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Comparative Investigation of FSW and TIG Welded Joints of 7075-T6 Aluminum Alloy.

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ABSTRACT

The comparative microstructural and mechanical characteristics of fusion welds (Tungsten Inert Gas - TIG) and solid-state welds (Friction Stir Welding - FSW) of aluminum alloy 7075-T6 (AA7075-T6) are investigated in this paper. Microstructures of base metal and welded zones are analyzed by optical microscopy. The mechanical properties of welded joints are evaluated through hardness measurements and uniaxial tensile tests. The experimental results shown that the TIG welded joints are often cracked along the joins. The grain size grows in welded zone of TIG are dramatically coarser than that of FSW. Furthermore, comparison with the base metal, both the hardness and tensile strength in the welded TIG are reduced significantly in comparison with those in the FSW. Specifically, the tensile strength of the TIG and of the FSW welded joints is approximately 42% and 70% that of the base metal, respectively.

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Introduction:

AA 7075-T6 is one of the aluminum alloy commonly used in the aerospace industry due to lightweight and high strength. However, it is difficult to join by fusion welding as TIG welding. Therefore, the fabrication process is often used rivet joints to replace.

In order to overcome this drawback, in 1991, the Welding Institute of British (TWI) has introduced a new welding technology that is able to create the weld with high strength and applicable to all kinds of aluminum alloy, that is friction stir welding technology (Fig: 1) [11]. This is a welding process in the solid state, high strength, low residual stresses… [9]. In comparison with conventional fusion welding techniques as TIG, FSW has some advantages, such as no filler metal or cover gas, no smoke or dust. Additionally, FSW does not bring welding defects, such as hot cracks and porosity [5].

This paper compares the effect of a fusion welding technique (TIG) and a solid-state welding technique (FSW) on both microstructure and mechanical properties of AA7075-T6. In TIG welding, in order to form the joint, welding edge must have enough energy to the atoms of two surfaces can be moved and diffused into each other. The friction stir welding method, however, the state of the material in welding area is not the molten, in which is softer by heating friction due to welding tool. This field material will be stirred into each other by pin tool. The strength of welding will be investigated and discuss in this paper.

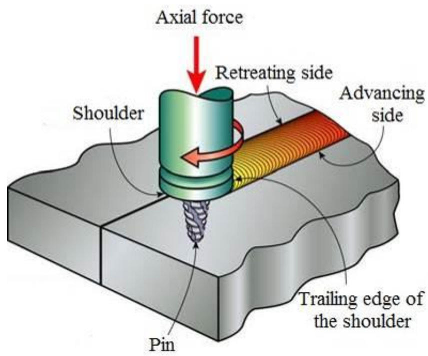

Fig. 1: Schematic diagram of friction stir welding

Experimental investigation:

Materials:

The chemical composition, and mechanical and thermal properties of the base metal (AA7075-T6) are presented in Table 1 and Table 2, respectively [1].

Table 1: Chemical composition (wt.%) of the base metal

Element	Al	Zn	Mg	Cu	Si
Base metal	87.1÷91.4	5.1÷6.1	2.11÷2.9	1.2÷2	Max 0.4
Element	**Fe**	**Mn**	**Ti**	**Cr**	
Base metal	Max 0.5	Max 0.3	Max 0.2	0.18÷0.28	

Table 2: Mechanical and thermal properties of the base metal

Material	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Hardness (Rockwell B)
Base metal	572	503	11	87
Material	Modulus of elasticity (GPa)	Poisson's ratio	Solidus (^oC)	Liquidus (^oC)
Base metal	71.7	0.33	477	635

Experimental Procedures:

The Friction stir welding AA7075-T6 aluminum alloys with size (300 mm length, 150 mm width, 5.0 mm thickness) (Fig. 2) were fabricated by friction stir welding machine at Nha Trang University (Fig. 3a). In this work, the tool is made of tool steel SKD 61 with hardness 45 HRC after heat treatment. The tool geometry was a scrolled shoulder tool and a truncated cone pin with a pin height of 4.8 mm, the pin diameter of 5.0 mm at the middle pin length, and a screw pitch of 1.0 mm (Fig. 4). The rotational speed ω and welding speed v are 600 rpm and 150 mm/min, respectively [4]. The pin was aligned at a tilt angle of 2.0 deg. in the plane describing the pin axis and the center weld line (the tilt angle is defined as the angle between the pin axis and the direction perpendicular to the workpieces).

