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# ROLE OF TOOL SHOULDER DIAMETER IN FRICTION STIR WELDING OF NANO-TIC REINFORCED AL6082 ALLOY

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**Abstract-***Friction Stir Welding (FSW) Technique is used for welding of aluminium based metal matrix composites successfully. In the present work, Titanium Carbide (TiC) nano powder inserted Al6082 plates were joined by FSW method. The paper focuses on tensile strength of welded composite plates by using three different tool shoulder diameters (15mm, 18mm & 21 mm). The tensile strength of aluminium composite specimen welded with 18mm shoulder diameter tool exhibited higher than that of the other composite samples and base alloy. Scanning electron microscope (SEM) equipped with (EDX) was used to analyse the uniform distribution of titanium carbide particles in the weld nugget zone.*

***Keywords****-FSW; Metal Matrix Composite; TiC; Tensile; Hardness*

## I. Introduction

Aluminium based metal matrix composites are replacing with Aluminium alloys due to their excellent mechanical, corrosive and wear properties [1-2]. Recently particle reinforced aluminium matrix composites have become more attention in automobile, defence, structural and marine applications due to their several advantages over conventional Aluminium alloys, such as high specific stiffness, lower weight, excellent fatigue properties, high formability and improved wear resistance [3-4]. However, the usage of Aluminium based composites is limited in such applications due to their difficulties in joining by traditional fusion welding process. Most of the previous studies on the joining of particulate reinforced aluminium matrix composites have dealt with gas shielded metal arc welding, laser welding, gas tungsten arc welding, electron beam welding and friction welding. By this welding techniques it is difficult to maintain the interfacial reaction between matrix and reinforcement particles. As a result of welding defects such as porosity, hot cracking & segregation occurs in the fusion zone [5-7]. Friction stir welding is a solid-state welding process. In this process the brittle solid formation is not easily formed due to their lower heat generation and less energy input than conventional fusion welding process [8].

Recent studies have shown that various reinforcements such as SiC, $B_4C$, TiC, $Y_2O_3$, $Al_2O_3$, $ZrB_2$, $TiB_2$ were used in fabricating of the Al matrix composite through FSW technique. [9]. In this technique a hardened non-consumable rotating tool with shoulder and a specially designed pin is inserted into the abutting edges of sheets or plates. The tool is traversed along the line of joint and the tool shoulder gives sufficient friction to the work piece. The tool shoulder and pin provide adequate heating and intermixing of the material to produce the joint [10]. Scialpi et al. [11] have found that the tool with cavity and fillet produced sound weld joint of 6082-T6 alloy. H.J.liu et al. [12] reported that the increase in welding speed increases the tensile strength of friction stir welded 6061-T6 aluminium alloy. Recently Masoumeh et al. [13] have successfully fabricated the lap joint of dissimilar metals i.e. St37 steel and Al 1100 by friction stir welding. The maximum shear tensile load (1925N) strength was achieved at lower traverse speed (50 mm/min) and higher rotational speed (400 rpm). Fe-rich inter metallic compounds upto 93 μm thick layers were formed in joint interfaces.

Ke Zhao et al. [14] fabricated FSW of Al2009/3%Vol. CNT alloy at tool rotational speed of 800 rpm and traverse speed of 100mm/min. The 87% welded joint efficiency was successfully achieved due to the CNT distribution in the nugget zone. CNT act as load transfer mechanism and the joint efficiency was larger than HAZ. Mohsen et al. [15] inserted nano SiC particles in the Al 7075 alloy and welded with FSW technique. The ultimate tensile strength and elongation of the welded composite sample were improved 7.2% and 137.7% respectively. C. Minak et al. [16] investigated the effect on tensile and fatigue properties of different FSW process parameters on cast Al6061/$Al_2O_2$ composite. Recently Y.Z Li et al. [17] have investigated the effect of different weight fractions of $B_4C$ particles in the Al6061composite on the mechanical properties of FSW of Al6061/$B_4C$ alloy. With increase in reinforcement particle the hardness of the welded nugget has been increased. Most of the previous studies have been focused on ex situ FSW of Aluminium composites only, very little work has been carried out on in situ FSW of Al alloys. Titanium carbide having excellent properties such as high elastic modulus, good wettability and act as a grain refiner [18]. This paper focuses on FSW of in situ Al6082/TiC composites and studied the effect of different tool shoulder diameter on the weld strength properties.

