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Influence of Traverse speed on Microstructure and Mechanical Properties of AA6082-TiC Surface Composite Fabricated by Friction Stir Processing

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Abstract

Friction stir processing (FSP) has evolved as a novel solid state technique, for refinement of microstructure, enhancement of mechanical properties and fabrication of aluminium matrix composites (AMCs). In this work, AA6082/TiC surface AMC was produced by FSP technique and the effect of traverse speed on microstructure and mechanical properties were investigated. The traverse speed was varied from 40 mm/min. to 80 mm/min. in steps of 20 mm/min. The rest of the process parameters such as groove width, tool rotational speed and axial force were kept constant. Micrographs of the AA6082/TiC AMCs were obtained using optical microscope and scanning electron microscope. Microhardness and wear behaviour of the surface composites were analysed. Results revealed that the traverse speed significantly influenced the area of surface composites, dispersion of TiC, grain size of matrix, microhardness, and wear rate of the AA6082/TiC AMCs. The traverse speed was inversely proportional to the area of surface composites. The homogenous distribution of TiC particles was attained with lower traverse speed, whereas poor distribution of TiC particles was influenced by the higher traverse speed. Also increase in the traverse speed of the surface composite enhanced microhardness and reduced the wear rate when compared with lower traverse speed.

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Keywords: Aluminiumn Matrix surface Composites; Friction Stir Processing; Microstructure; Microhardness; Wear rate.

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1. Introduction

The requirement of excellent properties such as high specific strength, superior wear resistance and low thermal expansion has emphasized the researchers to focus on Aluminum matrix composites (AMCs). Rahimian et al.(2009); Sharifi et al.(2011); Hemanth et al.(2009) reported that AMCs are widely replacing conventional aluminum alloys in many applications and components in aerospace, automobiles and marine industries. Research is being carried out across the world to improve the properties of AMCs using novel techniques and application based reinforcements. Ramesh et al. (2009); Kalkanli et al. (2008); Romankova et al.(2011) produced AMCs using conventional liquid metallurgy routes such as stir casting, squeeze casting and compo casting respectively . Ma ZY (2008) reported that it was difficult to mix the reinforcement with molten aluminum and it was kept in suspension due to the poor wettability. Arora et al. (2011) reported that at elevated temperatures the ceramic particle had an affinity to react with molten aluminum or decompose to form undesirable compounds resulting in deterioration of the properties of AMCs. Though, liquid metallurgy routes are economical, the homogeneous distribution of reinforcement particles across the casting is a challenge.

Mishra et al. developed FSP concept based on the principles of friction stir welding (FSW), which was invented by The Welding Institute (TWI) at UK in 1991. Morisada et al. (2006) produced surface composites using grooves on aluminum plates and packed with ceramic particles. A non –consumable tool is plunged into one end of the rigidly clamped plate and traversed across the plate. Matrix material plastic deformation and its interfacial friction generate sufficient heat to plasticize the material and the deep stirring action of the tool pin mixes the ceramic particle to the plasticized material. FSP overcomes the limitations of liquid metallurgy routes. Mishra et al. (2003); Morisada et al. (2011) successfully fabricated surface composites using Friction stir processing (FSP). They reported that it was an innovative solid state technique to fabricate bulk and surface composites. The temperature during FSP is below the melting point of the matrix material which avoids interfacial reactions and porosity.

Morisada et al. (2006) reported that the traverse speed of the tool significantly influenced the grain size. Higher traverse speed led smaller grain size. Barmouz et al. (2011) successfully fabricated Cu/SiC surface composites. He reported that the higher traverse speed led to poor distribution of SiC particles and vice versa. Kurt et al. (2011) produced AA1050/SiC AMC using FSP and reported that increasing tool rotational speed and traverse speed caused more uniform distribution of SiC particles. Dolatkhah et al. (2012) produced AA5052/SiC AMC using FSP and analyzed the effect of process parameters on the microstructure. Mahmoud et al. (2008); Sharifitabar et al. (2011); Asadi et al. (2010) analyzed the influence of traverse speed on the surface composites fabricated on aluminium and magnesium alloys.

In this study, FSP is used to fabricate Aluminium-TiC surface composite and study the effect of traverse speed on the microstructure, microhardness and wear rate of the surface composites.

