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MECHANICAL AND CORROSION BEHAVIOUR OF FRICTION STIR WELDED AA7075 T-651 ALUMINIUM ALLOY JOINTS

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ABSTRACT

High strength heat treatable aluminium alloy AA7075T-651 is widely used in aircraft, defence and automobile industries. However, the application of aluminium alloy in marine environment exhibits poor corrosion performance. High strength aluminum alloys are very difficult to weld in fusion technique due to poor solidification and microstructure in nugget zone. Friction Stir Welding is reliable technique to join aluminium alloys in solid state condition with sound weldability. In this work, rolled aluminium plate with thickness of 10 mm were square butt welded by Friction Stir Welding (FSW) process. The corrosion behavior and mechanical properties of FSW joints were investigated comparatively and in detail. The microstructure changes of substrate metal and weld nugget zone of FSW was studied using optical microscope. The mechanical behaviors such as fracture toughness, tensile strength and hardness test have been carried out in substrate and weld metal. Pitting corrosion resistant was determined by potentiodynamic polarization test. It was observed that, the mechanical properties and corrosion resistant of weld joint is lower than the base metal.

Key words: *Aluminium alloy, Friction stir welding, Fracture toughness and pitting corrosion.*

1. Introduction

The mechanical properties of high strength aluminium alloys are widely used in marine application, particularly in welded condition limits their application range. Much attention has been dedicated to the corrosion behavior of AA7075 alloy since this material is extensively used in aerospace, defence and military applications due to its good mechanical performance and low density [1]. During friction stir welding the material is subjected to plastic deformation in below the critical temperatures, due to the forging pressure and string action of tool material. FSW achieves solid state joining by local heat input and plastic deformation causes fine grain microstructure changes in aluminum alloy. The welding temperatures in friction stir welding of AA7075 alloys are below the melting point. The friction stir welded joint is divided into four zones: Base Metal (BM), Heat Affected Zone (HAZ), Thermo-Mechanically Affected Zone (TMAZ) and Nugget Zone (NZ). The welding temperature never exceeds 80% of the melting point temperature of the base alloy [2-4].

FSW process performed fine grain refinement in the nugget zone due to which, the tensile strength of the joint increases with loss of ductility [5]. The nugget zone is affected by the peak temperature that can reach 495°C [6] and the highest plastic deformation. Friction stir welded microstructure usually consists of fine equiaxed grains due to the full active recrystallisation. The microstructural changes induced by the plastic deformation and the frictional heat. The FSW processes were studied by several authors. It was shown that there was a relationship between microstructure and micro hardness in each FSW zone. Micro hardness changes along the FSW joint are unswervingly linked with the precipitated components [7-9]. In some research works it is reported that the FS weld nugget region is more susceptible to localized corrosion than the base material region [10–16]. Among these works, only few authors exhibited a variation of electrochemical surface reactivity between the various zones of a FSW. The present investigation was undertaken to determine the fracture toughness, tensile strength, micro hardness and corrosion behavior of friction stir welds of AA7075T-651.

2. EXPERIMENTAL DETAILS

2.1 Material

Plates of AA7075-T651having a thickness of 10mm was used as the base material for friction stir welding process. The welding process parameters are

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given in Table1. The dimensions of rolled AA7075T-651 plate are 150 mm×150×10 mm. The chemical composition of base metal is given in Table2. The test samples for fracture toughness, tensile test, micro hardness and corrosion study were extracted from the welded plates.

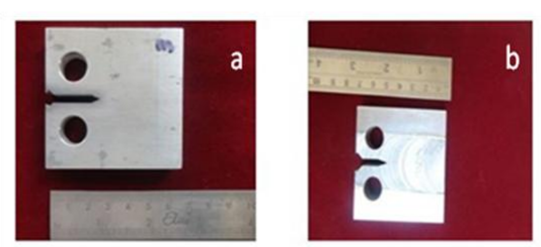
Table 1. FSW process parameters

Process parameters	Tool rotational speed (rpm)	Axial load in kN	Welding speed in mm
Range	750	12	30

Table2. Chemical composition (wt %) AA7075 T651 aluminium alloy

Material	Mg	Mn	Si	Cu	Zn	Fe	Al
AA7075-T651	2.1	0.1	0.5	1.2	5.2	0.3	Bal

Image analyzer has been performed on the parent and friction stir welded samples as per ASTM–E8-03 standard. The macro and microstructures were observed with optical microscope. The fracture toughness tests were conducted as per ASTME399 guide line on the parent metal and FSW joints. The micro hardness of the sample is tested by using Vickers hardness tester 0.5kgf of applied load and 15 seconds of dwelling time. As per the ASTM standard the grain structure and precipitates are studied by using Scanning Electron Microscope .Figure 1 shows the fracture toughness test samples of parent metal and weld joint.



