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Micro Structural and Mechanical Behaviours of Nano-TiC-Reinforced AA6082 FSW Joints

Mohd Rashid[1], N. Yuvraj[2], Shailesh Kumar Singh[3]

[1]*Production Engineering, Delhi Technological University, New Delhi, 110042, India*
[2]*Department of Mechanical Engineering, Delhi Technological University, New Delhi, 110042, India*
[3]*Production Engineering, Delhi Technological University, New Delhi, 110042, India*
[1]*rashid.khan04@gmail.com*

Abstract: *Friction Stir Welding (FSW) is a solid state welding process for joining materials. In this process a high speed tool is introduced into the weld seam and due to localized frictional heat, plastic deformation and transverse movement along the weld seam, joining is accomplished. This welding technique is energy efficient, environment friendly, and versatile. In particular, it can be used to join high-strength aluminium alloys and other metallic alloys that are hard to weld by conventional fusion welding. The present work focuses on FSW of 6082 AA-T651 aluminium (Al) alloy which have gained wide acceptance in the fabrication of light weight structures requiring higher strength, and excellent corrosion resistance.FSW of AA6082 was done with and without reinforcement of nano sized titanium carbide (TiC) particles of size 10-30nm. The effect of processing parameters and reinforcement on the mechanical and microstructural properties of 6082 AA-T651 joints was analysed in this study. Welded specimens were produced by employing different combinations of welding speeds and tool rotational speeds. Tensile test, microstructure, micro hardness and EDX (Energy dispersive X-ray spectroscopy) analysis has been performed to evaluate the weld zone molecular characteristics and strength of friction stir welded alloy. Result shows that welding process reduces the strength and hardness of material which can be partially regain by reinforcement of TiCnanoparticles during welding process. Scanning electron microscope (SEM) equipped with (EDX) was used to analyse the chemical compositions of the alloy and titanium carbide particles of the weld nugget zone (NZ), it indicates that TiC is uniformly distributed in NZ.*

Keywords: *FSW, SEM, EDX*

1. INTRODUCTION

Aluminium matrix composites (AMCs) have enhanced properties as compared to their base material. However, their use are limited because they encountered difficulties during machining, forming, and when joined by traditional fusion welding processes [1].Recently particulate reinforced aluminium matrix composites have become a major focus of attention in aerospace, motor sport and automotive industries due to their several attractive advantages over conventional base alloys, such as high specific stiffness and strength to weight ratio at room or elevated temperatures, excellent fatigue properties, high formability and improved wear resistance [2, 3]. However, one of the main limitations for the particulate reinforced aluminium matrix composites is the difficulty in using conventional fusion welding methods because of the porosity, hot cracking, segregation and deleterious reactions between the reinforcement particles and liquid aluminium in the fusion zone [4, 5]. Friction stir welding is a promising candidate for joining particulate reinforced aluminium matrix composites since this method is a solid state process, therefore, the formation of brittle solidification products are not easily produced, the energy input and distortion are significantly lower than fusion welding techniques, thus improving the welding properties. Most of the previous studies on the joining of particulate reinforced aluminium matrix composites have dealt with gas shielded metal arc welding [6], laser welding, gas tungsten arc welding [4], electron beam welding [4] and friction welding but now friction stir welding is widely used for making joint of aluminium matrix composites [7-10].

Friction stir welding (FSW) is a relatively new solid-state joining technique which eliminated most of the problems that are encountered during conventional fusion arc welding. Low distortion, low energy consumption, high quality joints, better fatigue property, lower residual stresses, fewer weld defects, no harmful emission, high level of dimensional stability, repeatability and low production cost makes FSW an important solid-state joining process. It has expanded rapidly since it was invented at, The Welding Institute (TWI) of UK in 1991 [11].The basic concept of FSW is very simple**.** A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates to be joined and traversed along the line of joint. The two primary functions of tools are heating of work piece and Stirring/ intermixing of material to produce the joint.