Butt joints for TIG welding were fabricated by using filler material and argon as shielding gas (Fig. 3b). The other parameters were: welding current 150 amperes, voltage 18 volts, filler rod diameter 2.4 mm, welding speed 200 mm/min, gas flow 10 lit/min (Table 3).

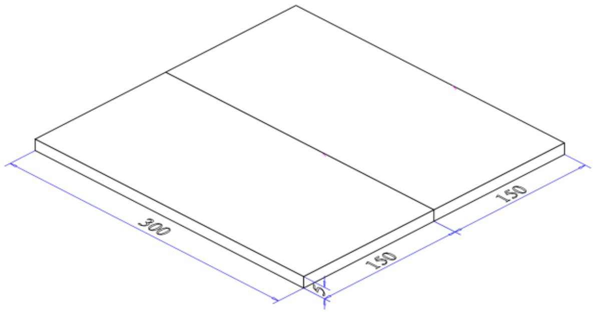

Fig. 2: Dimension of the aluminum alloy AA7075-T6

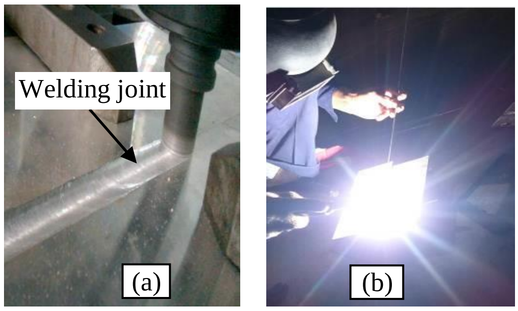

Fig. 3: Process of FSW (a) and TIG weld (b).

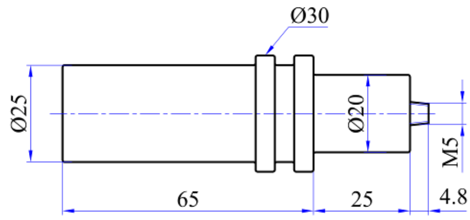

Fig. 4: Dimension of tool used in this study

Temperature measurements were made on the welded joint during the process by means of thermocouples placed at the end weld center and at the shoulder limit areas in retreating side (1.0 mm far from the shoulder limit line). Thermocouples were attached to a data acquisition system and data collection was accomplished with the system attached to a personal computer (Fig. 5).

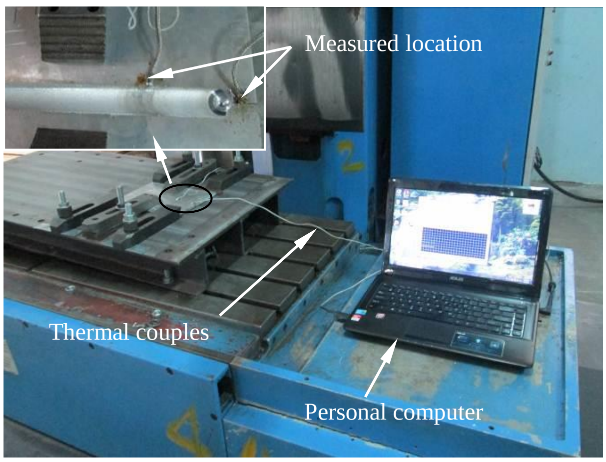

Fig. 5: Process of measuring temperature

Table 3: Welding conditions and process parameters

PROCESS	FSW	TIG
Welding machine	Friction stir welding machine	Miller Syncrowave 250
Rotational speed (rpm)	600.0	-----
Welding speed (mm/min)	150.0	200.0
Tool shoulder diameter (mm)	20.0	-----
Pin diameter (mm)	5.0	-----
Pin length (mm)	4.8	-----
Filler wire diameter (mm)	-----	2.4
Voltage (volts)	-----	18
Current (amps)	-----	150
Shielding gas	-----	Argon
Gas flow rate (lit./min)	-----	10