2. Experimental procedure

In this work, Aluminium alloy AA6082 plates of size 100 mm x 50 mm x 10 mm having a groove of width 0.8 mm and depth 5 mm made along the centre line of the plate using wire cut EDM were compacted with TiC powder (2 μm). In order to prevent spilling over the TiC particles, the top surface of the groove was closed with a pinless FSP tool. A tool made of High Carbon High Chromium (HCHCr) steel, oil hardened to 62 HRC, was used as a threaded profile. The tool had a shoulder diameter of 22 mm, and a threaded pin M6 x1 mm profile and length of 5.5 mm. An indigenously built FSW machine was used to carry out the FSP. A downward force of 10 kN and rotational speed of 1200 rpm were applied on the tool. The traverse speed was varied from 40 to 80 in steps of 20 mm/min. A specimen was prepared perpendicular to the FSP direction to carry out microstructural and mechanical characterization. The specimen was polished as per standard metallographic procedure and etched with Keller’s reagent. The digital image of the macrostructure of etched specimen was captured using the digital optical scanner. The microstructure was observed using a metallurgical microscope and scanning electron microscope (JEOL-JSM-6390). The microhardness was measured using a microhardness tester (MITUTOYO-MVK-H1) at 500 g load applied for 15 s along the cross section of the specimen. The sliding wear behavior of AA6082/TiC surface composites was measured using a pin-on-disc wear apparatus (DUCOM TR20-LE) at room temperature according to ASTM G99-04 standard. AA6082/TiC pins of size 6 mm x 5 mm x 40 mm were prepared from the FSP zone by wire EDM. The wear test was conducted at a sliding velocity of 1.0 m/s, normal force of 25 N and sliding distance of 2500 m. The polished surface of the pin was slid on a hardened chromium steel disc. A computer aided data acquisition system was used to monitor the loss of height. The volumetric loss was computed by multiplying the cross sectional area of the test pin with its loss of height. The wear rate is obtained by dividing volumetric loss to sliding distance.

3. Results and discussion

3.1. Macrostructure of AA6082/TiC AMCs

Several trial experiments were conducted initially to select a set of optimized process parameters that were used for the production of surface composites.Fig.1 shows the effect of the traverse speed on macrostructure when the traverse speed is increased from 40 to 80 mm/min. It is evident from the figure that traverse speed significantly affects the area of surface composites and the area of the AMC decreases when the traverse speed is increased. The area of the AMC was measured using an image analyzing software and the FSP zone area was computed to be 48 mm^2 at 40 mm/min and 30 mm^2 at 80 mm/min. The reason for the reduction in the area of AMC with the increase in traverse speed is dealt in detail below. TiC particles were initially compacted into the groove along the centre line of the plate and the same tool without change in tool rotational speed and axial force were used for friction stir processing of all plates. The increase in surface area was achieved by decreasing the traverse speed. Mishra et al. (2005) reported that traverse speed influences the amount of frictional heat generated. When traverse speed is increased from 40 mm/min to 80 mm/min, the amount of the frictional heat generated is decreased and to less amount of aluminium is plastisized. The area of the surface composite is consequently reduced. Typical FSW defects including tunnels, pin holes or worm holes etc. are not observed in the macrostructure of the surface AMCs. This indicates that the selected set of process parameters is appropriate to produce sound AMCs.

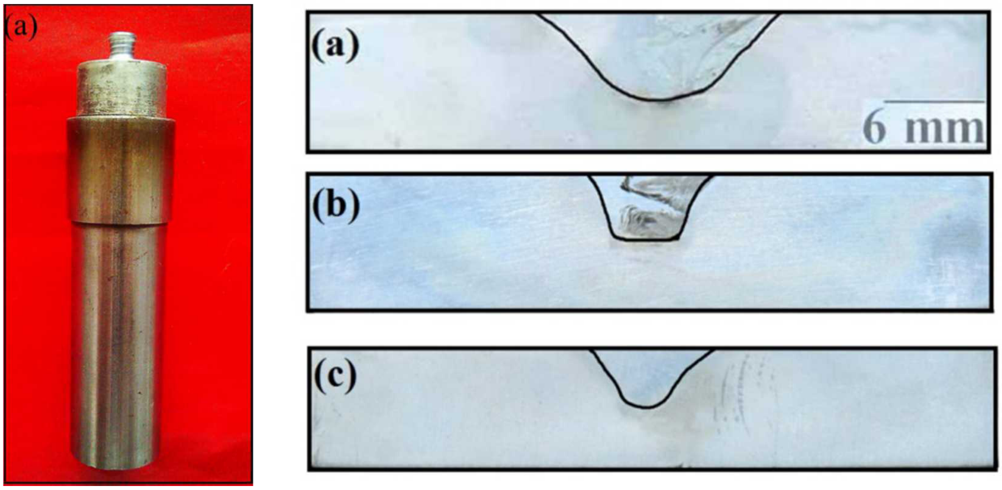

Fig.1. FSP tool and Macrostructure of friction stir zone at traverse speed; (a) 40 mm/min; (b) 60 mm/min; (c) 80 mm/min.

