base metal experiences no metallurgical changes and maintains the original elongated cold worked microstructure.

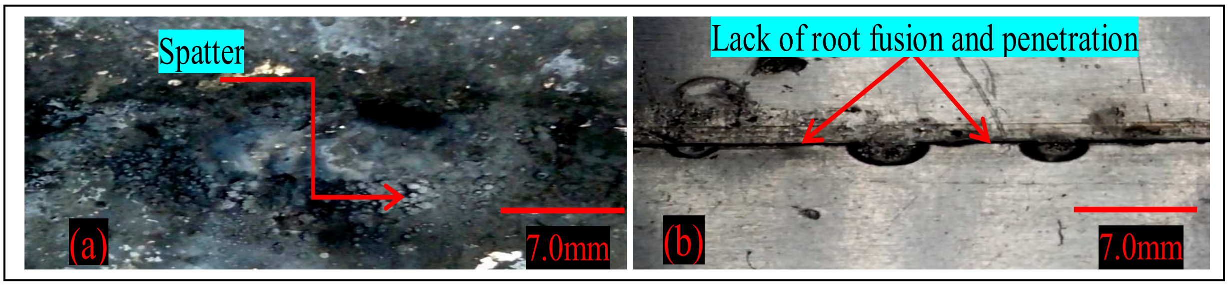


Fig. 4: The weld profile of the Al-Al GMAW joint (a) the top side (b) the bottom side.

The grains at the HAZ are slightly coarser than the grains at the TMAZ. The thermal exposure had caused the grains to grow. The relation between grain size and the mechanical properties (strength and hardness) can be expressed by the Hall–Petch equation [8].

$$\sigma = \sigma_0 + K_h d^{-1/2} \quad (2)$$

Where, $\sigma$ is the strength of the material, d, is the grain size diameter, $\sigma_0$ and $K_h$ are experimental constants and are different for each metal. Eq. 2 shows that smaller grain size diameter results in higher strength of the material. This explains as well the relatively higher hardness values at different regions of the of the Al-Al weld joints produced at the high rotational speed. Fig. 5(a), shows the microstructures at the welding zone (WZ) and the HAZ of Al−Al weld joint. In general the WZ has a dendritic structure due to the fast heating of the base metal melt [9].

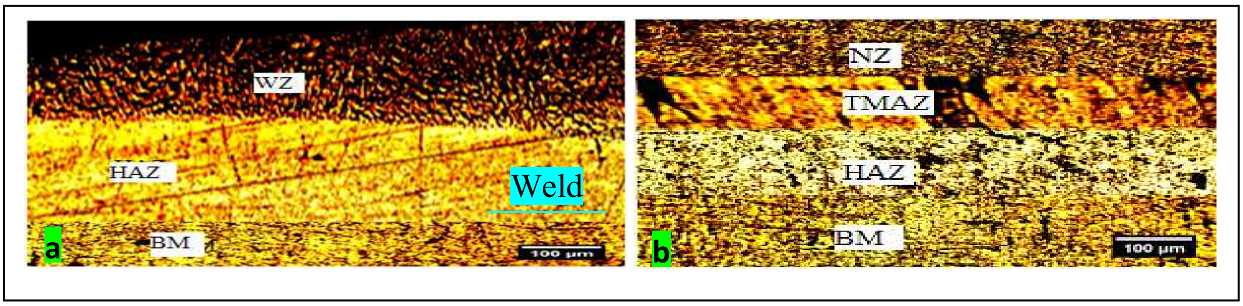


Fig. 5: (a) The welding morphology of the Al-Al MIGAW joint depicts the microstructures of the welding zones (b) superimposed optical image of the FSW joint conducted at 2720 RPM revealing the microstructure of different welding zones.

Fig. 6, clearly illustrates the inferior strength of all weld joints as compared to the base metal strength. Among all four welded joint set, the Al-Al FSW joint conducted at a speed of 2720 RPM gave the highest tensile strength. This was due to the grain refinement effect resulted from the stirring action at high rotational speed. The Al-Al GMAW joint possessed the low tensile strength among all welded joint set. This attributed the presence of many defects associated with the fusion welding process.

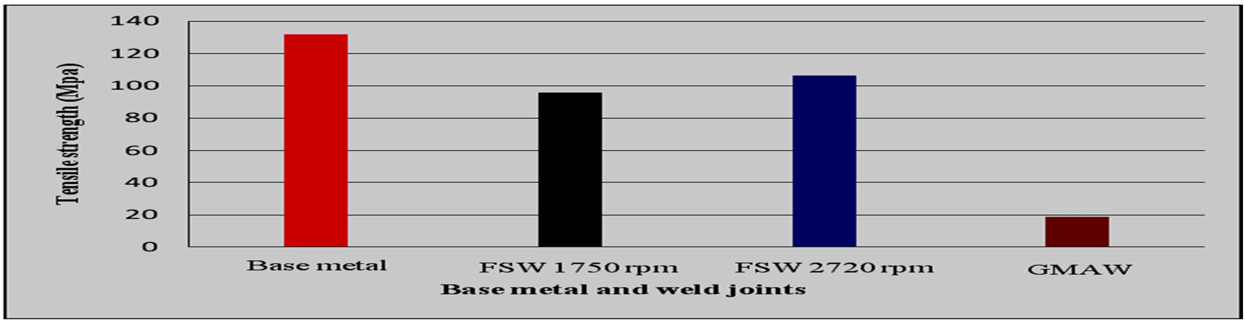


Fig. 6: The tensile strength of the base metal and the weld joints produced by the FSW and the GMAW techniques.

## Conclusions

The powers consumed by the FSW and GMAW techniques to execute similar strip pairs joint were about 1537 watts and 2400 watts respectively. This proves that FSW has higher welding/heat generated efficiency than that of GMAW. GMAW process releases a higher amount of carbon monoxide and carbon dioxide in the surrounding as opposed to that of FSW. In short, FSW is a better technique to fabricate light relatively soft metal welding joints compared to GMAW from energy consumption, welding quality and cleanness and environment perspectives.

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