 

## II. EXPERIMENTAL PROCEDURE

A commercial Al6082-T6 alloy of 6 mm thickness, 80mm width and 200 mm length was used. The chemical composition (%) of the base metal is 1.2Si, 0.78Mn, 0.75Mn, 0.4Fe, 0.15Cr and rest Al. The nano sized TiC particles size of 30-60nm average and purity of 99.9% were used as reinforcements. The SEM micrograph of TiC nano particles is depicted in Figure 1. In the plates the 0.3mm width and 5mm depth groove has been in the faying surface of each plate. The cross-section dimensions of the plate to be weld specimen is presented in Figure. 2. The specimens were fixed in the welding fixture and grooves were filled with TiC particles. Prior to filling of ceramic particles, the grooves were cleaned with acetone. The reinforcement particles were mixed with acetone and filled inside the groove in the form of the slurry.

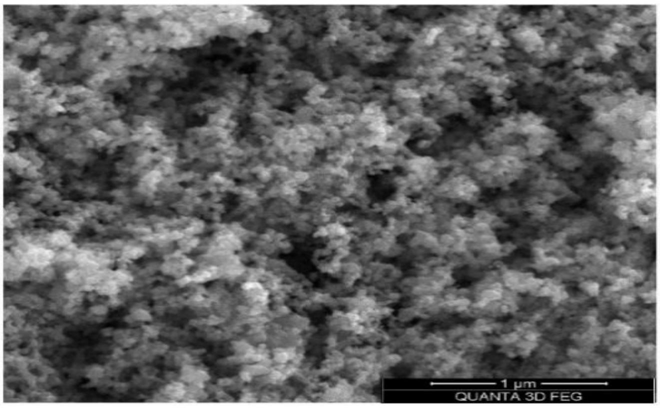


**Figure. 1 SEM micrograph of TiC particles**

FSP Tool was made of hardened H13 steel. Three FSW tools with three different shoulder diameters i.e. 15, 18 and 21mm were used in FSW. The tool pin had a length of 5.7mm and diagonal length of 6mm. The fabricated tools are shown in Figure. 3. The rotational speed and traverse speed were fixed at 1000 rpm and 25 mm/min respectively after number of trials. FSW experiments were performed by 11kW, 40KN capacity friction stir welding machine equipped with hydraulic fixture. The experimental setup is shown in Figure. 4. After the welding the tensile test specimens were extracted from the welded joint in transverse direction by wire EDM. The test specimens were prepared as per ASTM standards. The tensile tests were performed by using Tensile testing machine (Tinius Olsen H50KS) at a speed of 1mm/min in room temperature. The micro hardness test specimens were extracted from the nugget zone and measured at the cross section of the weld zone. Hardness testing (Leica VM HT auto) was carried out on Microhardness tester with test load of 100 gm and dwell time of 10 sec. Micro structural characterization was observed on Scanning Electron Microscope (SEM) (Hitachi S3700) attached with an energy dispersive X-ray spectroscopy (EDX).

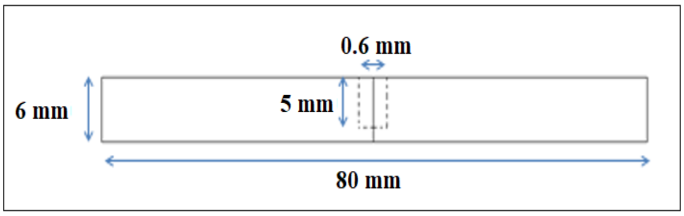


**Figure. 2 Cross section of plate to be welded**

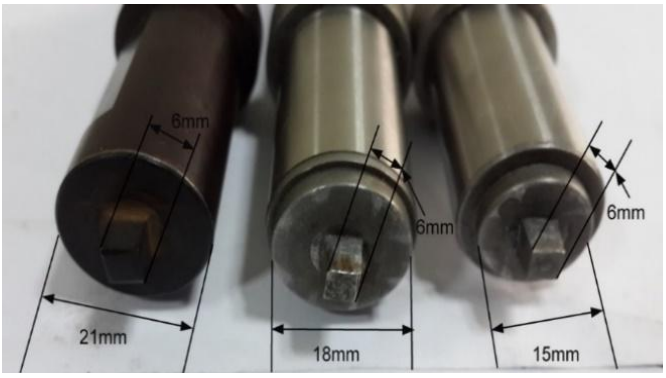


**Figure. 3 Fabricated FSW tools**

 

## III.RESULTS AND DISCUSSION

Al6082/TiC composite plates were successfully welded by FSW Technique. Figure. 5 shows the typical composite alloy welded plate. Based upon the literature studies and number of trials, it was identified that the most important process parameters which greatly influence on mechanical properties of welded joint were tool shoulder diameter, traverse speed and rotational speed. In FSW, metals never reach their melt temperature in the processed region. The forging force of the tool shoulder is one of the main responsible for generation of heat and plastic deformation in the nugget region. Designing of a suitable tool shoulder diameter provides sufficient heat generation and creating forging pressure during welding.

