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Fabrication of Al7075/TiB_2 Surface Composite Via Friction Stir Processing

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Abstract In this work friction stir processing was utilized to successfully disperse and embed TiB_2 particles with global size of 2.62 μm in Al 7075. The effects of rotational and traverse speeds with two FSP passes on particle distribution and microstructures were studied. Microstructure observations were carried out by employing optical microscopy and scanning electron microscopy (SEM) of the modified surface. The results showed that increasing the rotational speed caused a more uniform distribution of TiB_2 Particles. Microhardness of the cross section and tensile test result were also evaluated. The microhardness values of produced composite surface raise with increasing the rotational and traverse speed and improved almost 3 times as compared with base aluminium. Tensile test result shows rising in yield strength by more than two times of base metal.

Keywords Friction Stir Processing, Metal Matrix Composite, Al7075 alloys, TiB_2 (titanium boride) Powder

1. Introduction

Aluminium and its alloys are used commonly in aerospace, aircraft structures and transportation industries because of their high strength to weight ratio. Especially aluminium based Metal Matrix Composites (MMC) exhibited high strength and improved resistance to fatigue and wear[1]. However, these composites also suffered from low ductility and toughness due to incorporation of the hard ceramic reinforcements[2-3], which limited their wide applications. For many applications, surface properties determined by the useful wear and fatigue life. In these situations, it is desirable that only surface layer of components was reinforced by ceramic particles while the bulk of component retained the original properties and structure with higher toughness. Surface composites can be produced using several techniques including plasma spraying and high-energy electron beam irradiation[4-5], that consist of melting treatments. Friction stir processing for surface modification of light metal alloys are also available in solid-state condition[6].

Friction stir welding (FSW) is a solid state joining process developed by the Welding Institute in Cambridge England[7]. By adapting the concepts of FSW Mishra et al.[8] developed FSP for fabrication of metal matrix composites. Also FSP has been shown as an effective technique to refine the microstructure of Al- alloys and fabricate metal–matrix composites[9-12]. In the FSP, a cylindrical rotating tool with a concentric pin and shoulder travels down the surfaces of metal plates, and friction between the rotating tool and workpiece produces localized heat and locally raise the temperature of the material but work piece does not reach to the melting point. The FSPed zone consists of a weld nugget, a thermo-mechanically affected zone and a heat affected zone.

During this process, the material experience intense plastic deformation at nugget zone, resulting in significant grain refinement[13-16]. The fine grain structure in the nugget zone causing a higher mechanical strength and ductility[17-18]. The microstructure and mechanical properties of the FSPed zone can be controlled by optimizing the tool design and FSP parameters such as temperature, tilt angle, penetration depth and rotational and traverse speeds[19-20].

Many different ceramic particles like oxides carbides and borides such as SiC, B4C, Al2O3, TiC and etc have been added to aluminum alloys. Among these particles, Titanium diboride (TiB_2) has appeared as an outstanding reinforcement. This is due to the fact that TiB_2 is stiff hard and it does not react with aluminium to form any interphase at the interface between the reinforcement and the matrix[21]. Furthermore, in contrast to most ceramics TiB_2 is electrical and thermal conductive[22].

In the current investigation, Several Al7075-TiB_2 surface composite were fabricated using two FSP passes by various tool rotational and traverse speeds. The focus in this work is the microstructural and mechanical characterization of the composites, Also studied the effects of speeds on microstructure and microhardness of the developed surface

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composites.

2. Experimental

The materials used in this work are Commercial AL7075-O alloy (Al-Zn-Mg, annealed condition) rolled plate as the substrate material and TiB_2 powder with average particle size of 2.62 μm as the reinforcement. The surface of AL7075 alloy plates was cleaned before processing. Work pieces were prepared with a thickness, width, and length of 4, 45, and 160 mm, respectively. A shallow groove was machined thorough the center surface of the substrate with a width and depth of 1 and 2mm, respectively. TiB_2 powder was filled in the groove and specimens were subjected to two FSP passes.

A hardened H-13 tool steel was used that consisted of a shoulder with a diameter of 16mm and a pin with a diameter and length of 5.4 and 3mm, respectively. The shoulder tilt angle was fixed at 3°. The tool rotation rate was adjusted at 450, 825, 1115 rpm, and the rotating tool was traversed at a speed of 32, 60 mm/min along the long axis of the work piece.

The metallographic specimens were prepared by mounting and grinding and polishing by use of alumina nanopowder and etched with Keller's reagent. Microstructural observations were carried out by employing optical and scanning electron microscopy (SEM) of the cross sections perpendicular to the tool traverse direction.

The Vickers hardness of the stirred zone was measured on a cross section and perpendicular to the processing direction using a Vickers hardness tester utilizing a 200 gf load for 15 s. Mechanical properties were evaluated by tensile test at room temperature with an initial strain rate of 10-3s-1. Tensile test specimens prepared by EDM cut from the nugget zone parallel to the processing direction. The tensile tests were carried out using a GALDABINI universal testing machine. The gage dimensions of the specimens were 100 mm in length and 15 mm2 in area respectively.

