# Comparison of mechanical and microstructural behaviour of TIG, MIG and friction stir welded 7075 aluminium alloy

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**Abstract**

In this study, 6 mm thick Aluminium Alloy 7075 has been welded using three different welding methods, namely the solid state joining method Friction Stir Welding (FSW), fusion welding methods Tungsten Inert Gas Welding (TIG) and Metal Inert Gas Welding (MIG). Welded joints have been investigated and compared in terms of their microstructures, mechanical behaviour and hardness. Microstructural examination reveals that smaller grain sizes are obtained in the weld centre of FSW, whereas grain growth has been observed in TIG and MIG welds. The results show that among the three welding methods employed, FSW has yielded the best mechanical properties.

Key words: friction stir welding, MIG, TIG, aluminium alloy, microstructure, tensile properties

## 1. Introduction

Friction Stir Welding (FSW) is an innovative joining process, patented at The Welding Institute (TWI) in 1991. FSW technology is being widely considered by modern aerospace, shipbuilding and automotive industries for high performance structural demand [1–5].

FSW has several advantages over the commonly used fusion welding techniques. Following from its relatively low process temperature, below the melting point, the method is suited for joining thin or difficult to weld materials [6]. With no melting, the cast microstructure formed during conventional fusion welding is avoided as well as the weld zone shrink from solidification. Furthermore, there is limited risk for porosity in the weld zone, which is common in fusion welds. The FSW joint is created by friction heating with simultaneous severe plastic deformation of the weld zone material. Since the amount of heat supplied is smaller than during fusion welding, heat distortions are reduced, thereby reducing the amount of residual stresses. The deformation control is therefore easier [7]. Some aluminium alloys can be welded with electrical resistance techniques, provided that an extensive surface preparation and oxide formation are controlled. On the contrary, FSW can be used with success to weld most of aluminium alloys considering that superficial oxide generation is not deterrent for the process and no particular cleaning operations are needed before welding. Another crucial aspect in welding of aluminium is the presence of brittle solidification phases; this problem is generally overcome by the FSW technique [3, 5]. Moreover, consumable filler material, shielding gas, or edge preparation are normally not necessary with FSW [8, 9].

The FSW process operates by generating frictional heat between a rotating tool of harder material than the workpiece being welded in such a manner as to thermally condition the abutting weld region in the softer material. The tool is shaped with a larger diameter shoulder and a smaller diameter pin, which are specially profiled [8]. This process constitutes a development of the classical friction welding methods. The shoulder is pressed against the surface of the materials being welded, while the pin is forced between the two

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Table 1. Chemical composition (wt.%) of base metal (AA 7075) and filler metals

| Type of material | Zn | Mg | Cu | Si | Fe | Cr | Ti | other | Al |
|---|---|---|---|---|---|---|---|---|---|
| Base metal (AA 7075) | 5.7 | 2.4 | 1.8 | – | 0.15 | 0.04 | – | 0.55 | Bal. |
| Filler wire for MIG welding (5356) | 0.1 | 4.9 | – | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | Bal. |
| Filler rod for TIG welding (4043) | 0.1 | 0.05 | 0.04 | 4.9 | 0.2 | – | 0.15 | – | Bal. |

components by a downward force. The rotation of the tool under this force generates a frictional heat that decreases the resistance to plastic solid-state joining process; hence, welding takes place below the melting point of the material. The softened material then easily moves behind the tool and forms a solid-state weld as the stirred material is consolidated [2]. The stirring of the tool minimizes the risk of having excessive local amounts of inclusions, resulting in a homogenous and void-free weld [7].

Literature review reveals that there is still lack of material property data regarding the comparison of FSW with TIG and MIG. Although it is observed that FSW, in general, yields stronger welds than fusion welds, more data are needed in order to support this fact, for the time few comparisons have been made of the same material welded by different methods [9–12].

In this paper a comparison has been proposed on the mechanical and microstructural behaviour of welded 7075 Aluminium Alloy, by three different welding techniques: MIG, TIG and FSW. The results are compared in terms of microstructural examinations of tensile properties and hardness variations across the weld joint.