Base metal **Weld metal**

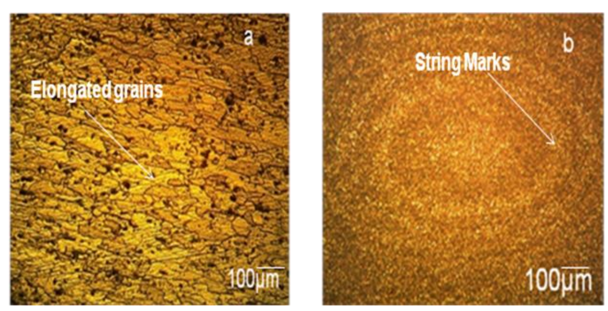
Fig.1 Fracture toughness test samples

Computer based polarization test were performed on the substrate and friction stir welded samples in order to study on pitting corrosion behavior of the alloy. Platinum and a saturated calomel electrode were used as auxiliary and reference electrodes, respectively. Pitting corrosion test were conducted in 3.5% wt NaCl solution. The potential scan rate was carried out at 0.156 Mv/s with the initial potential of -0.25 to 0.5V (OC) SCE. The exposure area of this test was conducted in 10 mm^2. The potentio dynamic tests have been tested as per the ASTM-G34. In Tafel plot at when current increased severely was consider a pitting potential, Epit. The optical microscope was used to analyze the corrosion morphology of corroded samples.

3. RESULT AND DISCUSSIONS

3.1 Microstructure

Figure 2 shows the optical micrograph of parent material and FSW nugget zone is represented. The welded microstructure reveals significantly smaller than the parent material grain structure, due to the influence of plastic deformation by FSW. The fine and equiaxed grain structure were formed in weld nugget zone. It was developed by forging action and frictional temperature of FSW process.



Base metal **Weld metal**

Fig.2 optical micrograph of base metal and weld metal

The metallographic cross sectional of base metal structure confirmed the coarsening grain size along the rolling direction. The weld nugget zone has been appeared like a string marks, commonly it is denoted as onion ring. Several researchers investigated the micro structure resulting from FSW on 7075 aluminum alloy [16], and it indicated a fine equiaxed grain structure in weld nugget on the order of 3-11microns.

3.2 Tensile and Fracture toughness Test

The transverse tensile properties such as yield strength, tensile strength, notch tensile strength, of friction sir welded AA7075 aluminium alloy joints are presented in Table 3. In each condition, three specimens were tested and the averages of three tensile tests were recorded. The mechanical properties of FSW joints depends on grain structure which in turns depends on the welding parameter such as tool rotation speed, weld ding speed and axial load.

Table 3. Tensile properties of Parent and FSW joints

Material	0.2% YS (MPa)	TS (MPa)	EL %	NTS (MPa)	FT MPa$\sqrt{m}$
AA7075 - T651	485	589	11	600	30
FSW	330	389	9	410	23

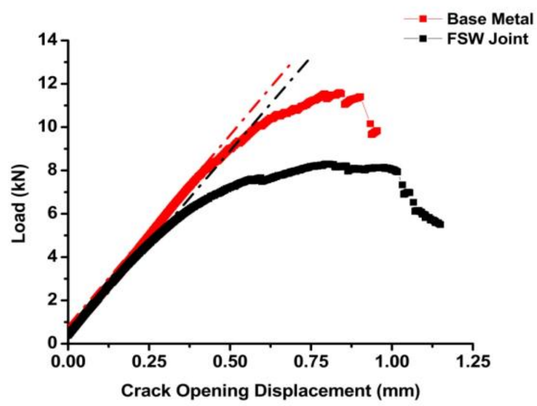
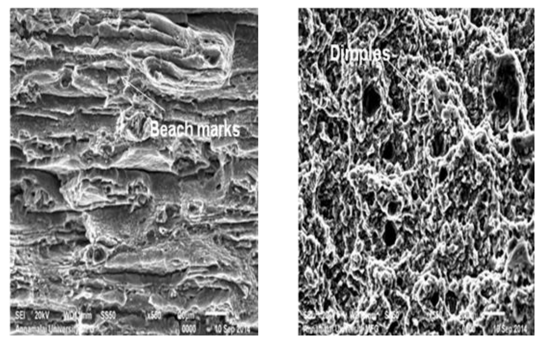


Fig. 4 Load vs crack opening displacement

The weld joint strength is lower than the base material tensile strength. The ultimate tensile strength of the material is based on ductile properties. From the result the notch tensile property exhibits superior to smooth tensile specimen. The fracture test was carried out in instron fatigue machine. The CT specimen was prepared as per ASTM E399 standard. The fracture toughness of parent and weld metal are prescribed in Table4. The FSW joint fracture toughness is increased when compared with other conventional welding process. Figure4 shows the relationship between crack opening displacement and applied load of parent metal and FSW.