3. Result and Discussion

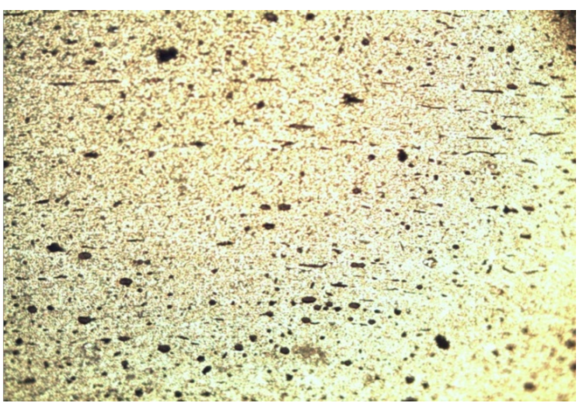

Figure 1. Optical microstructure of the 7075 annealed (400x)

Figure. 1 illustrates optical microstructures of the base material. The fine dark particles widely existed in the base metal are precipitate phase in Al–Zn–Mg system compounds ($MgZn_2$) and most of them elongated on rolling direction.

Surface appearance of surface composite layer produced by FSP shows very smooth and there are almost no prominences or depressions. Defects, such as voids and cracks, are not observed on the surface.

Figure. 2 shows the cross sections of the FSPed specimens. As it is shown in Figure. 2(a) the stir zone in the samples prepared with 450 rpm of rotational speed is not homogenous and TiB_2 particles tended to stay agglomerated just below the surface in a line that started from the advancing side and elongated toward the retreating side. As the rotating speed increased up to 825 rpm, distribution of particles was improved (Figure. 2(b)).

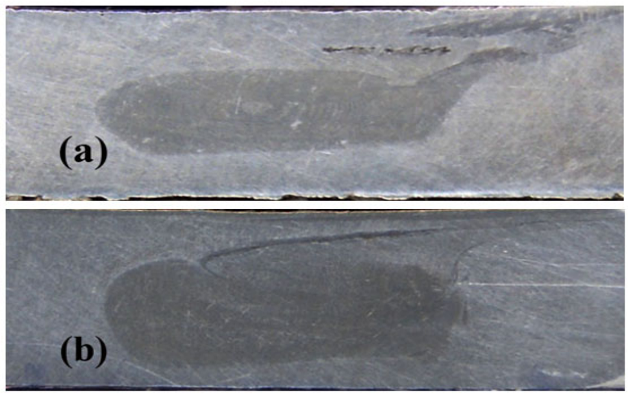

Figure 2. Cross section of friction stir processed with (a) 450 rpm and 32 mm/min, (b) 825rpm and 32 mm/min

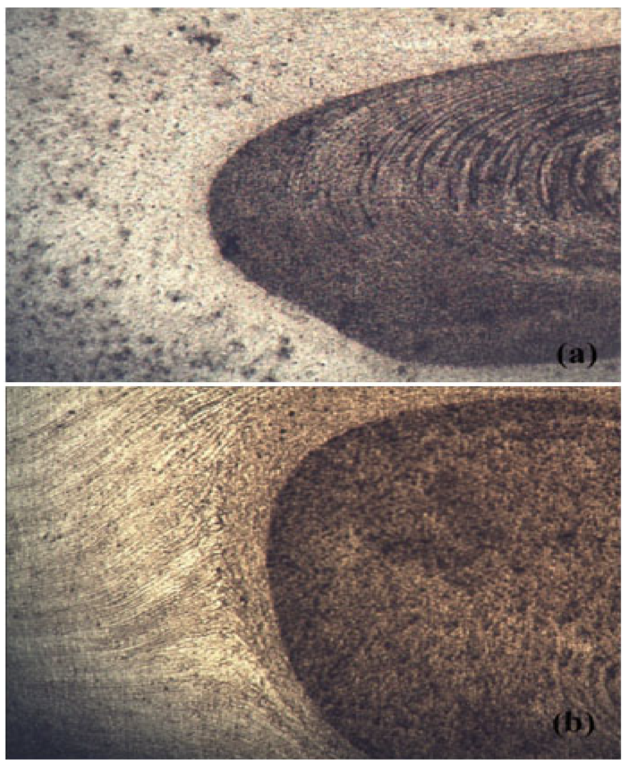

Figure 3. Optical micrograph of interface zone, (a) 450 rpm and 32 mm/min (b) 1115 rpm and 32 mm/min

Figure. 3 shows optical micrographs of interface zone between surface composite layer and substrate. The surface composite layer appeared to be very well bonded to the AL7075 alloy substrate. The classical formation of the elliptical “onion” structure in the nugget zone is well observed in Figure.3(a), because material stirring and plastic deformation isn’t enough, so powder particles move in clustered shape. By increasing tool rotation, raising the localized temperature, material flow and particle distributing is improved (Figure .3(b)). This means that, material flow enhances with increase of rotational speed because plastic strain and temperature increase. Also from optical microscopy observations Figure .3(b), stir zone and thermo mechanical effected zone (TMAZ) is well evident.