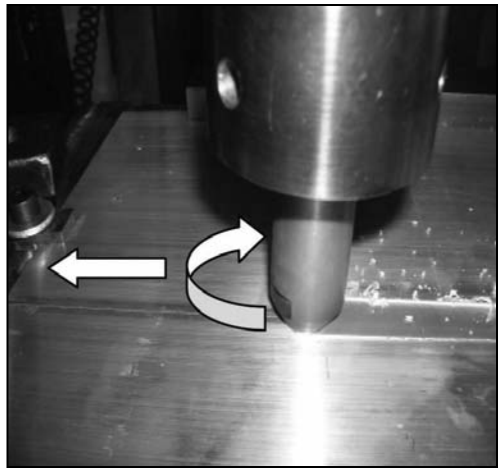

Fig. 1. Schematic view of FSW process.

Table 2. Mechanical properties of the filler wire 5356 and filler rod 4043

| Filler metal | YS (MPa) | UTS (MPa) | Elongation (%) |
|---|---|---|---|
| 5356 (MIG) | 125 | 275 | 20 |
| 4043 (TIG) | 60 | 135 | 14 |

## 2. Experimental procedure

### 2.1. Material

The material used in this study is Aluminium Alloy 7075 (AA 7075) in T651 condition produced as extruded flat plate, with 6 mm thickness, with dimensions of 275 × 150 mm$^2$ (length × width). The chemical compositions of AA 7075 base metal and the filler metals used for MIG and TIG welding are given in Table 1.

### 2.2. Friction stir welding

The tool used in FSW process consists of a shoulder with a diameter of 20 mm and a pin with a diameter of 6 mm and a length of 5.7 mm. The FSW tool was fixed to the rotating axis of a milling machine; the tool was 3° tilted from the normal direction of the plate and rotated clockwise. Figure 1 shows the FS application of AA 7075 [13]. In this study, the optimum tool rotation and welding speeds for FSW process are chosen as 1600 rpm and 200 mm min$^{-1}$, respectively, as a result of previous studies [14].

### 2.3. TIG and MIG welding

The longitudinal directions of the TIG and MIG welds were taken parallel to the rolling direction of AA 7075. The abutting surfaces were cleaned before welding with a steel brush followed by light sanding with 400 grit SiC paper and degreasing with acetone. The cleaning media contained no carbon. A gap of 2 mm was left between the two plates being welded; no V joint configuration has been prepared. AA 5356 (Al-5% Mg) grade filler wire was used with a diameter of 1.2 mm for MIG welding, while AA 4043 (Al-5%Si) grade filler rod with a diameter of 2.6 mm was used for TIG welding; mechanical properties of the filler metals are given in Table 2.

Pre-heating was carried out in both TIG and MIG

Table 3. TIG and MIG welding process parameters

| Process | MIG | TIG |
|---|---|---|
| Welding machine | Rockweld Migarm | Miller |
| Tungsten electrode diameter (mm) | – | 3 |
| Filler wire/rod diameter (mm) | 1.2 | 2.6 |
| Current (A) | 185 | 150 |
| Voltage (V) | 30 | 24 |
| Welding speed (mm $min^{-1}$) | 180 | 130 |
| Shield gas | Argon | Argon |
| Gas flow rate (l $min^{-1}$) | 16 | 16 |
| Pre-heat temperature (℃) | app. 150 | app. 150 |