After welding, the samples were sectioned normal to the welding direction and then prepared by grinding disks, polished, and finally etched with a reagent: 150 mL H_2O, 3 mL HNO_3, 6 mL HCl, and 6 mL HF [6]. The microstructure was observed by Scanning Electron Microscope. The hardness in and around the welded zone was measured by a Rockwell machine with a ball indenter, 100 kg loading [2] (Fig. 6d). The tensile specimens were prepared according to ASTM E08 [10] by removing both the weld surface and the root surface layers of 1.5 mm thickness from the 5.0 mm FSW plate as shown in Fig. 7. The tensile tests were performed by an Instron machine 3366, 10 kN at a constant strain rate of 2.0 mm/min.

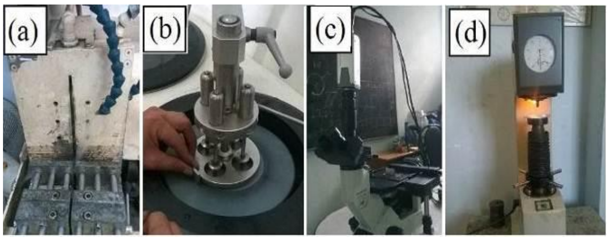

Fig. 6: Process of observing the microstructure and measuring hardness

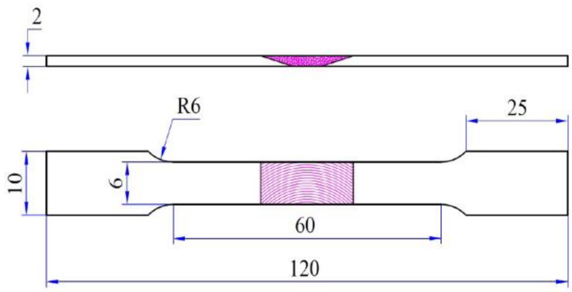

Fig. 7: Geometry of tensile specimen.

Experimental results and discussion:

Temperature distribution:

The temperature distribution within and around the stirred zone was important to analysis the microstructure of friction stir welded joints. It influences directly on grain size, grain boundary character, coarsening and dissolution of precipitates [3], [7], [8], [12]. The results of temperature distribution of friction stir welding measured at the retreating side and end weld center are shown in Fig. 8. The results show that the temperature distribution is always lower than the melting temperature. Therefore, during the welding process, material is always plastic state without being melted. The existence of residual stress and distortion due to soldering temperature will decrease. It is completely difference in comparison with the TIG welding that welding temperature is higher than melting temperature of the base materials.

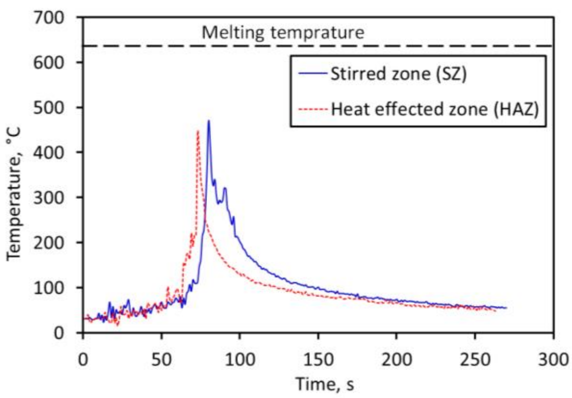

Fig. 8: The temperature distribution of friction stir welded joints

Surface and microstructure of welded joints:

Surface of FSW and TIG welding are presented in Fig. 9. Experimental results show that, the TIG welding is cracked along welded line. This result may be due to the shrinkage of the material during cooling. Additionally, the TIG welding surface is not smooth compared to that of FSW (Figure 9).

