MICROSTRUCTURE AND HARDNESS DISTRIBUTION IN FRICTION STIR WELDED AL6061-TIB$_2$ IN-SITU METAL MATRIX COMPOSITE

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Abstract- This paper reports on hardness distribution and microstructure evolution in friction stir welded(FSW) Al6061-TiB$_2$ in-situ metal matrix composite processesd by stir casting technique. Composite plates were butt welded using FSW3T friction stir welding machine under optimized process parameters. Results show an higher micro hardness in the stir zone and parent zone where as a lower microhardness in heat affected zone. Optical micrographs reveal an extensive grain refinement and homogeneous re-distribution of fine TiB$_2$ particles in the stir zone and formation of coarse precipitates with grain growth in the heat affected zone.

Keywords- Al6061 alloy, Friction stir welding, In-situ composite, Microhardness, Titanium di-boride.

I. INTRODUCTION

Aluminum based metal matrix composites are considered as one of the most promising structural materials for advanced engineering applications in field of aerospace, military, and automotive industries. Combining ductility and toughness of the soft matrix material and strength, hardness and modulus of hard reinforcement excellent mechanical and tribological properties can be derived from aluminum based metal matrix composites.

In-situ technique composite manufacturing involves synthesis of reinforced particles/ phase within the matrix material by triggering a chemical reaction. Reduction in reinforcement particle size and uniform distribution of reinforced particles in the matrix alloy are the two important advantages of in-situ composites over ex-situ composites. Aluminum-TiB$_2$ is a composite system that can be manufactured using in-situ reaction technique. With TiB$_2$ as reinforcement material, the properties of Aluminum alloy can be greatly improved. This is due to fact that TiB$_2$ exhibits outstanding features such as high melting point , high hardness and high elastic modulus and good thermal stability. Thus, Aluminum-TiB$_2$ composite system exhibit very unique characteristics. The tailor made properties of Al-TiB$_2$ system can be used hi-tech structural and functional applications. Many critical applications of composite materials involve complex designs. In order to develop a large and complex structural component, sometimes it is necessary to join aluminum composites to themselves or to other materials. However, joining of aluminum composites by conventional methods is a difficult task due to presence of reinforced particles. High viscosity of molten composite materials, formation of inherent solidification defects such as porosity, shrinkage etc, interfacial reaction between matrix and reinforcement, agglomeration of reinforced particles during welding formation of undesirable phases are the other common issues with fusion or conventional welding techniques.

On the contrary, friction stir welding is a most promising alternative to the existing conventional methods to join metal matrix composites. FSW posses several advantages over the conventional types of welding due to the fact that the process is carried out in solid state. Removal of melting helps in minimizing porosity and eliminates oxide inclusion. H.Izadi et al have applied friction stir welding (FSW) for the modification of microstructure of sinitered Al-SiC composites with particle concentrations ranging from vol% 46. It has been observed that the hardness of the 4 and 8 vol% of 490N grade SiC composites Increased from 130HV and 145HV to 171HV and 177HV.The SiC particles were uniformly distributed during FSW. It was also shown that the increase in hardness with SiC concentration in the friction stir processed samples appeared to be related to the mean inter-particle spacing. Sain et al have studied the hardness of FSW Al6061-T6 the joints fabricated by single pass weld which will give higher hardness number for both Brinell and Rockwell hardness at 3080rpm with feed rate of 30mm/min. The cylindrical pin profile tool in single weld exhibited increasing and decreasing type hardness number for varying speed and feed rates. Khodir et al have investigated the effects on microstructure hardness distribution and tensile properties of the joints using a three types of backing materials such as SUS304, pure copper block and a combination of copper-block with 0.5mm SUS304 were used with a AL2024-T3 aluminum alloy plates were friction stir welded at a constant refraction speed of 1250m^{-1} and welding speeds of 50 and100mm/m. They have concluded a reduction of grain size in stir zone(SZ) were realized when using type 2 of backing material at the same welding condition and with type1 of backing material there was a larger grain size in SZ were obtained. Type 3 of backing plate resulted with the best tensile properties and joint efficiency was 93.6%. Hardness varies in SZ and HAZ depending on backing materials. Yahya et al have investigated weldability of AA2124 with 25% of SiC particles with T4 heat treated aluminum MMC plates at low welding speed. AA2124/SiC/25p-T4 plates were joined by friction stir welding at low welding parameters. They have observed that grain size changes from base MMC to stir zone. Due to age hardening mechanism the increase in hardness from both advancing and retreating side of the HAZ to TMAZ. Fracture surfaces have revealed a mixed brittle-ductile mode. Luri Boromei et al have studied the effect of the friction stir welding process on the microstructure and impact toughness of the AA6061-20%vol Al_2O_3 and AA7075-10%vol Al_2O_3 composites. They have found decrease of the interparticles matrix micro hardness from about $80HV_{0.02}$ in the base material up to about $50HV_{0.02}$ at the middle line of FSW zone.

