MECHANICAL PROPERTIES OF AL6082/TiC NANO COMPOSITE FABRICATED BY FRICTION STIR WELDING AT DIFFERENT ROTATIONAL SPEEDS

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Abstract—Recent Years Friction Stir Welding (FSW) is used for joining of metal matrix composites. In this study TiC nano particles were inserted as reinforcements in Al6082 alloy and friction stir welded with three different rotational speeds (750mm, 1000rpm & 1250rpm). The mechanical properties of the welded joints and base alloy were investigated. The specimen welded with 1000rpm rotational speed exhibited better tensile strength and hardness. The enhancement of weld strength is attributed to the uniform dispersion of nano reinforcement particles in the alloy.

Keywords—FSW, TiC, Tensile, Hardness, Rotational

I. INTRODUCTION

Nowadays, Aluminum matrix composites (AMCs) are giving more attention in fabrication of industrial components due to their excellent mechanical, wear and corrosive properties [1-2]. The welding of AMC is very difficult by traditional fusion welding processes due to their porosity, hot cracking, detrimental reactions between reinforcement and base alloy [3-4]. Friction stir welding (FSW) is a solid-state joining technique which eliminated most of the problems that are encountered during conventional fusion arc welding. Friction stir welding is a favorable welding technique for joining metal matrix composites due to the low energy input and distortion. In this technique the welding takes place lesser than melting temperature of the alloy therefore, the formation of brittle solidification is not easily formed. The principle of FSW is explained elsewhere [5-7]. Recent studies have shown that various reinforcements such as B4C, TiC, SiC, Y2O3, Al2O3, ZrB2, TiB2, WC were used in fabricating of the Al matrix composite through FSW technique. [8-9].

Most of the earlier studies has been focused on bulk Aluminum composites only, very limited work has been carried in selective region composite welding of Al alloys. M. Paider, (2018) [10] employed WC nano particles as a reinforcement in Al5182 alloy to enhance the mechanical and wear properties of the friction stir welded joint. Refined grain size, uniform dispersion of reinforcement in the composite without clustering effect with base alloy. In addition, separation of reinforcements in the base alloy were accountable for improvement of properties. P.N. Karakizis et al., (2018) [11] studied the effect of SiC and TiC nano particles in AA5083 alloy during friction stir welding. The reinforcement particles had a favorable impact in hardness and tensile properties. SiC gives more strength, which is suitable for intense stresses applications and TiC particles dispense higher surface hardness, which is suitable for surface engineering applications. A.C.F. Silva et al., (2017) [12] studied the different methods of temperature measurement during friction stir welding. The different methods were Tool-workpiece thermocouple method (TWT), thermocouple inserted on the tool (TTC) and thermocouples inserted on the workpiece to be welded (WTC) method. The TWT method having the ability to check the feedback control during welding in faster and accurate. Mohsen et al., (2015) [13] welded Al7075 alloy with adding of nano SiC particles through friction stir welding method. The tensile properties of the composite samples were improved due to addition of reinforcements. M. Pourali et al., (2017) [14] welded lap joint of dissimilar metals i.e. St37 steel and Al 1100 by FSW technique and studied the effect of tool rotational speed and traverse speed. The strength of joint value was achieved 1925N at tool rotational speed of 400 rpm and tool traverse speed of 50 mm/min. The formation of Fe-rich intermetallic compounds in the dissimilar interfaces enhances the strength of the joint. P. Yuvanarasimman and R. Malayalamurthi, (2017) [15] studied
the effect of SiC & B₄C particles and process parameters on tensile strength of Al-SiC-B₄C composite plate welded through FSW method. The traverse speed is the key process parameter for determining the tensile and fracture properties of welded joints. R.R. Baridula et al., (2017) [16] studied the effect of copper nano particles and process parameters in FSW of dissimilar aluminium alloys i.e AA5052 and AA6063 alloy. Forging force parameter is greatly influenced for welding of strong joint and followed by rotational speed & traverse speed. H. Das et al., (2018) [8] reported that influence of various reinforcement particles and process parameters in the friction stir welding. Titanium carbide having outstanding properties such as good elastic modulus, superior wettability and act as a grain refiner [17]. This paper focuses on FSW of in situ Al6082/TiC composites and studied the effect of different tool rotational speeds on the weld strength properties.

II. MATERIALS AND METHODS

Al6082 plate with thickness of 6 mm were used as a base alloy. Chemical composition of the base alloy is presented in Table 1. Rectangular specimens with size of 40mm x 200mm were prepared by milling machine. In the plates the 0.3mm width and 5mm depth groove has been made in the faying surface of each plate for filling of reinforcements. The groove dimensions of specimen plate are shown in Fig. 1. The grooved plates were fixed in the hydraulic fixture of FSW machine. The reinforcement particles were mixed with acetone and inserted inside the grooves tightly in the form of slurry. The SEM image of the TiC nano particles is exhibited in Fig. 2.