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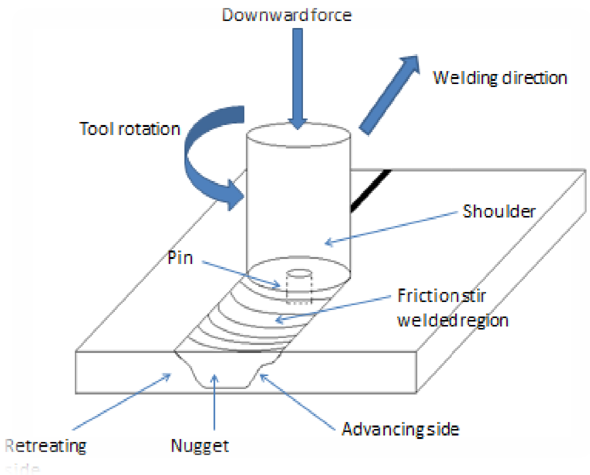

Fig. 1. Schematic diagram of FSW

The heating is accomplished by friction between the tool and the work piece. During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in the generation of fine and equiaxed recrystallized grains [12]. Since the amount of heat supplied is smaller than fusion welding, heat distortions and residual stresses are reduced [13].

The 6xxx-group of Aluminum Alloys (AA) contains magnesium and silicon as the major alloying elements. Al–Mg–Si alloys have recently been used for automotive body sheet panel for weight saving [12]. In spite of the importance of 6xxx series AA to various industries a limited number of research work have been devoted to FSW of this series. Koumoulosa et al. [14] studied the FSW of AA6082-T6 and find that welding process softens the material, since the weld nugget is the region where the most deformations are recorded. Scialpi et al. [15] suggested that Tool with cavity and fillet can be considered the best tool for FSW of 6082-T6. Cavaliere et al. [16] find that AA6082 friction stir welded with the advancing speed of 115mm/min exhibited the best fatigue properties and the higher fatigue limit. H.J.liu et al. [17] reported that the tensile strength of FS Welded 6061-T6 aluminum alloy defect free joint increases with the welding speed and maximum tensile strength is equivalent to the 69% of that of base material. Many studies that have focused on the FSW of 6xxx AA series alloys were devoted for the 6061 and 6063 alloys, but limited attention was given to particularly the 6082 alloy. AA6082 has very good weldability but strength is lowered in the weld zone. Applications of AA6082 are typically used in highly stressed applications, Trusses, Bridges, Cranes, Transport applications, Beer barrels etc.

The present work focuses on the application of different welding parameters (rotational speed; rpm, feed rate; mm/min) on friction stir welding of AA 6082 plates in T651 condition and evaluating the mechanical properties and microstructural characteristics of the welded condition as well as after reinforcing with Titanium carbide (TiC) nano-particles

2. EXPERIMENTAL PROCEDURE

A commercial 6082-T651 AA plate which is solution heat treated, stress relieved by stretching then artificially aged is used as specimen for FSW.

The chemical composition of AA6082-T651.

TABLE 1.

Element	Si	Mg	Mn	Fe	Cr	Zn	Ti	Cu	Other	Al
Wt.%	1.2	.75	.79	.40	.15	.10	.07	.06	.10	Balance

Plate of 6 mm thickness, 80 mm width and 200 mm length was prepared by machining through milling. Subsequently, a 0.6 mm wide, 5 mm deep and adequately long profile was created on the faying surface of each plate. When two plates were fixed under a purpose-built fixture, asymmetrical bottom-closed groove was made lengthwise as shown in figure 2. Next, the TiC nano particles were added into the groove and pressed tightly. Using square shape pin as shown in figure 3, FSW was carried out with and without TiC nano particles.

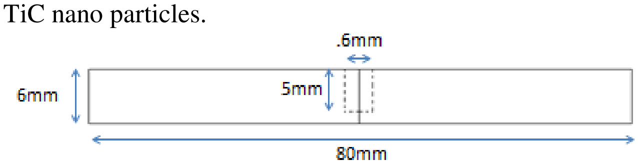

Fig. 2. Cross section of plate to be welded

Tool was fabricated from H13 hot working steel and heat treated to 58HRC (Hardness, Rockwell C-scale). This tool had a 5.7 mm long pin. The diagonal of square pin was 6 mm, Shoulder diameter of tool is18 mm.

Fig. 3. Square shape pin tool

All the joints were produced with the following optimized welding speed and tool rotational speed.

TABLE 2.

