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WEAR PROPERTIES OF B_4C PARTICLES REINFORCED MAGNESIUM SURFACE COMPOSITES PRODUCED BY FRICTION STIR PROCESSING

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Abstract- *The aim of this paper is to investigate the hardness and wear properties of the Magnesium based surface composite produced by Friction Stir Processing (FSP) method. By employing three different type of tool pin profiles namely cone, triangular and square separately to produce surface composites. The hardness and wear properties of the surface composite fabricated with square pin profile were higher than other tool pin profile fabricated composite samples. Grain refinement and uniform mixing of reinforcement particles in the matrix are the main reasons for enhancement of the wear properties of material. The wear worn out surfaces of the composites were investigated through Scanning Electron Microscope (SEM) for understanding the wear mechanisms.*

Keywords- *FSP, Magnesium, Surface Composite, Boron Carbide (B_4C)*

I. INTRODUCTION

Recently Magnesium alloys are widely using in aerospace and automotive applications due to their lower weight, good damping capacity, specific strength and machinability. Lesser weight with higher strength of magnesium alloys reduces the fuel consumption with good greenhouse emissions in industrial applications. Most of industrial applications are required good wear and corrosive properties of the surfaces [1-2]. To enhance the surface properties of the material the ceramic particles are added on the surface in order to produce metal matrix surface composites. There are varies surface composite fabrication methods such as cladding, laser process, sintering, electron beam irradiation, thermal spray coating etc are used to fabricate surface composites [3-7]. These techniques are used only certain micrometres thickness level of the surfaces. The recent new surface FSP technique is used to modify upto several millimetres thickness of the surface composite. The FSP method surface composite fabrication is explained elsewhere [8-9]. Various researchers are reported on fabrication of magnesium-based surface composite through FSP method [10]. The various ceramic particles such as Silicon Oxide (SiO_2) [11], CNT [12], Aluminium Oxide (Al_2O_3) [13] Silicon Carbide (SiC) [14] Zirconium Oxide (ZrO_2) [15] and Titaniunm carbide (TiC) [16] are added on surface of the magnesium alloy and modified through FSP method. Aude Simar et al., (2018) [17] have layered C fibre in between AZ91D magnesium alloy and friction stir processed in order to make C fibre reinforced composites. The hardness of the composite specimen is improved to 1.35 ± 0.5 Gpa. Whereas unreinforced alloy hardness is 1.27 ± 0.5 Gpa. The enhancement of hardness of the composite sample is due to grain refinement of the matrix material and homogeneous distribution of fibres in the matrix material. The harness and tensile strength further improved with heat treatment of the composite samples due to significant strengthening mechanism. J. Liang et al., (2017) [18] reported that tensile strength of ultrasonic assisted FSPed CNT/Mg composites were increased from 357±9 Mpa (0.5 vol% CNTs) to 389±8Mpa (1.0 vol% CNTs). Further increase in volume percentage of CNTs the tensile strength was slightly decreased due to presence of CNTs cluster in the matrix. During FSP there was formation of Al_2MgC_2 protrusions between the interfaces of matrix and reinforcement material. M. Sharifitabar et al., (2016) [19] produced $Mg–ZrSiO_4–Al_2O_3$ surface hybrid composites through FSP technique by different number FSP passes. With increase in number of passes the hardness and wear rate of the composite sample has improvement considerable amount. The improvement of hardness and wear resistance in the composite sample is due to uniform distribution of $ZrSiO_4$ andAl_2O_3 particles in the matrix.