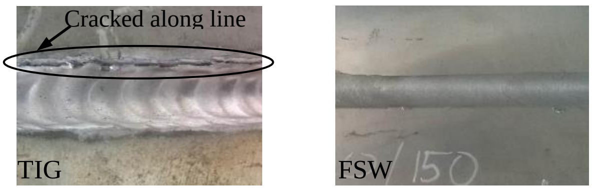

Fig. 9: Surface of FSW and TIG welding

Fig. 10 shows the microstructure of the weld center. Results showed that TIG welding have defects due to porosity. This reduces the mechanical properties of the weld. The friction stir welded joints are not defects (Fig. 11). The grain sizes of the two welds are also different. Particle size in the region of the TIG welding is about 25-40 μm, while that of the FSW is

10-15 μm. Therefore, it differently effect on the weld properties.

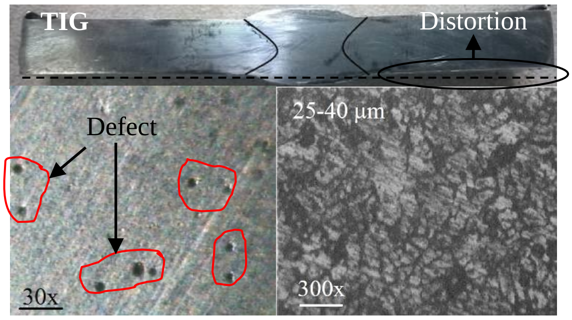

Fig. 10: Microstructure in the cross section of TIG welding

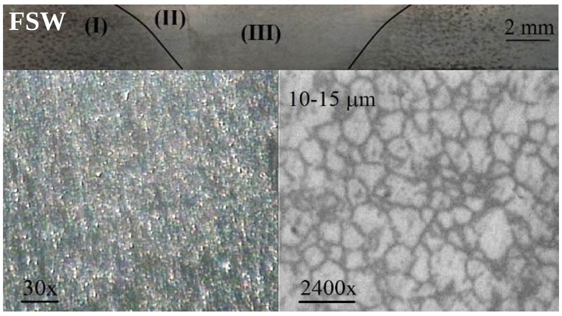

Fig. 11: Microstructure in the cross section of FSW

Hardness distributions:

The hardness distribution of both the weld is shown in Fig. 12. Hardness distributions were measured at mid thickness region across the weld. The results show that, the hardness of FSW is higher than that of TIG in all positions. Hardness in stirred zone of FSW is higher than that of heat affected zone, however, TIG welding is opposite. Heat affected zone of the TIG welding is wider than FSW. This can be caused by temperature in during process.

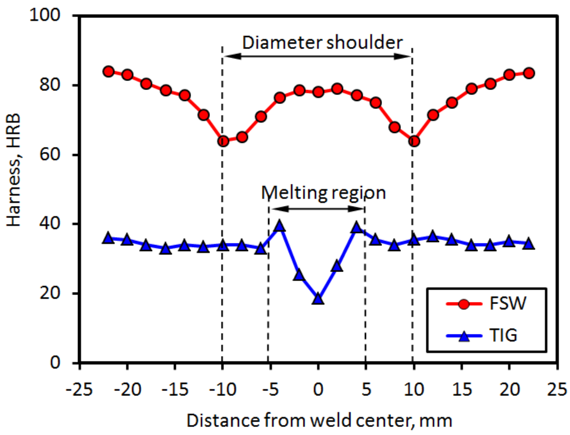

Fig. 12: Hardness distribution in the cross section of the TIG welding and FSW

Tensile strength:

Fig. 13 shows stress-strain curves of FSW and TIG welding compared to the base metal. The results showed that the strength and elongation of them are lower than that of base material. In addition, the strength and deformation of FSW is higher than that of TIG welding. This result is due to the grain size of FSW smaller than in comparison with TIG welding. The strength of FSW is approximately 70% compared to that of the base metal, while that of TIG welding is around 42%.