However, meager information is available as regards characteristics of FSW of in-situ Al6061-TiB_2 metal matrix composite although it is widely used for industrial applications.

In the light of the above, present investigation focuses on friction stir welding of Al6061-TiB_2 in-situ metal matrix composites processed by stir casting technique. Microstructure modifications and Hardness distribution in different regions of weld joints were discussed.

II. EXPERIMENTAL DETAILS

Commercially available Al6061 alloy, Al-10%Ti and Al-3%Br master alloys were melted in a stochiometric proportion using a 6kW electrical furnace to a temperature of 800°C. Molten mixture was maintained at a temperature of 800°C for 30 minutes and stirred using a ceramic coated metallic stirrer rotating at a speed of 300 rpm for duration of 5 minutes at the interval of every 10 minutes. Composite mixture was degassed and then poured in to preheated metallic moulds. The developed Al6061-10wt% TiB_2 composite plates were machined to the size of 50*100*8mm using a vertical milling machine. Friction stir welding was carried out under optimized process parameters (Rotational speed: 800 rpm, welding speed: 40 mm/min, Axial load: 8KN) using FSW3T, friction welding machine at M/S ETA Technology, Peenya, Bangalore, India. Welding tool was rotated in the clockwise direction and tool had 8mm diameter shoulder, 4 mm diameter probe and 1.8 mm probe height. Fig. 1 shows the photograph of friction stir welding process. Complete details of composite preparation and friction welding procedures are described in our earlier work.

Microstructure examination and grain size analysis were carried out using Metallurgical Microscope at M/S Advanced Metallurgical laboratory, Peenya, Bangalore, India. Highly polished surfaces were observed under Meiji microscope. Vickers hardness tests were carried out on the centre line of cross section perpendicular to the welding direction throughout the length with an internal spacing of 0.5mm. Tests were performed with a load of 100grams for duration of 10 seconds.

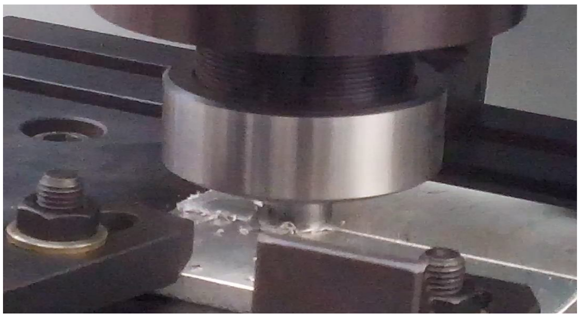


Fig.1 Photograph of friction stir welding process

III. RESULTS AND DISCUSSIONS

Microstructure of as cast composite

Fig.2 shows optical micrograph of Al6061-TiB_2 in-situ metal matrix composite. It is observed that Titanium di-boride (TiB_2) particles are distributed in fairly uniform manner throughout the matrix alloy. It is also observed that TiB_2 particle sizes are in the range of 10-20 microns. Further, the bond between matrix alloy and reinforced particles are excellent.