Table 1. The chemical composition of Al6082 alloy

| Element | Si | Mg | Mn | Fe | Cr | Zn | Ti | Cu | other | Al |
|---------|----|----|----|----|----|----|----|----|--------|----|
| Wt.%    | 1.2| 0.75| 0.79| 0.40| 0.15| 0.10| 0.07| 0.06| 0.10   | Balance |

Figure. 1 Dimensions of cross section of plate to be welded

A square tool pin made from hardened H13 steel having shoulder diameter, pin diagonal length and pin length of 18mm, 6mm and 5.7mm respectively. The experiments were carried out by 11kW, 40KN capacity friction stir welding machine (Fig. 3). The plates were mounted on the hydraulic fixture for rigid gripping. The traverse speed was fixed at 25 mm/min after number of trials. The three different rotational speeds of 800rpm, 1000rpm and 1200rpm were selected in this study. The tool tilt angle was fixed at 1°. The experimental setup is shown in Fig. 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 was carried out on Microhardness tester (Leica VM HT auto) with test load of 100 gm and dwell time of 10 sec. Micro structural characterization was observed on Optical microscope and Scanning Electron Microscope (SEM) (Hitachi S3700) attached with an energy dispersive X-ray spectroscopy (EDX). Standard metallographic procedure were followed for this study.
Figure. 2 SEM image of TiC particles

Figure.3 Friction Stir Welding Machine
III. RESULTS AND DISCUSSION

3.1 Microstructural studies

Fig. 5(a) shows the cross section optical micrograph and SEM image of FSW of Al6082/TiC welded joint. The refined microstructure was observed in the nugget zone of the welded specimen. SEM indicates that the uniform dispersion of reinforcement particles (Fig. 5(b)) and EDX confirm the TiC particles in the nugget region (Fig. 6). In welding of Al6082 alloys needle-shaped β"
precipitates are forming due to heat generation as a result of softening takes place in the stir zone [18].
3.2 Mechanical Properties

Fig. 7 shows the tensile test samples were extracted from the welded region. Fig. 8 shows the tensile test results of base alloy and composite samples. The tensile strength of without reinforcement welded sample and base alloy were 210Mpa and 300Mpa respectively. After adding of reinforcements in the base alloy the tensile strength was significantly improved. This can be attributed to uniform distribution and pinning effect of the reinforcements in the alloy. The tool pin creates uniform mixing of reinforcement particles in the matrix through stirring action and tool shoulder provides sufficient heat for softening of the material. The tensile strength of Al/TiC specimen welded at rotational speed of 1000rpm was shown significant improvement in compare with other tool rotational welded composite samples. The peak temperature of 400-450°C was observed during welding and it was measured by using thermal imaging camera. The FSW temperature measurement is shown in Fig. 9. Lower rotational speed produces lower heat generation due to inadequate stirring action and higher rotational speed produces excessive heat generation which results in adverse properties of material. M.A. Moghaddas, and S.F. Kashani-Bozorg, (2013) [19] reported that rotational speed is one of the main process parameter for generation of heat during friction stir processing. The relationship shows the heat index during processing with tool rotational speed and traverse speed.

\[ \frac{T}{T_m} = k \left( \frac{\omega^2}{v \times 10^4} \right)^\alpha \]  

(1)

Where T -processing temperature, \( T_m \) -base material melting point, \( \omega \) -rotational speed of tool, \( v \) -traverse speed of tool, \( \alpha \) -exponent and k -constant. The above relationship clearly shows that with increase rotational speed increases the heat input in the processing region. A.M. Faradonbeh et al., (2018) [20] reported that the peak temperature of friction stir welding of Al-B₄C
composite with higher rotational speed was higher than lower rotational speeds. The rotational speed was one of the most dominant factors for generation of peak temperature during welding.

![Temperature measurement during FSW](image)

**Figure. 9 Temperature measurement during FSW**

![Tensile fractography of FSW Al6082-TiC alloy](image)

**Figure. 10 Tensile fractography of FSW Al6082-TiC alloy**

![Micro hardness test results](image)

**Figure. 11 Micro hardness test results**

The tensile fractured surface of the Al/TiC composite specimen is shown in Fig. 10. The fractured surface shows that finer size of dimples which are related to the matrix. In between the dimples the reinforcement particles are visible which relates that good bonding between reinforcement particles and matrix material. No intermetallic were formed only dislocations occurs during welding. The microhardness value of the welded specimens is shown in Fig. 11. The maximum hardness value of 102Hv was observed for Al/TiC composite sample welded at rotational
speed of 1000 rpm. Base material hardness was 70Hv. The enhancement of hardness in the composite sample is due to hard nano reinforcement particles in the matrix.

**IV. CONCLUSIONS**

In this study the effect of different rotational speeds on mechanical properties of Al6082/TiC alloy joined by FSW joints were investigated and the following conclusions are derived.

a. The optimum tool rotational speed of 1000 rpm produced maximum tensile strength value of 300Mpa.

b. Appropriate peak temperature is required for sound welding and tool rotational is one of the key parameter for heat generation during welding.

c. The welding strength of without reinforcement specimen is decreased and significantly improved with addition of reinforcement particles.

d. Hard nano reinforcement are uniformly dispersed in the matrix and refinement of grain size is responsible for improvement of mechanical properties of composite specimen.

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