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Tribological Properties of Nano TiB_2 particle Reinforced 6061-T6 Aluminum Alloy Surface Composites via Friction stir processing

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Abstract

This research work is emphasized on the fabrication of nano Titanium Boride (TiB_2) particle reinforced 6061-T6 Aluminum Alloy surface composites via Friction stir processing (FSP). Influence of volume percentage of nano sized TiB_2 (average size is 35 nm) reinforcement particles on tribological properties and microstructural characterization of 6061-T6 Aluminum alloy based surface nano composite fabricated via FSP was studied. The fabricated surface composites have been examined by optical microscope (OM) and scanning electron microscope (SEM) for dispersion of reinforcement particles, thickness of nano composite layer formed on the Aluminum alloy substrate and wear morphology. The friction stirred zones were characteristically about the size of the rotating pin that is width and depth of 8 mm and 4 mm respectively.The depth of surface nano composite layer is measured as 3683.82 µm along the cross section of stir zone of surface nano composite normal to the FSP direction. Microstructures of all the surface composites are revealed that the distribution of reinforcement particles in the nugget zone (NZ). It is observed that increase in the volume percentage of TiB_2 reinforcement particle, the microhardness was increased up to 132 Hv and this value is higher than the as received Aluminum alloy's microhardness (104 Hv). It is found that high wear resistance exhibited at 4 volume percentage (vol. %) as compared with the 2 and 8 vol. %. The observed tribological properties were correlated with microstructure and wear morphology.

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Keywords: Friction stir processing; TiB_2 nano particles; Microstructure; Mechanical properties.

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1. Introduction

Aluminum alloys are candidate materials that are widely utilized in military and different numerous applications in trade and owing to their properties like low density, smart strength to weight ratio and resistance to corrosion. [1]. Aluminum matrix composites (AMCs) which are produced by reinforcing Aluminum alloys with ceramic phases like SiC, Al_2O_3 and TiB_2 etc., are the new generation materials. These AMCs exhibit higher properties than parent alloy such as stiffness, improved tribological characteristics and high strength. Further these properties can be enhanced by using nano scale ceramic materials [2-4]. A proper technique can be employed to refine the microstructure and homogeneous dispersion of reinforcements only on metallic surface [4]. Dispersion of nano reinforcement particles on metal surface and the control of its dispersal are more difficult to attain by conventional surface modification techniques [5]. Earlier researches [6,7] reported that thermal spraying and laser beam techniques were utilized to prepare surface composites, in which it degrades the properties due to creation of unfavourable phases. These techniques operate at higher temperatures and impossible to avoid the reaction between the reinforcements and the matrix, which forms detrimental phase. A process can be employed which is operated at a below melting temperature of the matrix for the fabrication of surface composites which can be avoided the above mentioned complications. Considering these problems, Friction stir processing (FSP) is the best technique suited for preparation of surface composites and surface modification. In FSP, a rotating tool with the shoulder and pin is plunge onto the surface of a material, which creates frictional heat and dynamic mixing of material area underneath of the tool and it results to incorporate and/or disperse the reinforcement particles in the matrix material such as Aluminum alloys, Magnesium alloys and Copper alloys [8-11]. Devaraju et al. [12] achieved homogeneous dispersion of SiC particles (20 μm average size) on a surface of Aluminum alloy 6061-T6 via FSP. Hybrid composites are prepared by reinforcing with a mixture of two or more different type of particles which combines the individual properties of each type of particle. This investigation is aimed to fabricate the nano Titanium Boride (TiB_2) particle reinforced 6061-T6 Aluminum Alloy surface composites via FSP. Extended to study the influence of volume percentage of nano sized TiB_2 (average size is 35 nm) reinforcement particles on tribological properties and microstructural characterization of 6061-T6 Aluminum alloy based surface nano composite fabricated via FSP.

2. Experimental Details

The base material employed in this study is 6 mm thick Aluminum alloy 6061-T6. The nano sized reinforcement particles such as Ti_2B is used and varying the volume percentage as 2 vol. %, 4 vol. % and 8 vol. %. The average size of the reinforcement particles is 35 nm and scanning electron microscope (SEM) microstructure of as-received TiB_2 nano-particles are shown in Fig.1. The tool rotational speed of 1120 rpm, tool travelling speed of 40 mm/min, axial force 5 KN and tool onward tilt angle of 2^0 along the centre line were used in FSP. The FSP is carried out on a Vertical milling machine (Make HMT FM-2, 10 hp, 3000 rpm). After FSP, microstructural observations were carried out at the cross section of NZ of surface nano composites normal to the FSP direction, mechanically polished and etched with Keller's reagent (2 ml HF, 3 ml HCl, 20 ml HNO_3 and 175 ml H_2O) by employing optical microscope (OM). Microhardness tests were carried out at the cross section of NZ of surface hybrid composites normal to the FSP direction, samples with a load of 15 g and duration of 15 sec using a Vickers digital microhardness tester. Wear test is carried out on a pin-on-disk tro-bometer as per ASTM: G99-05 standard. Prismatic pins of 8 mm diameter were cut from the NZ, with the axis of the pin normal to the FSP direction. The disk was made of EN31 steel with hardness of 62 HRC. The diameter of the sliding track on the disk surface was 100 mm. The wear tests were performed under dry sliding conditions with a constant load (40 N), rotational speed (650 rpm) and sliding speed (3.4 m/s). Wear rate is calculated by, [Wear rate (mm^3/m) = Volume loss / Sliding distance].