3.3 Fractography analysis

The fractured tensile samples are shown in Figure5. The Scanning Electron Microscope (SEM) analysis was performed on the smooth tensile specimen of parent metal and FSW AA7075T-651 aluminium alloy joints. The SEM fractured micrograph shows elongated and beach mark grain structures were observed. In FSW joint, more dimple type fracture is confirmed. From the tensile properties evaluation, it is seen that friction stir welded samples produce lower elongation compared to the base materials. In both welded and base metal, fracture occurred in ductile mode. Additionally, SEM images confirms intergranular and transgranular fracture occurs in parent metal and welded samples. The intergranular fracture is caused by intermetallic component such as MgZn2 and Al2Cu in high strength aluminium alloy.



Parent Metal FSW

Fig. 5 Fracture surface of Parent and FSW joints

3.4 Pitting Corrosion

Fig. 6 shows the potentio dynamic polarization curve of parent metal and friction stir welded aluminium alloy joint. Table4 compared the corrosion rate of AA7075T-651alloy and FSW joint. It is inferred that, the base metal has a low corrosion potential of -0.734mV.cm^2. From the Figure 6 and Table 4, the corrosion resistance of FSW joint is less than the base metal. The friction stir Welding process produced fine grain structure and more grain boundaries, which are thermodynamically susceptible to corrosion. Due to this factor weld joint has poor corrosion resistance than parent metal. The FSW corrosion potential of second phase precipitates such as $MgZn_2$ and Al_2Cu not the same as the parent alloy.

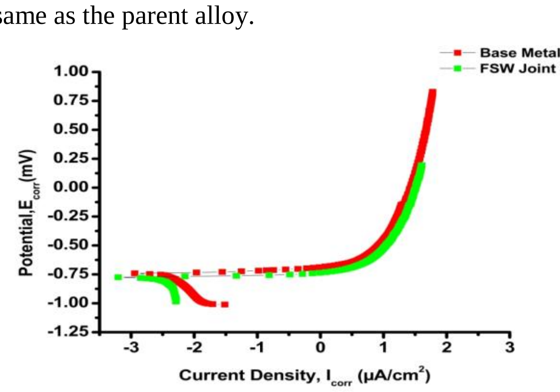
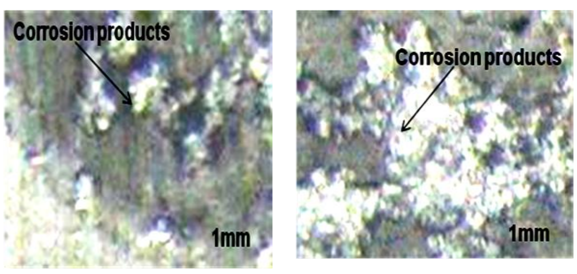


Fig. 6 Potentiodynamic polarization curve of Base Metal and Weld Metal

Table 4. Potentio dynamic results of parent and FSW joints

Material	Ecorr mV (vs.SCE)	I corr $\mu A/cm^2$	Corrosion rate mm/year
AA7075 T-651	-734	3.37	4.31
FSW	-789	3.97	5.01

This change creates the formation a galvanic cell. The η^1 phase normally attributes in grain boundaries. The second phase precipitates ($MgZn_2$) are having higher potential difference between matrix alloying elements, which causes more corrosion in Grain boundary region.



Parent metal FSW

Fig. 7 After corroded Samples

The more quantity of second phase precipitates act as a anodic dissolution. Figure7 compare the surface appearance of corroded AA7075T-651 alloy and FSW joint. The macro sample reveals more pits and corrosion products were formed in friction Stir Welded specimen. it is confirmed that more grain boundaries lead to increasing the corrosion rate

4. CONCLUSION

1. The microstructure in FSW has the relatively fine and equiaxed grains compared with parent metal.
2. The micro hardness of weld nugget is reduced due to the dissolution of stable precipitates. The notch tensile strength is higher, when compared with the strength of smooth tensile specimen. The fracture toughness of FSW joint is 23 MPa$\sqrt{m}$, it was achieved 78% of parent metal strength.
3. The FSW process produced more fine grains which in turns leads to more grain boundaries. As a result, pitting corrosion resistance becomes lower in welded sample than parent material.

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