	Specimen with reinforcement				Specimen without reinforcement	
	R_1	R_2	R_3	R_4	B_1	B_2
Tool rotational speed (rpm)	1200	1200	1000	1000	1200	1000
Welding speed (mm/min)	90	60	90	60	90	60

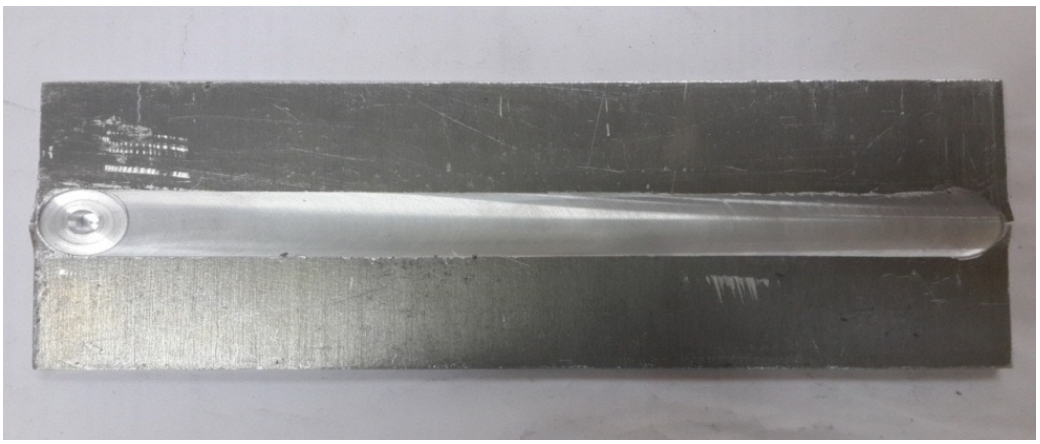

Fig. 4. Friction Stir welded AA6082 plate

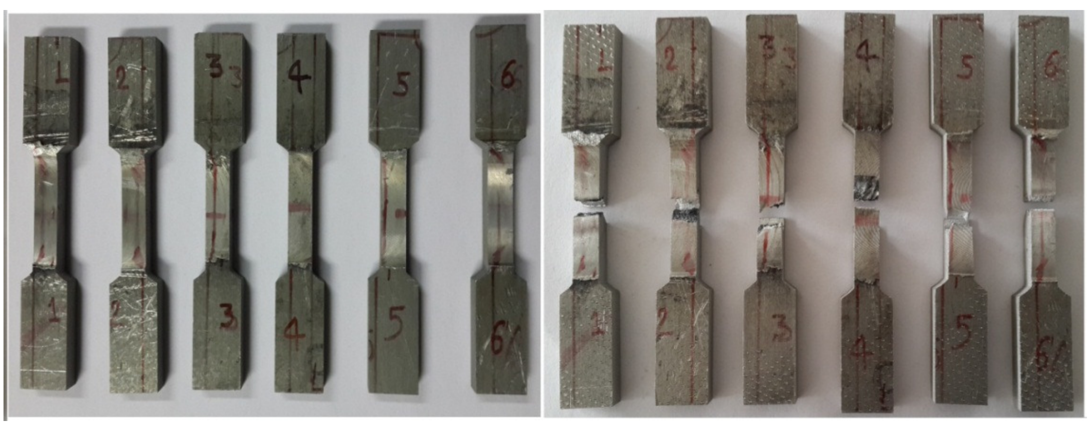

Fig. 5. Tensile test specimen before and after the test

Uniaxial tensile tests at room temperature were performed in order to evaluate the mechanical properties of the joints. To determine the tensile strength of the stir zone, small tensile test specimens were sectioned in transverse direction of the weld line with an electrical discharge machine (EDM). Specimen is cut as per ASTM:B557-06 standard. Tensile test is performed at a speed of 1mm/min.

Vickers hardness of friction stir welded AA6082 samples were measured using Vickers hardness tester. The test load applied was 200 gf and the dwell time was 5 seconds. All samples were taken from the transverse section of the welded area at the middle of the sheet thickness.Optical microscope was used to investigate the microstructure of a material.The sample preparation for the microscopic investigation includes grinding, dry and wet polishing with Al_2O_3 nano powder. After polishing Keller's etchant is applied on surface to reveal the grain boundary and micro structure of welded zone. It gives the clear view of different microstructural zone like stir zone (SZ), heat affected zone (HAZ), thermo mechanical affected zone (TMAZ). It also revealed the distribution of TiCnanoparticle in stir zone.Scanning electron microscopy (SEM) is used to investigate the microstructural modifications induced by the FSW process on the aluminium alloy matrix and reinforcement particles.The chemical compositions of the aluminium alloy matrix and titanium carbide particles of the weld nugget were analysed by a scanning electron microscope equipped with an energy dispersive X-ray spectroscopy (EDX) analysis system. The specimens were polished using conventional polishing methods and etched before analysis.