3.2. Microstructure of AA6082/TiC AMCs

Fig. 2. shows the effect of traverse speed on the microstructure of AA 6082/TiC surface composite. Fig.2a indicates a fairly homogenous distribution of TiC particles of surface composites that is produced at 40 mm/min. The distribution of TiC particles is not uniform as indicated in Fig. 2c. When traverse speed is increased, the distribution of TiC particles is gradually decreases. The variation on microstructures as a function of traverse speed can be observed at higher magnification provided with SEM micrographs in Fig 3. When traverse speed is increased, the average distance between two adjacent TiC particles is decreased. The traverse speed influences the stirring action of rotating tool and governs the transportation of stirred and plasticised material from advancing side to retreading side. The stirring of material is more at traverse speed of 40 mm/min. which yields higher plastic strain. The even distribution of TiC particles as found in the optical micrographs (Fig. 2a) can be attributed to deep stirring and sufficient material flow which enhances uniform distribution of TiC particles. When the traverse speed increases, the material transportation from advancing side to rereading side is reduced. The mixing of plasticised aluminium with TiC particles also reduced resulting in non-homogeneous distribution.

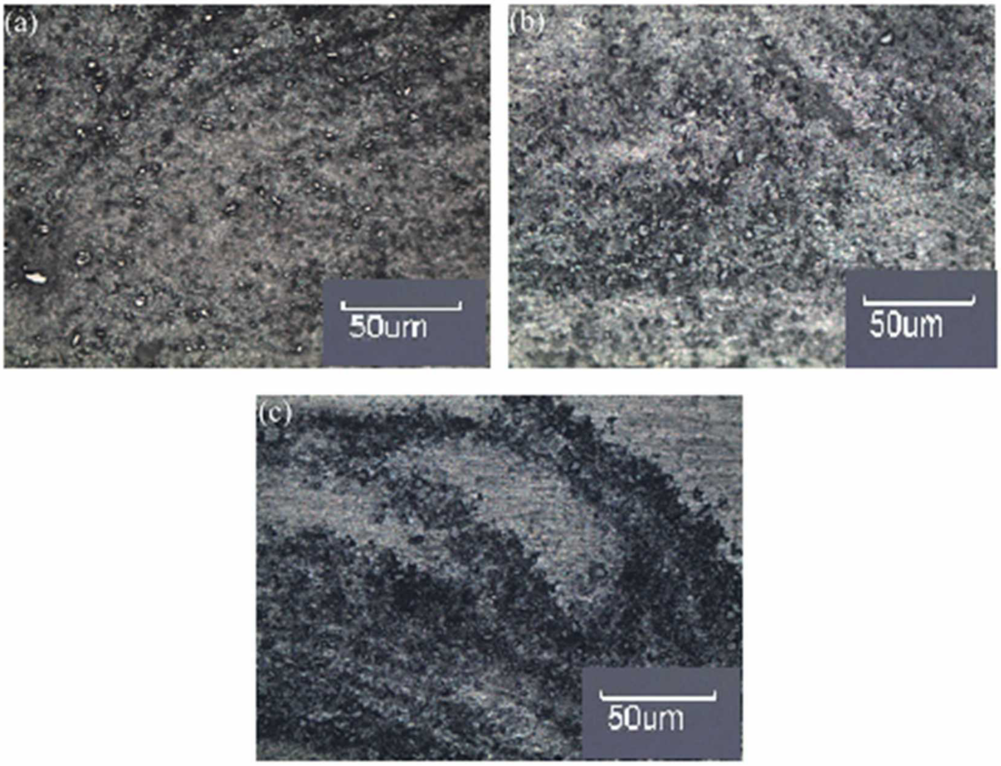

Fig.2. Optical micrograph of AA 6082-TiC surface composite at traverse speed; (a) 40 mm/min; (b) 60 mm/min; (c) 80 mm/min.

Lee at al. (2006) analyzed the various reaction products at the interface of TiC and aluminium matrix in Al/TiC AMCs prepared by infiltration casting route. The local temperature developed during FSP is very low compared to liquid metallurgy routes to initiate interfacial reaction. The details of the interface between the TiC particle and the aluminium matrix can be observed at higher magnification provided with SEM micrographs in Fig 3. From the figure it is observed that the interface is very clear without the presence of any reaction products or micro pores. A clean interface increases the load bearing capacity of the AMC and also provides good bonding between TiC particles and aluminium matrix.