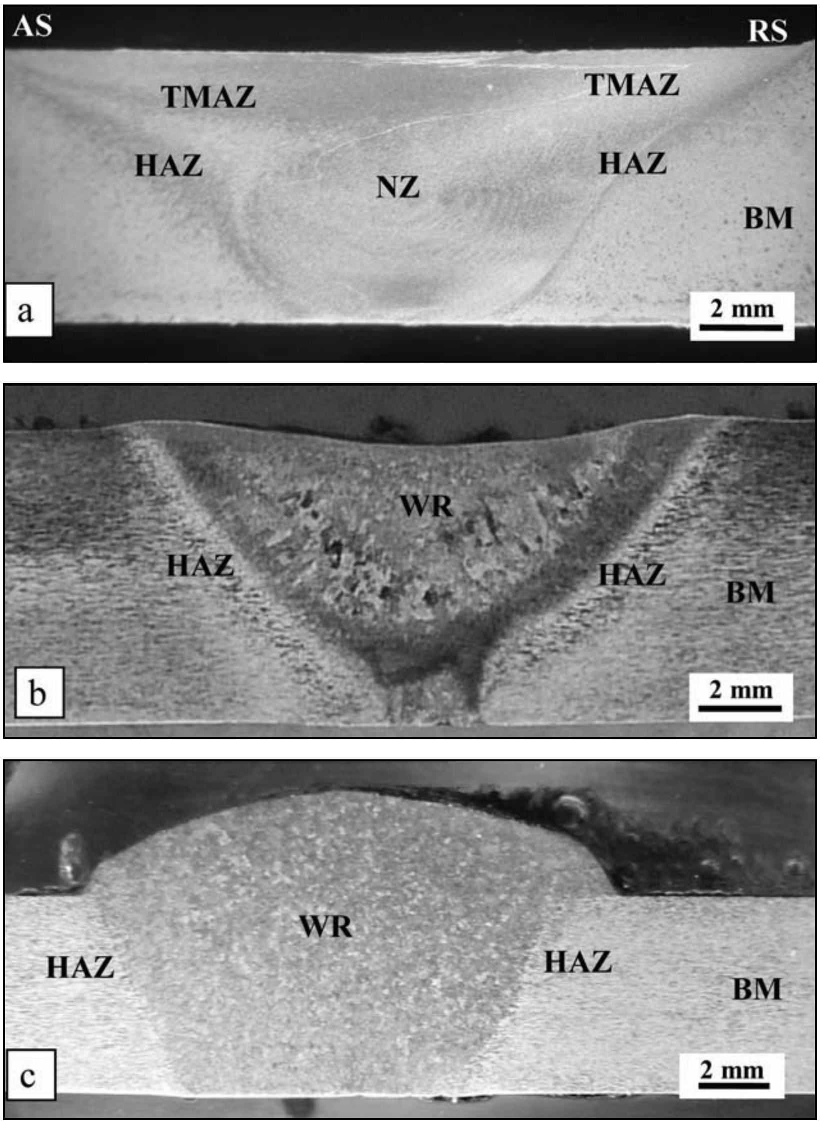


Fig. 2. Cross section of joints depicting the various zones formed as a result of (a) FSW, (b) TIG welding, (c) MIG welding.

welding for better penetration throughout the thickness of the plates. Single pass welding procedure was applied to fabricate the joints. High purity (99.99 %) argon gas was used as the shielding gas. Welding process parameters for TIG and MIG welding are given in Table 3 [18].