The fractured locations in TIG welding and FSW are presented in Fig. 14 and Fig. 15, respectively. The experimental results show that the specimens of TIG welding were fractured at the center zone where the defects is presented clearly in Fig. 10. And this location is the lowest hardness. On the other hand, the tensile failures of all FSW specimens took place at the HAZ in the advancing side or in the retreating side as seen in Fig. 15. It should be noted that all tensile failures occurred outside the stirred zone. The tensile fractured locations were well in agreement with the lowest hardness locations as seen in Fig. 12. This can be related to grain size in the welded zone.

The cross sections and the tensile fractured locations in FSWs are presented in Fig. 16. Slicing planes and sliding direction of the specimens that were destroyed inside and outside the welding zone were completely different. Sliding planes of TIG welding were always perpendicular to direction of axial force. This is demonstrated that the tensile failures were caused by only the normal stress mode [2]. Fig. 16 also shown that the FSWed tensile specimens were necking before fracturing this means that these specimens possess a higher ductility than those of the TIG welding.

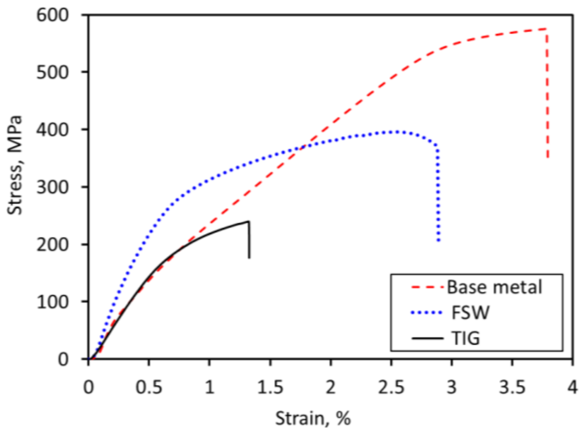

Fig. 13: Stress-strain curves of FSW and TIG welding

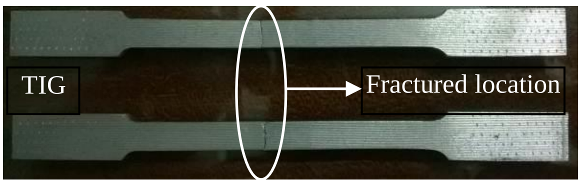

Fig. 14: Tensile fractured locations in the TIG welding

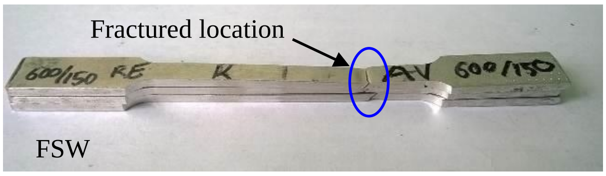

Fig. 15: Tensile fractured locations in the FSW

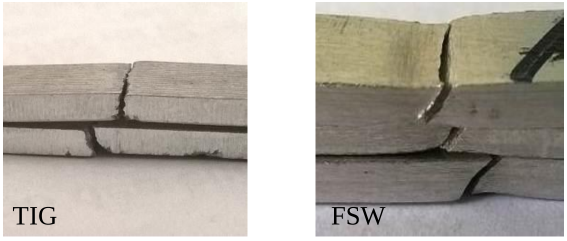

Fig.16: Cross sections and the tensile fractured locations in TIG welding and FSWs

Conclusions:

TIG welding and FSW has been fabricated and comparable quality through the microstructure and mechanical properties.

1. The temperature of the FSW is always lower than that of TIG welding as well as the melting temperature of the base material.
2. The microstructure of TIG welding are defects and grain size in the welding area is higher than that of the friction stir weld.
3. Hardness distribution of TIG welding is lower than the FSW.
4. Tensile strength of TIG welding is around 42% compared to the base material while FSW is 70%.

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