The following equation shows that heat producing during FSW is proportional to the tool rotation rate and inversely proportional to the tool traverse speed.

$$Q=4/3\pi^2\mu P\omega D^3 \text{-------- (1)}$$

Where Q is the heat input, μ is the coefficient of friction between tool shoulder and the work surface, P is the pressure, ω the tool rotational speed and D is the tool shoulder diameter [19]. With increase in tool shoulder diameter leads to an increase in the heat input and produces a larger volume of plasticized material around the tool pin due increase in frictional area. The heat losses also higher in the larger shoulder diameter and the volume of shoulder driven metal flow reduces marginally. The FSW tool geometry and process parameters are more responsible for obtain the defect free welds [20]. Elongavan and Balasubramanian [20] et al friction stir welded the 6061 Al alloy with different tool shoulder diameter and found that D/d ratio of 3 have shown better tensile properties compared to other D/d ratios.

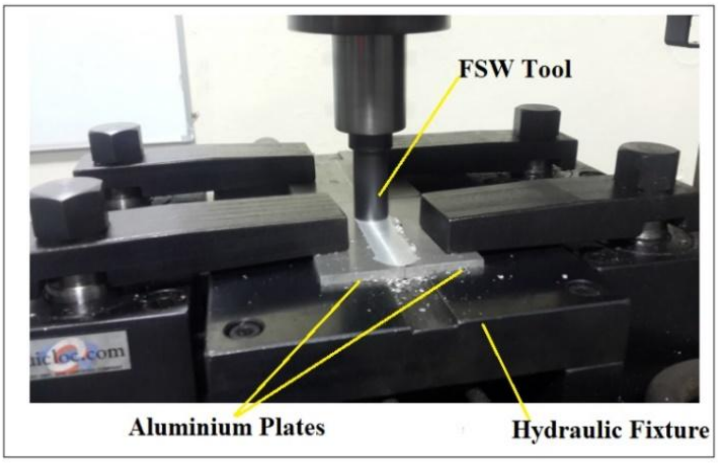


**Figure. 4 FSW Experimental set up**

**Figure. 5 Friction stir welded Al6082/TiC plate**

Figure. 6 (a) shows the optical micrograph of the cross section of the nugget region.In the nuggetregion the refined microstructure was observed. During FSW intensive stirring takes place in the nugget zone due to dynamic recrystallization. In the FSW of Al6082 alloys the softening takes place due to the decomposition of needle-shaped β" precipitates in the welded material due to hardening and strengthening. [21]. SEM image shows the uniform dispersion of TiC particles in the nugget zone (Figure. 6 (b)).

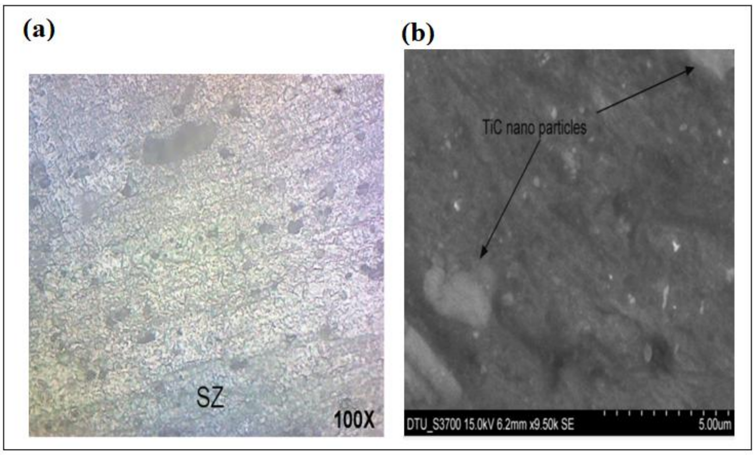


**Figure. 6 Al6082/TiC friction stir welded joint (a) Optical micrograph (b) SEM image**

Microhardness values of welded Al6082 alloy with and without TiC reinforcement particles are shown in Figure. 7. The hardness value of the particle reinforced sample is higher than without particle sample. Figure. 8 shows the welded tensile samples before and after testing. The tensile results of base materials and welded samples are depicted in Figure. 9. The average of three tensile tests were taken for experimental purpose. The tensile strength of composite sample welded with 18mm shoulder diameter has highest tensile strength in compare with other specimens. Lower shoulder diameter generates lower heat which was insufficient for welding and joining of the material. Larger shoulder diameter sample produced higher amount of heat which causes adverse effects of the material property which leads to decrease in strength. TiC nano particles are homogeneously dispersed in the nugget region, which results in improvement of the tensile strength. The EDX has taken in the nugget region and indicates that the presence of TiC particles in the welded zone (Figure.10). Besides, difference in coefficient of thermal expansion between matrix material and reinforcements are also responsible for enhancement of hardness and tensile strength of the composite sample in compare with base material welded joint.