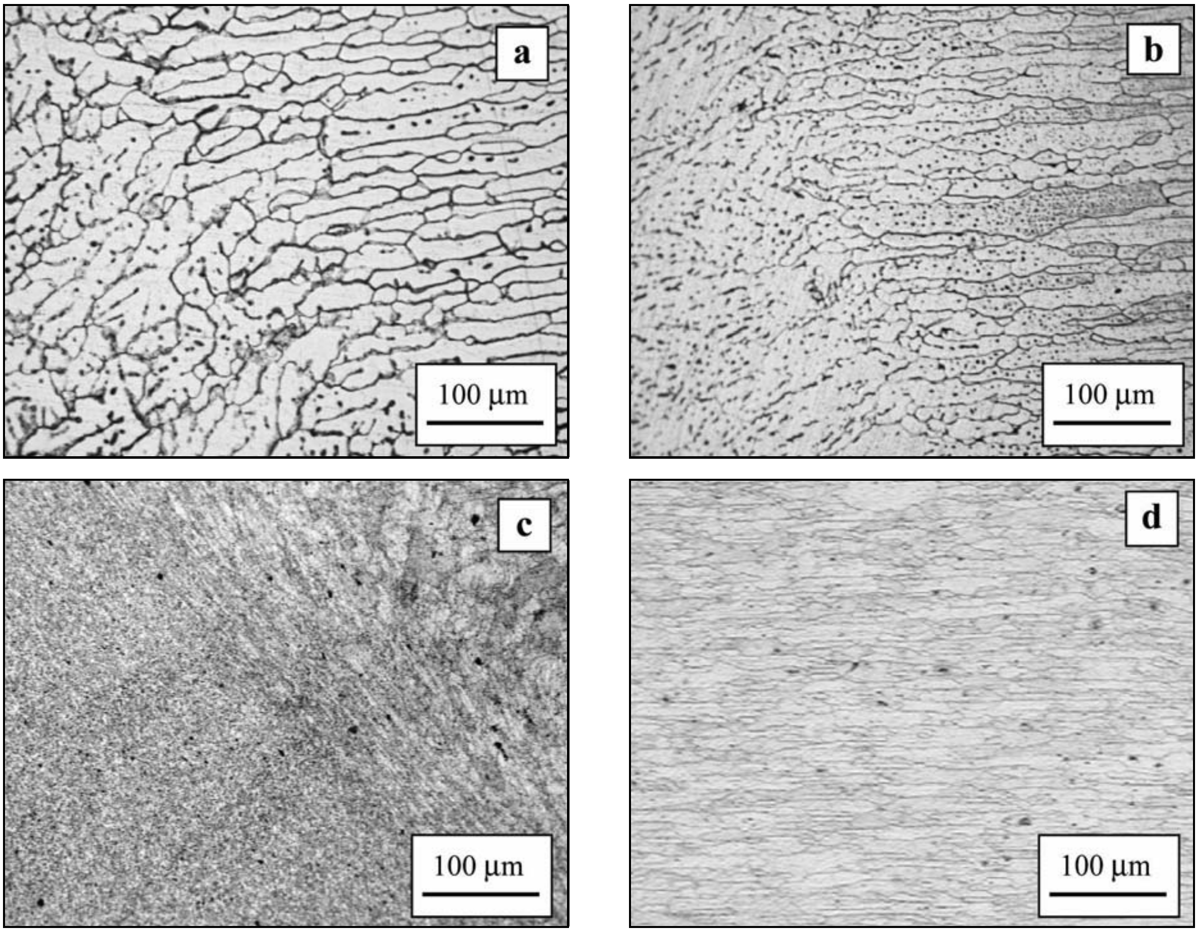


Fig. 3. Base metal to weld metal transition region: (a) TIG, (b) MIG, (c) FS welded specimen, (d) microstructure of base metal AA 7075.

After all three welding procedures, the joints were cross-sectioned perpendicular to the welding direction for metallographic analyses. The cross sections of the metallographic specimens were polished with alumina suspension. The welds were used in as-welded condition without the application of any heat treatments. The specimens have been prepared by standard metallographic techniques and etched with Keller's reagent (150 ml $H_2O$, 3 ml $HNO_3$, 6 ml HF). The etching solution was cooled to 0 ℃ and specimens were etched for about 20 s in order to study the grain structure of the weld zones and to allow for optical microscopy characterization [15]. The Vickers hardness profiles of the welded zones for all welds have been obtained over the weld cross section using a Vickers indenter with 85 gf load for 10 s. Tensile tests have been performed in order to evaluate the static properties of the welded joints. The tensile specimens were cut out perpendicular to the weld axis. Tensile tests were carried out at room temperature at a crosshead speed of 1 mm $min^{-1}$ using a computer-controlled testing machine. Tensile tests are carried out according to ASTM E 8 Code.

## 3. Results and discussion

### 3.1. Microstructure

The transverse macro section in Fig. 2a illustrates the zones of the FSW joint for the Al alloy used in this study. As seen in the figure, the joint region of FS welds exhibits four distinct regions, namely the Parent Metal (also called the Base Metal – BM), Heat Affected Zone (HAZ), Thermo-Mechanically Affected Zone (TMAZ) and the Nugget Zone (NZ) [13]. The BM has long-equiaxed grains oriented along the rolling direction (shown in Figs. 3a and 3b for MIG and TIG welding), whereas the weld nugget is composed of fine-equiaxed grains due to recrystallization, which are formed under high temperature and plastic deformation in the weld centre due to the stirring process, in agreement with literature, Fig. 4c [13, 16]. The TMAZ is the region surrounding the nugget on either side where there is less heat generation compared to the weld centre and therefore, it may exhibit partial recrystallization [15]. Adjacent to the TMAZ is the HAZ, where the material progressively tends to re-