H. Patle et al., (2017) [20] reported that machining characteristics and corrosion behavior of friction stir processed AZ91 Mg alloy was improved due to refinement of grain size and decrease in secondary phase during processing. Better refinement of the grain size took place in the square pin FSP tool in compare with simple taper and threaded taper pin profile. A. Alavi Nia et al., (2016) [21] fabricated AZ31/SiC and AZ31/CNT surface composites through FSP technique and studied the effect of different volume % of ceramic particles on mechanical properties of composite. With increase in Volume % of ceramic particle the hardness has improved slightly improved in both the composites. The AZ/SiC composite hardness was improved in compare with AZ/CNT composite due to better refinement of grain size, uniform distribution of particles in the matrix. In the AZ31/CNT composite the CNT particle gets agglomerated during processing. Recently M. Azizieh et al., (2017) [22] studied the effect of different rotational speeds on wear properties of the friction stir processed surface AZ31/Al_2O_3 nano composite. The pinning effect of the nano particles and refinement of grain size are the main reasons for enhancement of the properties. With increase in rotational speed there was slight decrease in hardness of the composite. The higher rotational speed forms grain growth through generation of higher heat during processing. S. Arokiasamy and B. AnandRonald, (2017) [23] investigated the mechanical properties of magnesium-based hybrid stir cast composite subjected to FSP. The grain size of FSPed sample is reduced to 7µm. Whereas without FSP grain size is 84µm. The presence of hard SiC and Al_2O_3 particles in the composite are main reasons for enhancement of hardness and wear resistance of the composite. In this study the effect of different tool pin profiles on hardness and wear properties of the surface composite were investigated.

II. Materials and Methods

Mg-Al-Zn-Sn based cast alloy plate with 200mm long, 50mm width and 6mm thickness used as a substrate. The commercially available B_4C ceramic particle size of 30 µm used as reinforcements. The SEM micrograph of B_4C particles is shown in Fig. 1. In the middle of the substrate a groove size of 1mm width and 3 mm depth was made and filled with ceramic particles tightly. Before filling of ceramic particles, the groove was cleaned with acetone. The ceramic particles were mixed with acetone in the form of slurry and the slurry was filled in the groove. To preventing the escape of the particles from the groove the groove was closed with the tool having only shoulder without pin. The process parameters such as tool rotational speed (800 rpm), traverse speed (50mm/min), tool tilt angle (1^o), plunge depth (0.15) were kept constant after number of preliminary trials. The FSW (make RV machine tools, Coimbatore) with the machine capacity of 40 kN was used. The experimental set up is shown in Fig. 2. The FSP tool was made up of H13 hardened tool steel with shoulder diameter of 18mm, tool diagonal length of 6mm and tool pin length of 5mm were used. The three different tool pin profiles namely cone, triangular and square were selected in this study. The schematic diagram and fabricated tools are shown in Fig. 3(a) and (b) respectively. For uniform mixing of the particles two passes were selected in this study. After completing first pass, the traverse direction of tool was changed for second pass. For microhardness testing of the composite, the test samples were taken from the cross section from the processed region. Microhardness test were carried out by microhardness testing machine with load of 100g and dwell time of 10s. The 8mm diameter wear samples were extracted from the middle of the processed region by wire EDM. The dry sliding wear tests were carried out on a pin on disc tribometer as per ASTM G99-04 standard. Before and after the wear test, the test specimens were weighed with electronic weighing balance. Wear tests were performed at sliding speeds of 1 m/s at normal load of 50N and the sliding distance up to 2000m.The wear worn out surface were studied through SEM.