3. RESULTS AND DISCUSSION

Study on FSW of 6082-T6 with processing parameters ranging from 1000 to1200 rpm and 60 and 90 mm/min is conducted. Tensile test result shows that, tensile strength of Friction stir joint decreases with respect to the base material strength (302 MPa). Ehab A. El-Danaf et al [12] also reported this phenomenon of, softening in the stir zone(SZ) and thermo mechanical affected zone (TMAZ) in Friction stir welding of AA 6082 - T651. To avoid the softening of stir zone or reduction of tensile strength TiCnanoparticles is added during Friction stir welding. Tensile test results clearly shows that inclusion of TiCpartical partially amended the strength loss that occurred with FSW.Tensile strength of different F S Welded specimen is given in figure 6.

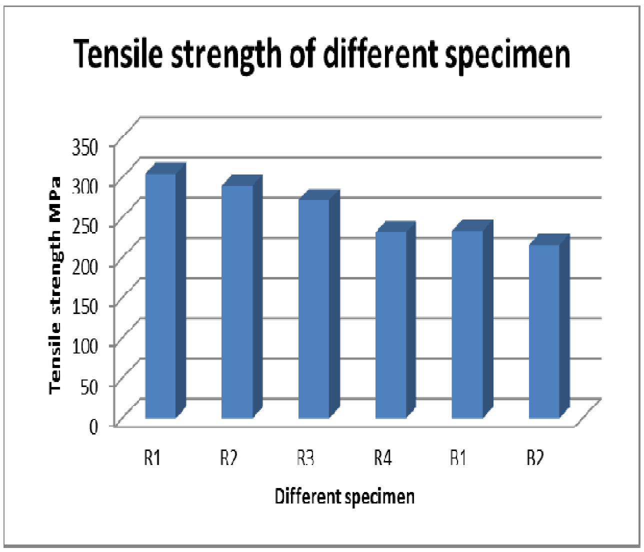

Fig. 6. Tensile strength of different specimen

Micro-hardness values of friction stir welded AA 6082 alloy and FS welded AA6082 with Tic nano particles at 1200 rpm, 90 mm/min is shown in figure 7. Joint obtained at optimized parameters shows that softening occurs in the stir zone (SZ) and thermo mechanical affected zone (TMAZ) compared to the unaffected base. The softening with respect to the base metal is due to the decomposition of needle-shaped β" precipitates which is the main source of hardening and strengthening, the coarsening of precipitates into semi- and non-coherent rod-shaped β' precipitates (over-aged precipitate structure) and the low dislocation density associated with the dynamically recrystallized structure [18]. TiCnano particles are induced during welding to increase the strength and hardness of joint. The microstructural changes induced by the reinforcement of TiC particles are responsible forthe improvement in mechanical properties.

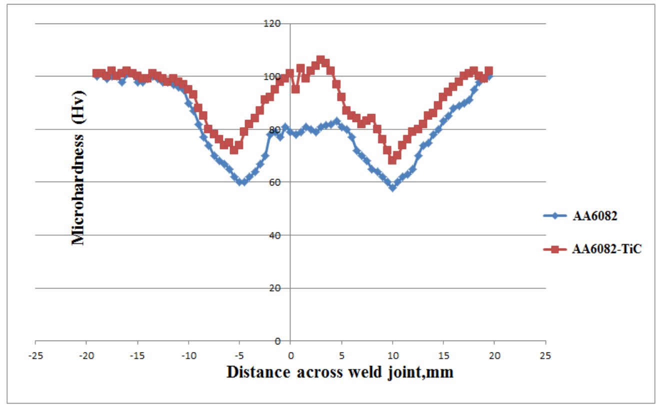

Fig.7. Micro hardness value of different specimen

Optical micrographs in Figure 8 show the typical zones of the weld nugget or stirred zone (SZ), the transitional zone (TZ) and the base material (BM). The transitional zones in FSW unreinforced aluminium alloys generally consisted of the thermo-mechanical affected zone (TMAZ) and heat-affected zone (HAZ), but probably due to the well-known lower sensitivity to thermal variations of ceramic reinforced composites, it was difficult to identify the HAZ, as also reported by Amirizad et al. [19]. The welded zone was mainly identified by a different size of the reinforcement particles and the aluminium alloy matrix with respect to the base material.