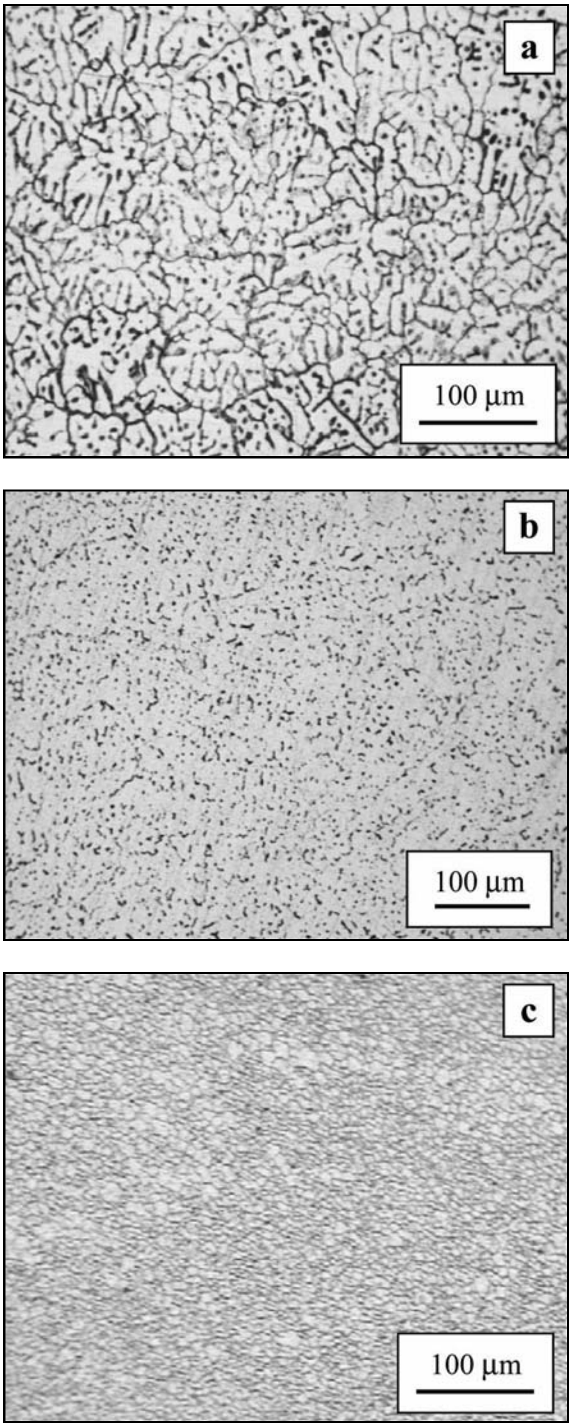


Fig. 4. Microstructure of weld centre: (a) TIG, (b) MIG, (c) FS welded specimen.

main unaffected, Fig. 3c [17]. The base metal microstructure of AA 7075 is shown in Fig. 3d.

The transverse macro sections of TIG and MIG welds are shown in Figs. 2b and 2c, respectively. In both TIG and MIG welds, grains show a tendency of having greater diameters in the HAZ and Weld Region (WR) compared to the base metal due to high heat input to the material and a dendritic structure is apparent in TIG welds. This trend is clearly observed in TIG welds, while in MIG welds a less clear growth is obtained, Figs. 3a and 3b. In the HAZ, the grains become less equiaxed and in the weld region there is a nonhomogeneous and unequiaxed grain distribution, Figs. 4a and 4b.

### 3.2. Microhardness

Microhardness measurements (HV) have been conducted throughout the BM and the weld region for MIG, TIG and FS welded AA 7075 aluminium alloy in order to determine the hardness profiles of different regions across the weld. The middle section (3 mm from the top surface) has been chosen for the hardness measurements. BM hardness values are around 155 HV. In friction stir welds, although hardness decrease has been observed at the HAZ region (about 120 HV), due to recrystallization in the nugget zone, the hardness recovers in this region and increases to about base metal levels. In TIG and MIG welds, hardness decrease has been observed both in HAZ and the weld centre due to softening and larger grain diameter compared to the BM. The lowest hardness measurement has been obtained at the weld centre of MIG welds as 100 HV. Figure 5 shows the microhardness distribution over the weld cross section of TIG, MIG and FS welded Al alloy 7075.