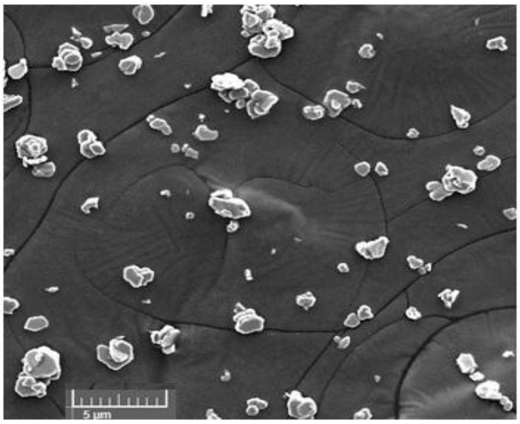

Fig.1. SEM micrographs of as-received TiB_2 particles

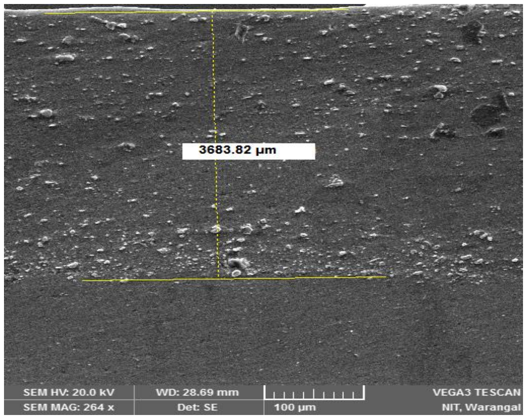

Fig.2. SEM image for depth of composite formed

3. Results and Explanation

3.1. Microstructure and Microhardness

The size of nugget zone (NZ) is normally about equal to the size of the rotating pin, width and depth of 8 mm and 3.5 mm, respectively.The cross section of stir zone of surface nano composite normal to the FSP direction is shown in Fig.2 and depth of surface nano composite layer is measured as 3683.82 µm. The SEM micrographs of Al-TiB_2 surface nano composites and as-received Al alloy are shown in Fig.3. It is observed that the nano-size TiB_2 particles were found to be distributed within this zone due to the occurrence of dynamic stirring during the FSP. It is also observed that the TiB_2 nano particles were dispersed uniformly in the nugget zone (NZ) at 4 vol. % as compared to other 2 and 8 vol. % of Al/TiB_2 surface nano composites made by FSP due to rotating tool gives sufficient heat generation and circumferential force to distribute the reinforcement particles to flow in wider area [12-13]. The Microhardness survey of Al-TiB_2-2 vol. %, Al-TiB_2-4 vol. % and Al-TiB_2-8 vol. % surface nano composites and as-received Al alloy is shown in Fig.4. It is observed that increase in volume percentage of TiB_2, microhardness increases up to 132 Hv and which is higher than as-received Aluminum alloy (104 Hv). This is due to fact that at 1120 rpm, tool shoulder supplied enough heat input and shear force to make the reinforcement particles more easily wrapped by the softening metal and rotated with FSP tool which results in well separation and distribution in the nugget zone.

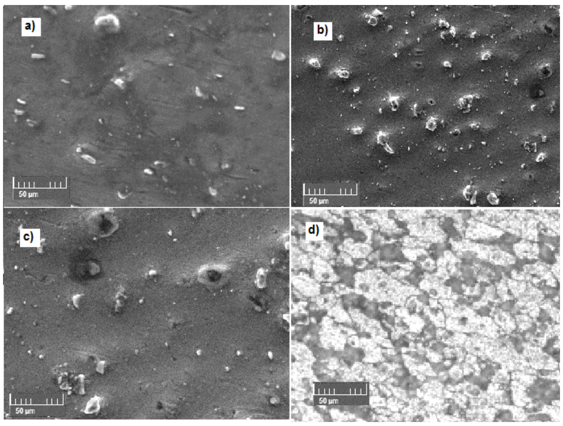

Fig. 3. SEM microstructures of Al/TiB_2 surface nano composites a) 2 vol. %, b) 4 vol. % and c) 8 vol. %