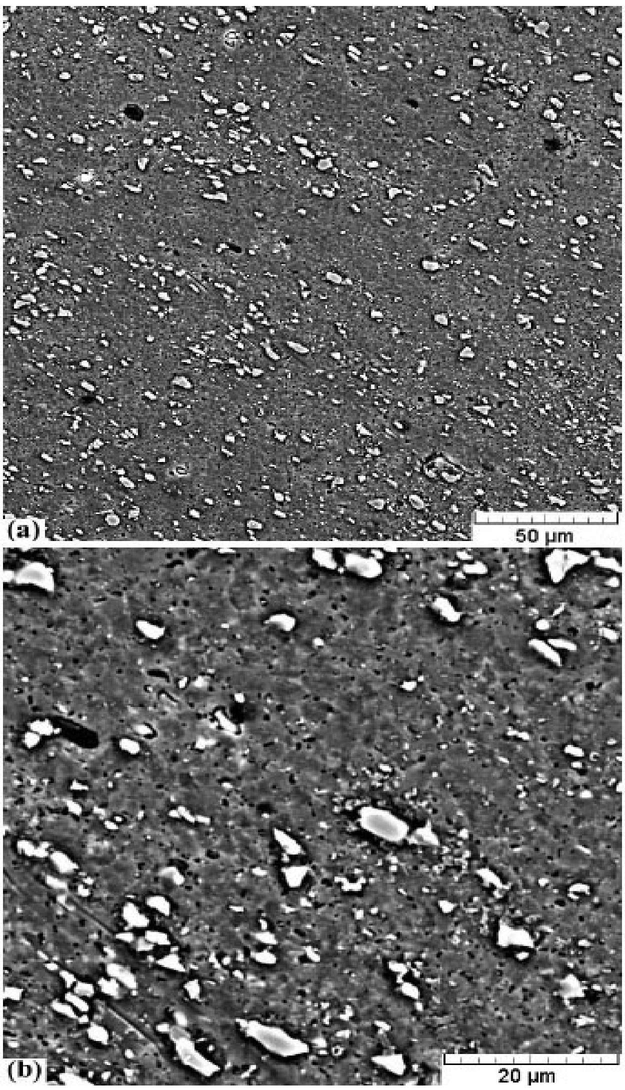

Figure 4. SEM micrographs showing (a) distribution of TiB_2 particles (b) precipitate dissolve substrate

Figure. 4 is SEM images of the surface composite fabricated FSP. The grey particles are TiB_2. As it shown in Figure. 4 the distribution of TiB_2 particles is very uniform and no obvious micro porosity defect can be observed. Furthermore this figure illustrated the interface condition of TiB_2 particles with substrate observed by SEM. After two FSP passes the precipitate dissolve in the aluminium substrate, As it plotted in Figure.4 (b).

Figure.5 shows the average microhardness measurement results trough the nugget zone. The Vickers hardness number raises more than 100 HV. The highest microhardness value is 179 HV and observed when the tool rotation speed is 1115 rpm with the traverse speed of 60mm/min. The average hardness of as-received AL7075 alloy was 64HV. Vickers hardness value has been characterized as traverse and rotational speeds dependent and more affected by traverse speed.

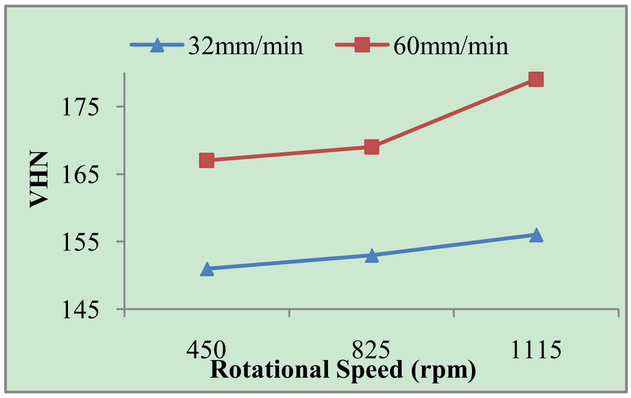

Figure 5. Vickers microhardness values

Result of tensile tests also revealed that the addition of reinforcement significantly increased the yield strength of the composite from 91Mpa to 184Mpa. Increasing of the rotational speed enhanced the ultimate strength but has not affected on the yield strength of composite.

5. Conclusions

The effects of processing parameters on particle dispersion and hardness were investigated in AL7075-alloy reinforced with TiB_2 micro-particles. OM and SEM confirmed that particles were imbedded in the stir zone of FSPed layer. It was found that increasing the tool rotational speed improved the distribution of TiB_2 particles in the Al-alloy matrix. Furthermore by increasing the traverse speed to 60 mm/min improve the hardness of surface layer composite. Also by tensile test result identified that yield strength of the composites is almost 2 times of the base metal.

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