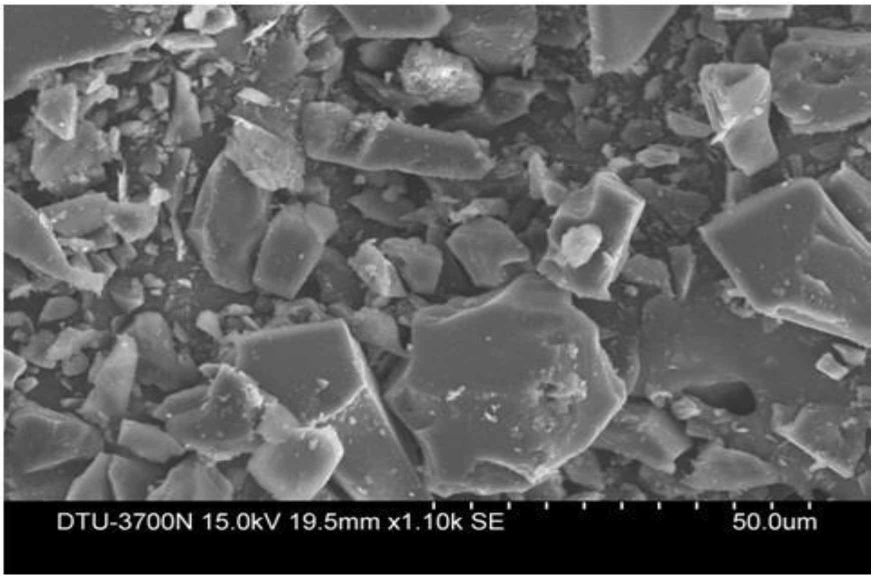

Fig. 1. SEM micrograph of B_4C particles

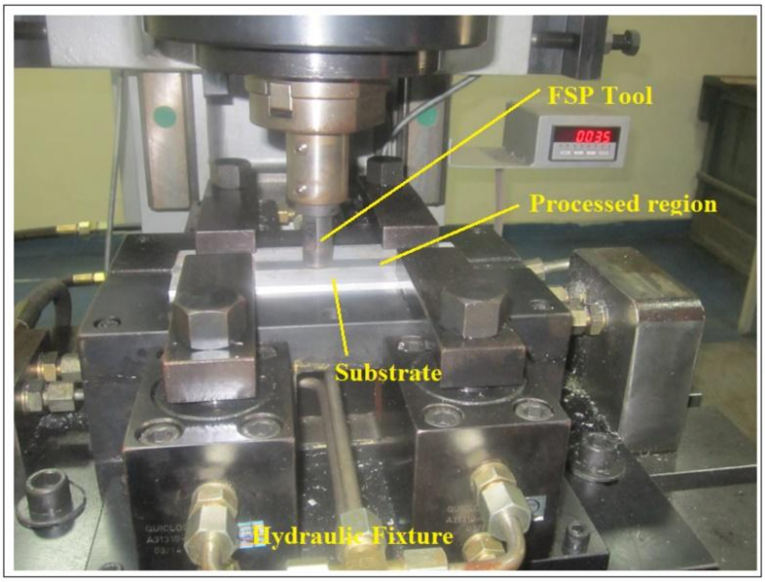

Fig. 2 FSP Experimental setup

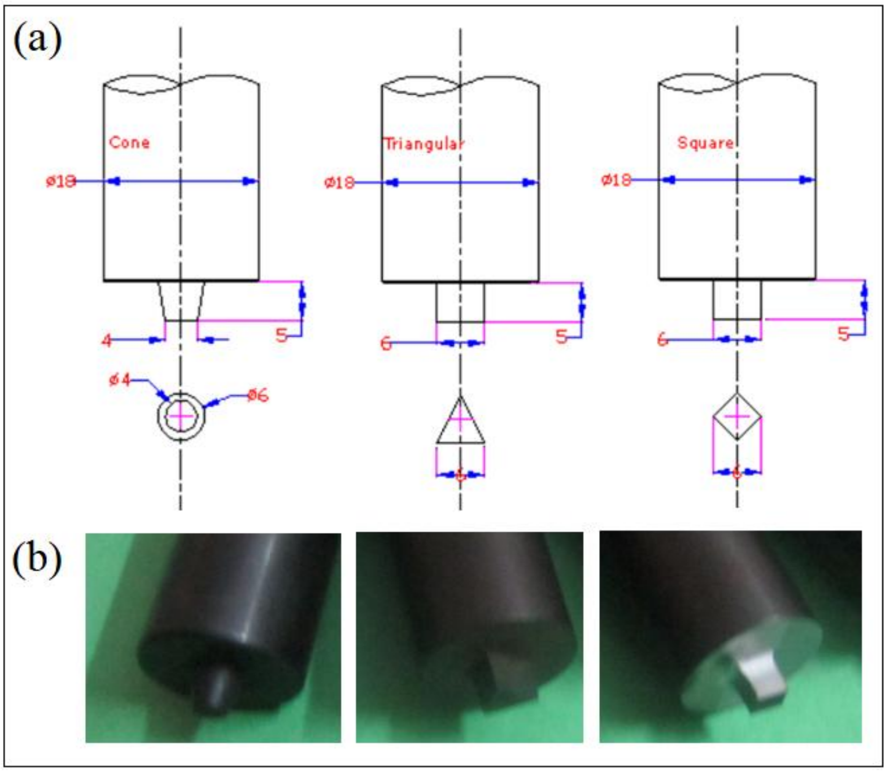

Fig. 3 FSP Tool (a) Schematic diagram (b) Fabricated tools

III. RESULTS AND DISCUSSIONS

3.1 Microstructural studies

The optical micrograph and SEM image of the stir region of the composite specimen processed with square tool shown in Fig 4 (a) and (b) respectively. Grain refinement and uniform mixing of particles took places during processing through dynamic recrystallization. After one pass the advancing side and retreating side of the tool was changed. This made more advantageous for homogeneous mixing of the particles in the matrix. The SEM indicates the uniform distribution of the particles in the matrix. Increase in number of passes reduces the magnesium precipitation in the matrix. Previous studies reported that in the cast magnesium alloy the intermetallic particles such as MgZn, Mg_2Sn, and Mg_2Al_3 are present in the alloy [24]. During FSP the intermetallic particles may breaks through during processing. The shape of the tool is an important for producing defect free with sound processed region. The geometry of the tool performs many functions such as creating sufficient forging pressure, generating heat and uniform mixing of the particles during processing. The cone shape tool profile does not provide sufficient mixing the particles with matrix due to insufficient flow of the material in between tool profile. The Triangular tool having insufficient tangential force for flowing of the material front and back of the tool due to lesser number of corners. The square tool having four corners which provides the sufficient tangential force for flowing of the material from advancing side to retreating side of the tool. Similar types of results reported by M. Bahrami et al. (2014) [25] for friction stir welding of Al7075-O alloy.

3.2 Hardness

The average microhardness value of the base cast alloy and processed composite samples with different tools are shown in Fig. 4. The hardness of the composite sample is higher than base cast alloy. The maximum hardness was observed in the square tool pin processed composite. During processing the grain refinement of the matrix and uniform dispersion of hard B_4C particles in the matrix are mainly responsible for enhancement of the hardness. Besides, the pinning effect of the hard-ceramic particles in the matrix, strong interfacial reaction between ceramic particles are also responsible for enhancement of the hardness. With the square tool pin processed sample observed maximum hardness due to the uniform mixing of the material from advancing side to retreating side. In addition, the FSP passes improves the uniform dispersion of ceramic particles in the matrix.