### 3.3. Tensile testing

The room temperature tensile properties of the BM, MIG, TIG, and FS welded alloys obtained from flat transverse tensile tests are given in Table 4. The given results are the average of minimum three tests. The transverse flat welded specimens all have failed from the joint sections. In FSW specimens, fracture of the specimen has occurred in the HAZ region, which is the weakest region in the weld area in terms of hardness. The fracture path has followed the weakest region where it can propagate easily. In MIG and TIG welded specimens, fracture has occurred in the weld centre. The highest joint efficiency in terms of ultimate tensile strength has been obtained in FSW as 69 %, for TIG welding it is 49 % and the lowest joint efficiency is obtained in MIG welding as 43 %. It is clear from this fact that the joint efficiency of FSW is higher compared to two other fusion welding methods. Table 4 also reveals that FSW joints are more ductile than TIG and MIG joints.

## 4. Conclusions

The following conclusions can be derived from this study:

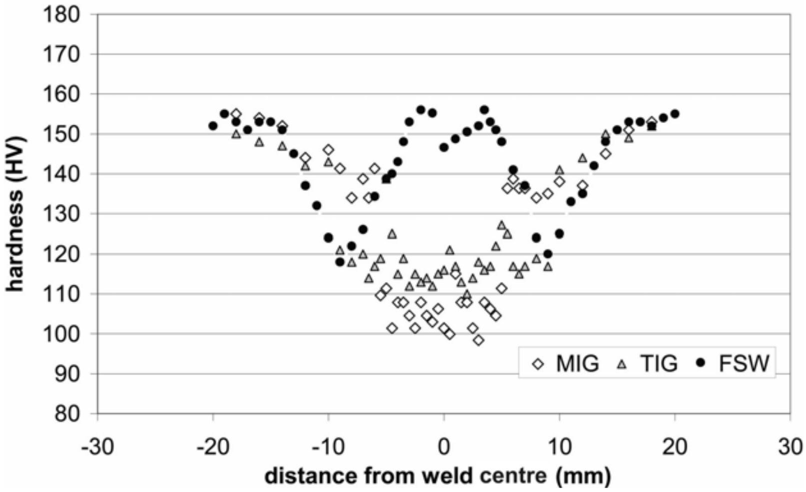


Fig. 5. Hardness profiles of weld cross section of TIG, MIG and FS welded AA 7075.

T a b l e 4. Mechanical properties of MIG, TIG and FS welded joints and base metal (BM)

| Joint | Yield strength $R_p0.2$ (MPa) | Ultimate tensile strength $R_m$ (MPa) | Total elongation (%) | Joint efficiency in terms of $R_m$ (%) |
|---|---|---|---|---|
| MIG | 160 | 207 | 1.4 | 43 |
| TIG | 175 | 233 | 1.6 | 49 |
| FSW | 240 | 330 | 2.54 | 69 |
| BM | 390 | 480 | 13.8 | – |

1. Three different welding methods, FSW, TIG and MIG have been successfully applied for the welding of Aluminium Alloy 7075 with no visible porosity and major distortions.

2. Microstructural examinations reveal that for FSW, the nugget zone exhibited a recrystallized fine equiaxed grain structure with grain sizes increasing moving from the weld region to the base metal, while in TIG and MIG welding grains show a tendency of having greater diameters in the HAZ and weld region compared to the base metal due to high heat input to the material.

3. Hardness distribution shows that in FS welds, HAZ is the lowest hardness region, whereas in TIG and MIG welds hardness values are seen to decrease both in HAZ and the weld centre.

4. Highest room temperature tensile properties are obtained in FS welds, with a joint efficiency of 69 %. MIG welding yields the lowest joint efficiency as 43 %. Further studies are planned in order to establish the effect of cooling during FSW and optimize welding parameters accordingly.

5. The overall results of this study reveal that FSW is the most suitable joining method compared to TIG and MIG welds, for the welding parameters utilized.

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