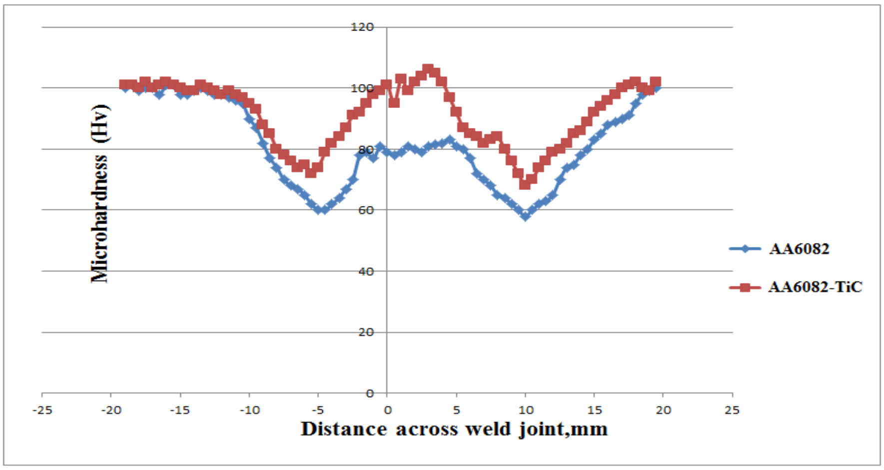


**Figure. 7 Micro hardness values**

**Figure. 8 Tensile specimens (a) before test and (b) after the test**

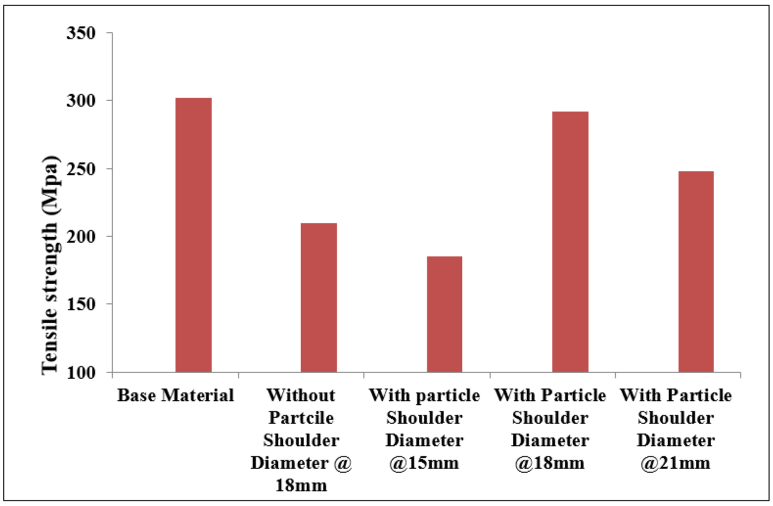


**Figure. 9 Tensile strength results**

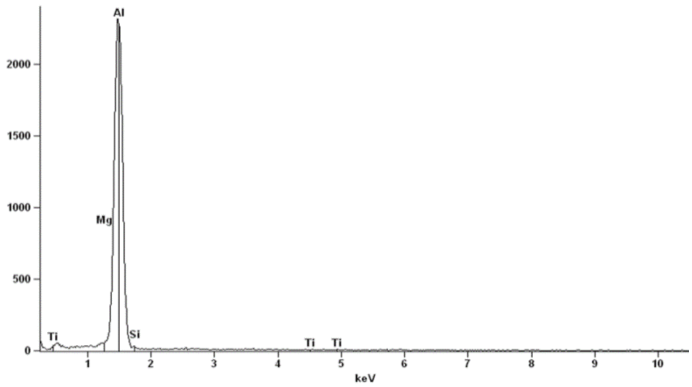


**Figure. 10 EDX analysis of nugget region of Al6082/TiC composite**

## IV.CONCLUSIONS

In this study the effects of tool shoulder diameter on hardness and tensile strength of nano-TiC reinforced Al6082 FSW joints were produced and the following conclusions are derived.

1. The addition of TiC particles in the aluminium alloy improves the mechanical properties of welded joint in compare with non-TiC welded samples.
2. Microstructural and SEM studies show that the grain refinement and uniform distribution of TiC nano particles in the nugget zone.
3. The optimum shoulder diameter of 18mm produced sound welded joint in compare with 15mm and 21mm shoulder diameter samples.
4. Grain refinement and uniform dispersion of reinforcement particles are responsible for improvement of the hardness and tensile strength.

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