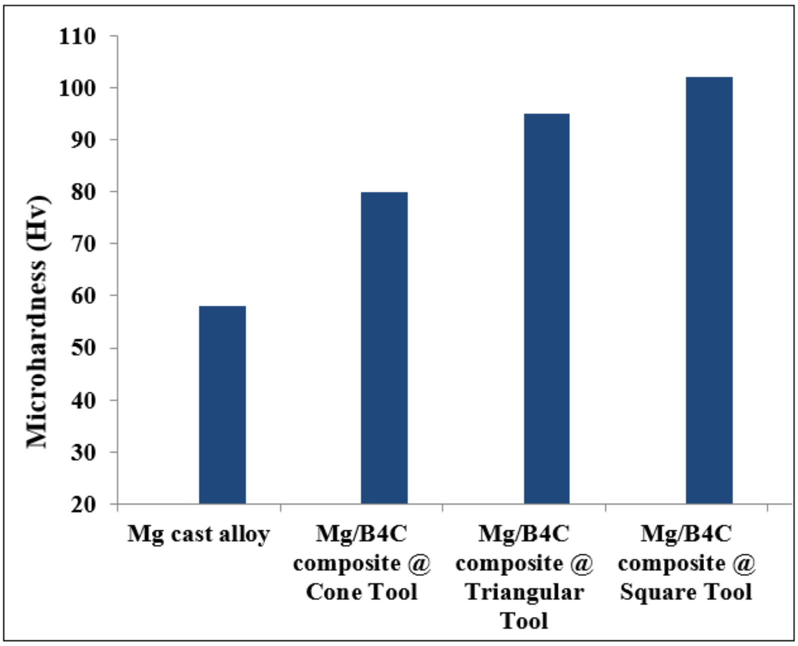

Fig. 4 Hardness test results

3.3 Wear properties

The wear test results of Magnesium cast alloy and processed surface composite samples with different tool pin profiles is presented in Table.1. The composite sample processed with square tool pin profile sample has maximum wear resistance than other composite samples and base cast alloy. The improvement of wear resistance is due to the higher hardness of the composite sample. As per Archard relationship higher hardness sample has lower wear rate. The friction coefficient of the composite sample has lower than base cast alloy [26]. Similar types of friction coefficient were observed in all composite samples. There was a marginal improvement in friction coefficient of the square sample. The Fig. 5 shows the variation of friction coefficient of base alloy and composite sample. In the base cast alloy there was a fluctuation observed in the friction coefficient graph due to insufficient lubricant effect occurred during the wear test. In other hand, there were a smooth friction coefficient graph was observed in the composite sample due to the lubricant effect of the pull-out iron particles from the hard disc and mixing with oxide particles during the wear test. In the base alloy the loss of material was higher in compare with composite specimens. The main wear mechanisms of the metal removal during wear test are oxidization, plastic deformation and abrasion. In the base alloy deeper and wider grooves were observed which is clearly visible in the SEM micrograph Fig. 6(a). The micro cracks and lesser damage of the surface was observed in the composite sample Fig. 6(b). In the composite samples the hard-ceramic particles act load bearing element. During the wear test the oxide particles forms a tribo film layer which results in reduction of friction coefficient.

Table 1. Wear test results

Test condition	**Wear rate (mg/m)**	**Friction coefficient**
Mg cast alloy	0.0451	0.45
Mg/B_4C composite @ Cone Tool	0.0311	0.38
Mg/B_4C composite @ Square Tool	0.0292	0.37