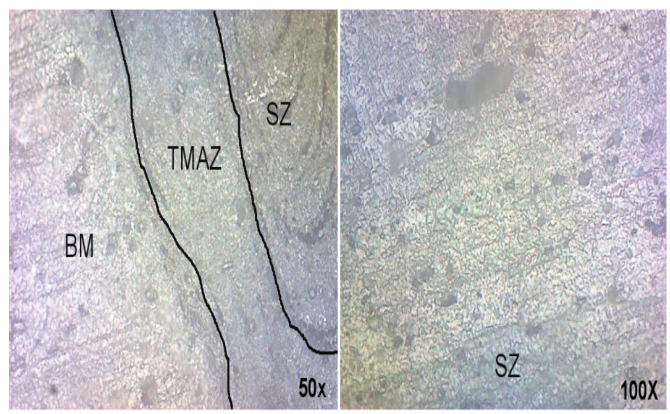

Fig. 8. Micro structure of FSW AA 6082 -TiC alloy

The SEM micrographs of the friction stir welded specimen are shown in Figure 9. The distribution of TiC particles is fairly homogeneous in the stir zone. The light regions in the macrostructure (Figure 9) exhibit bands of TiC particles. The grains are not clearly visible in Figure 9 because they are ultrafine in nature.The grain modification can be attributed to the presence of TiC particles in the joint because TiC particle acted as an effective grain refiner. The stirring action of the tool and the intense plastic strain were known to break the ceramic particles.TiC particles retained the original size and morphology which can be attributed to their initial smaller size. This result agrees with the findings of Chen et al. [20] who did not observe fragmentation of

B_4C particles in FSWof AA6063/ B4C AMC due to its smaller size.

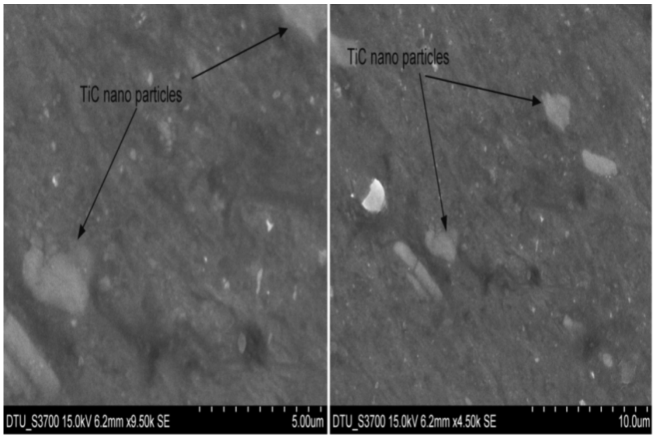

Fig. 9. SEM micro graph of FSW AA66082-TiC joint

The chemical compositions of the matrix and titanium carbide particles of the weld nugget were analysed by a scanning electron microscope equipped with an energy dispersive X-ray spectroscopy (EDX) analysis system. This analysis indicates that distribution of TiC particles is uniform in weld nugget zone.

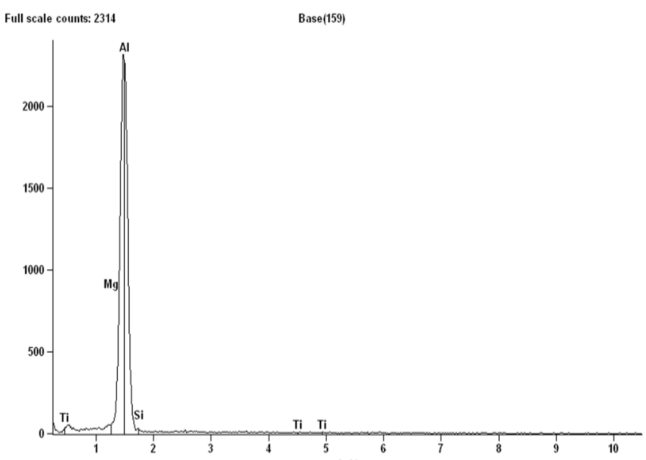

Fig. 10. EDX analysis graph

4. CONCLUSIONS

An AA6082–T651 alloy was friction stir welded, using different welding parameters, and the effects of this process on microstructure, tensile and micro-hardness were investigated.

1. Rotational speed is the factor that has greater influence on tensile strength, followed by welding speed and Shoulder diameter to pin diameter ratio.
2. Tensile strength at optimum condition were lower in small quantity as compare to the parent material due to presence of reinforcement particles which make the metal matrix brittle.
3. Micro hardness at optimum condition was higher in small quantity as compare to the parent material due to grain refinement.
4. Welding of AA6082 results in softening in the SZ and TMAZ being more significant. This negative effect on the welded joints strength and hardness can be partially recovered by inclusion of TiCnano particles during welding.
5. Microstructural and SEM analysis clearly indicate that distribution of TiCnano particles is homogenous in Stir zone (SZ).

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