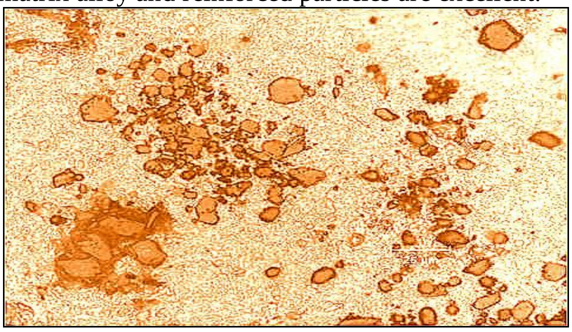


Fig.2 Optical micrograph of Al6061-10wt%TiB_2 in-situ composite

Hardness distribution and microstructure evolution

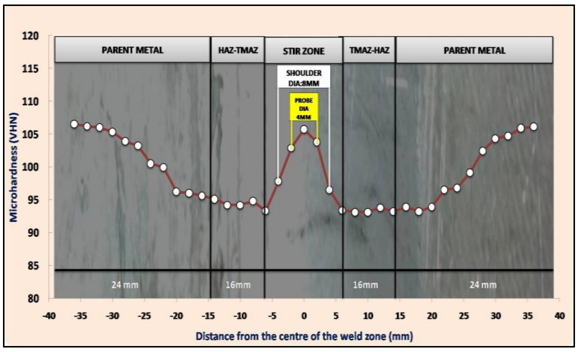
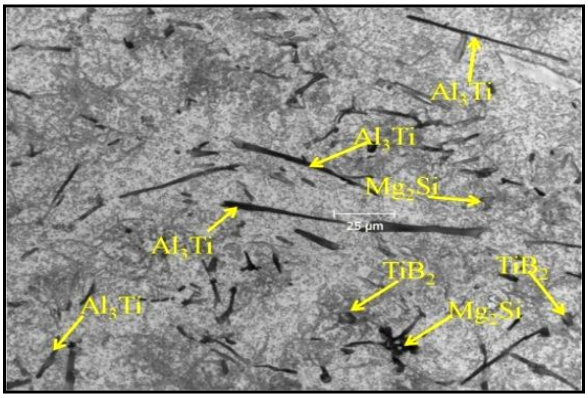


Fig.3 Hardness profile on the cross section of friction stir welded Al6061-TiB_2 composite

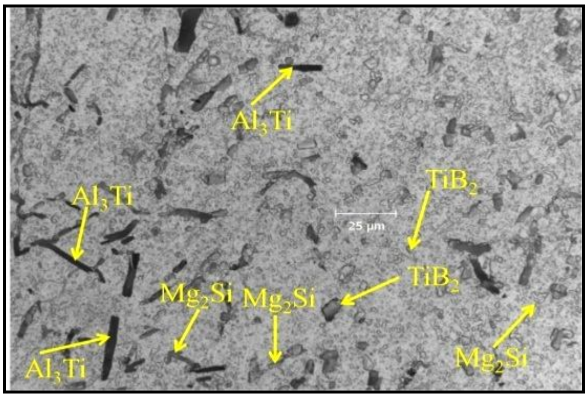
Fig.3 shows the hardness distribution along the centerline of the cross section perpendicular to the direction of welding under optimized conditions. From the graph, it is clear that a progressive decrease in the hardness is observed from the advancing side up to the boundary between heat affected zone and thermo mechanically affected zone. After minimum hardness is reached an increase in hardness takes place reaches a maximum value close to the parent metal at the centre line of the weld. From the centre line of the weld, again hardness decreases towards retreating side reaches minimum value and then increases towards the parent metal.

The sharp increase in hardness in the stir zone / centre line of the weld may be attributed to severe plastic deformation and fracture of TiB_2 phase in to fine particles and homogeneous re-distribution of reinforced particles in comparison with parent composite material which is evident from the optical micrograph captured in the stir zone (Fig.4a-c). Due to severe thermo mechanical action in the stir zone agglomerated and large sized TiB_2 particles have been breakdown into small size and distributes throughout the stir zone.