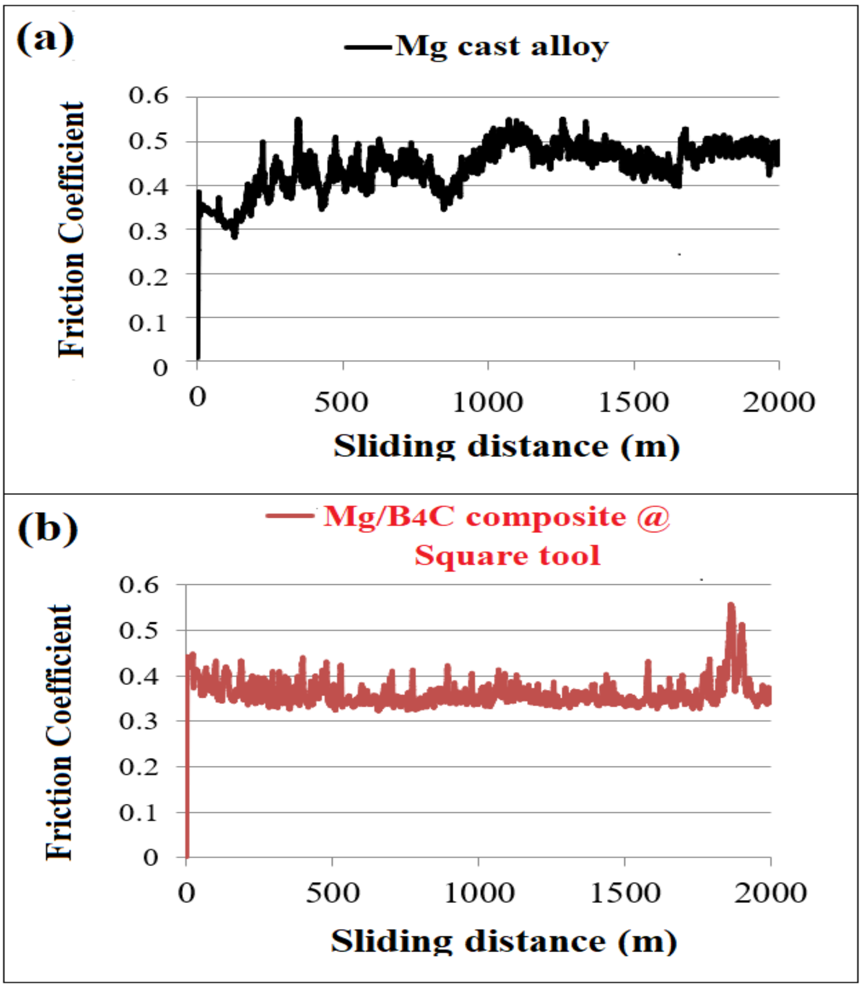

Fig. 5 Typical friction coefficient graph tested at 50N & 1m/s

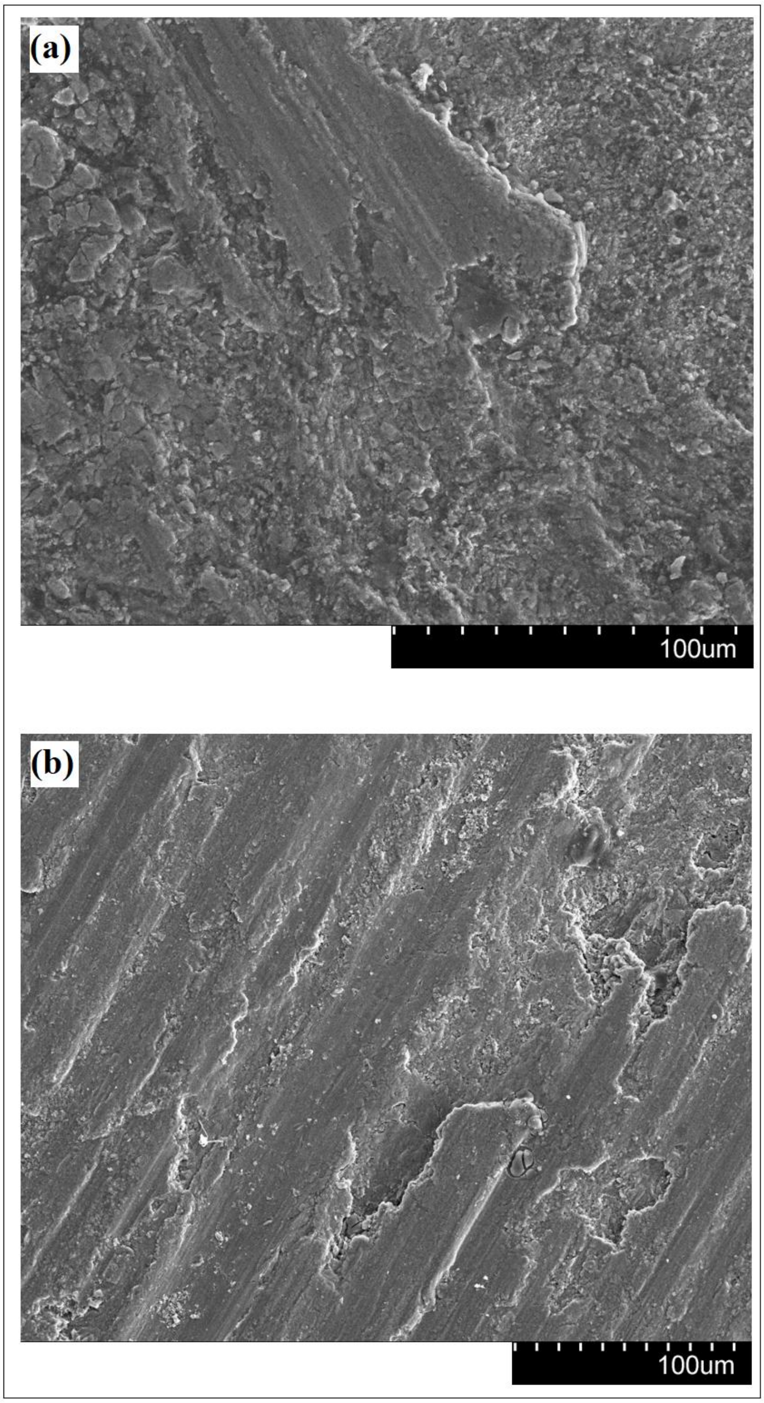

Fig. 6 SEM micrograph of the worn-out surfaces of (a) Magnesium cast alloy (b) Mg/B_4C composite processed with square tool

IV. CONCLUSIONS

The Magnesium/B_4C surface composite was produced through FSP technique with three different tool pin profiles namely cone, triangular and square. The hardness and wear properties of the base magnesium cast alloy and composite samples were investigated. The composite sample processed with square pin profile has maximum hardness (102Hv) and wear resistance (0.0292 mg/m). Uniform dispersion of ceramic particles in the matrix and grain refinement through strengthening mechanisms are responsible for enhancement of the hardness and wear properties. The friction coefficient has not shown any appreciable improvement with the different tool pin profile processed composite samples.

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