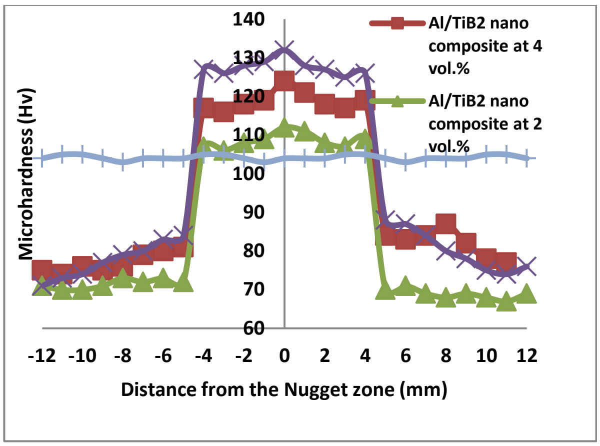

Fig. 4. Microhardness survey of Al/TiB_2 surface nano composites and as-received Al alloy

3.2. Tribological properties

The wear rate with respect to the sliding distance of Al-TiB_2 surface nano composites and as-received Aluminum alloy is shown in Fig. 5. It is observed that the increasing the volume percentage of TiB_2 particles decreases the wear rate. This is due to the enhanced hardness by the dispersion TiB_2 particles and acted as load-bearing elements. It is observed that the increasing the volume percentage of TiB_2 particles decreases the wear rate. At higher volume percentage of TiB_2 particles increases the wear rate due to pulled out of hard nano TiB_2 particles from the composite pin during the wear process, formed on the steel disk which acts as barrier and further converts the adhesive wear to abrasive wear which results in more amount of material worn-out from the composite pin [14-15]. The lower wear rate was obtained at the optimum condition of rotational speed of 1120 rpm, 4 volume percentage of TiB_2. The wear morphology of Al-TiB_2 surface nano composites and as-received Aluminum alloy is shown in Fig.6. It can be seen that the wear tracks are larger and deeper in the base alloy as compared to the Al-TiB_2 surface nano composites due to the presence of hard TiB_2 particles. However, the absence of TiB_2 particles which otherwise causes the micro ploughing of surface in contact during wear of making the rough surface [15].

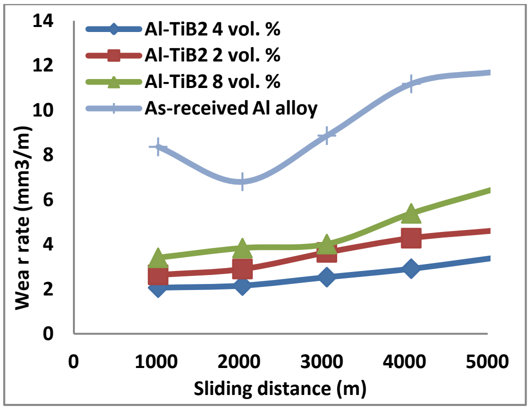

Fig.5. Wear rate of Al-TiB_2 surface nano composites and as-received Aluminum alloy

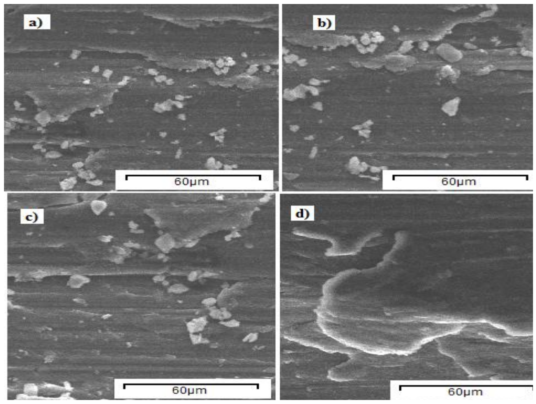

Fig.6. Wear morphology of Al-TiB_2 surface nano composites and as-received Aluminum

4. Conclusions

The nano composite surface layer by reinforcing TiB_2 particles on 6061-T6 Aluminum Alloy via FSP successfully fabricated. Effect of nano sized reinforcement particles such as TiB_2 (average size is 35 nm) on microstructure and mechanical properties of 6061-T6 Aluminum alloy based surface nano composites fabricated via FSP was studied and the following conclusions are to be obtained.

- The depth of surface nano composite layer is measured as 3683.82 μm.
- It is observed that increase in volume percentage of TiB_2, microhardness increases up to 132 Hv and which is higher than as received Aluminum alloy (104 Hv).
- It is found that high wear resistance exhibited at 4 volume percentage (vol. %) as compared with the 2 and 8 vol. %.
- It is observed that the worn debris formation is more at the 8 vol. %. of Al-TiB_2 surface nano composite.

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