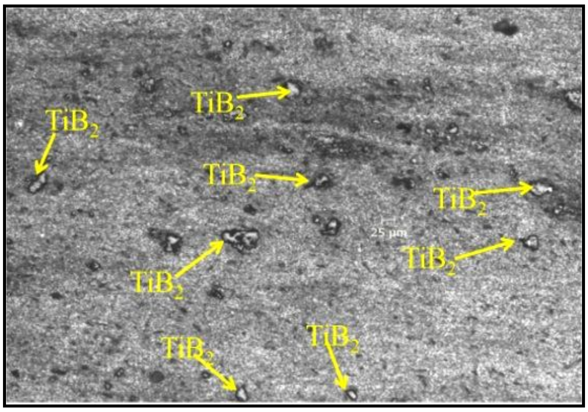
Further, thermo mechanical action in the stir zone would lead to increased dislocation densities and forms dynamic recrystallization in the matrix material. Fine and homogenous redistribution of reinforced particles occurs in the stir zone which has resulted in extensive grain refinement. As it is well known that, Al6061 alloy is a precipitation hardening alloy the sharp decrease in hardness at the interface between heat affected zone and stir zone may be attributed to re-solution of Mg_2Si precipitates during friction stir welding. In region of HAZ (Fig.4b), the micrograph shows coarse intermetallic precipitates (Mg_2Si) oriented randomly throughout the micrograph along with TiB_2 particles. Further, the microstructure clearly shows gradual change in size and distribution of TiB_2 particles. TMAZ zone which is between stir zone and HAZ was difficult to identify due trivial micro structural changes.



(a)Parent metal



(b) Heat affected zone



(c) Stir zone

Fig.4 (a-c). Optical micrographs of friction stir welded Al6061-TiB_2 composite captured in various zones.

However, micrographs 4(c-d) shows plastically deformed structure. HAZ is a thermally degraded zone due to heat generated during welding process. Degradation of HAZ occurs due to the over aging of the composite resulting in decreased micro hardness. The minimum hardness occurs between HAZ and TMAZ. This may be due to precipitation and reinforcement size and their distribution. Parent metal/ zone shows fine Mg_2Si precipitates and TiB_2, Al_3Ti particles of variable size.

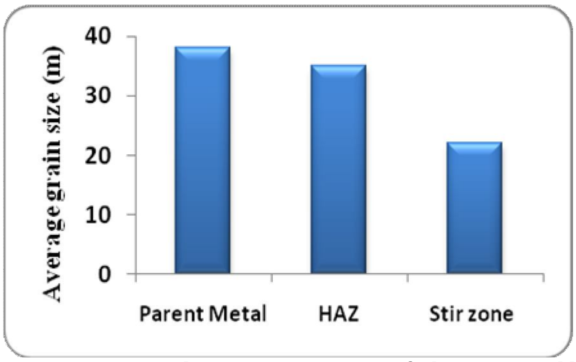


Fig.5. Grain size analysis in various regions of Al6061-TiB$_2$ weld joint

Fig.5 shows the grain size analysis carried out in the various regions/ zones of friction stir welded Al6061-TiB$_2$ in-situ metal matrix composite. It is observed that, stir zone exhibits a significant grain refinement compared with parent metal and Heat affected zone. Average reduction of 42% and 39% were noticed in the stir zone when compared with the parent metal zone and HAZ respectively. This reduction in grain size may be attributed to severe thermo mechanical action and dynamic recrystalization in the stir zone.

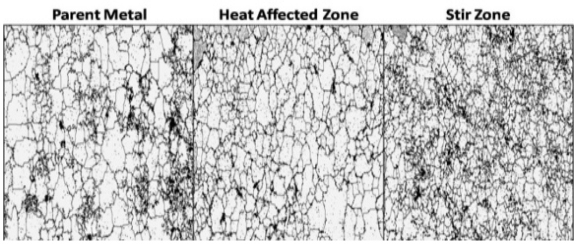


Fig.6 Grain boundary maps in different zones of friction stir welded Al6061-TiB$_2$ composite

Fig.6 shows, grain size and morphology of the grains in the parent zone, Heat affected zone and stir zone. Only equiaxial grains can be found in the parent zone. Whereas heat affected zone shows slightly elongated grains which are influenced by thermo-mechanical action in the stir zone. However, stir zone shows features of severe plastic deformation induced by friction stir welding process along with extensive grain reinforcement.

Combined re-solution of the precipitates and grain growth may be reason for decrease in the hardness in the HAZ after friction welding process. In accordance with well known Hall-patch equation decrease in the grain size generally increases the hardness.

CONCLUSIONS

Friction stir welded Al6061-TiB$_2$ composite shows an extensive grain refinement and homogenous re-distribution of TiB$_2$ particles in the stir zone due to which hardness was maximum. Combined re-solution of precipitates and grain growth has decreased the hardness in the heat affected zone.

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