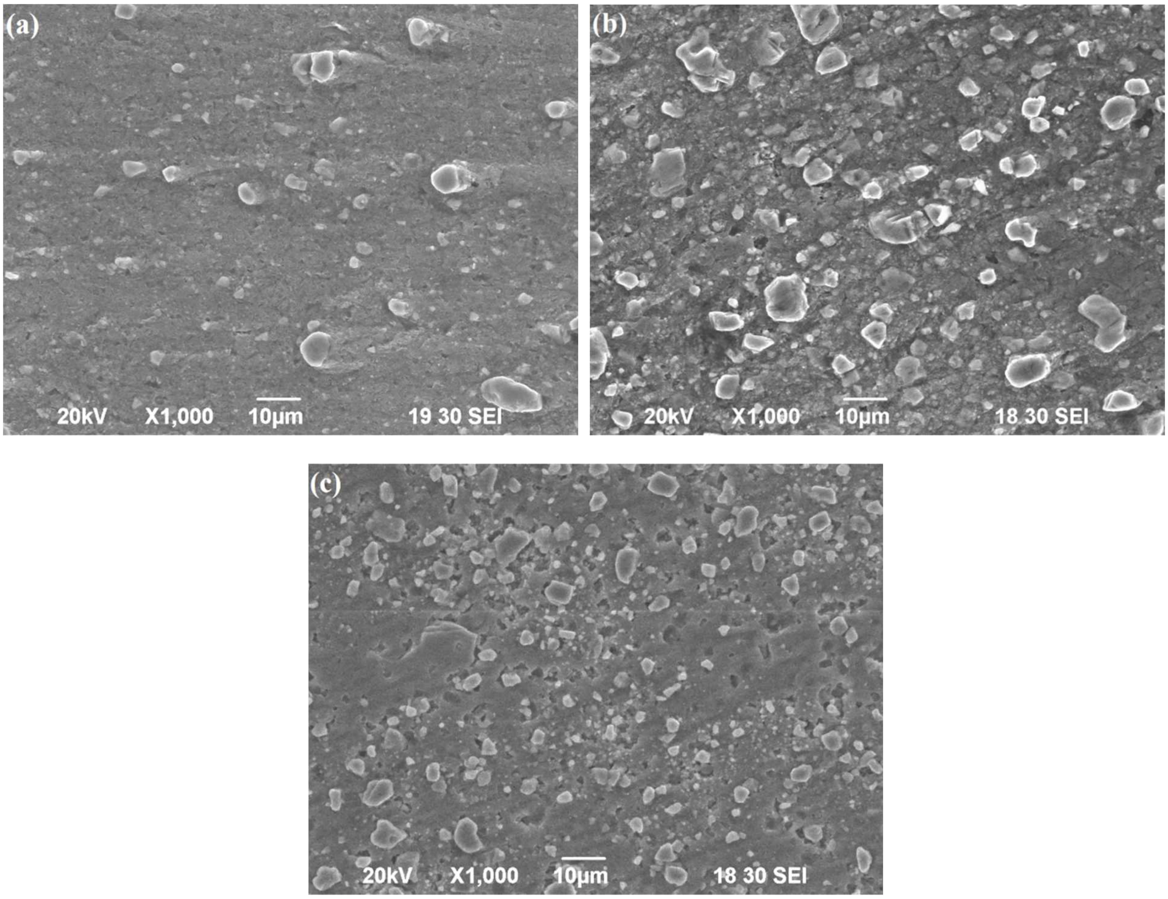

Fig.3. SEM micrograph of AA 6082-TiC surface composite at traverse speed; (a) 40 mm/min; (b) 60 mm/min; (c) 80 mm/min.

3.3. Mechanical properties of AA6082/TiC AMCs

The microhardness and the wear rate of AA6082/TiC AMCs at traverse speeds are presented in Fig. 4. The microstructural changes induced by the traverse speeds are responsible for the improvement in mechanical properties. When the traverse speed is increased, the microhardness and wear resistance are also increased. The microhardness is found to be 112 HV at 40 mm/min. and 135 HV at 80 mm/min. The wear rate was measured to be 546 x 10^{-5} mm^3/m at 40 mm/min. and 412 x 10^{-5} mm^3/m at 80 mm/min. Higher variation on microhardness across the surface composite is owing to the poor distribution of TiC particles. The possible strengthening mechanisms are discussed subsequently. When the hardness measurement was done at even spacing, the possibility of indenter applied directly on the TiC particles. This enhances to higher hardness value at 80 mm/min. The higher traverse speed of 80 mm/min. causes poor dispersion of TiC particles due to insufficient material transportation. The dispersion of TiC particles becomes fairly uniform at lower traverse speed of 40 mm/min. Since**,** the area of surface composites correspondingly decreases; it results in an overall increase in the volume fraction of TiC particles. Because, the same amount of the TiC particles packed in to the groove and the same is to be dispersed to the lesser amount of plasticized aluminium. Therefore, the higher traverse speeds of 80 mm/min. produce higher hardness of the surface composite.

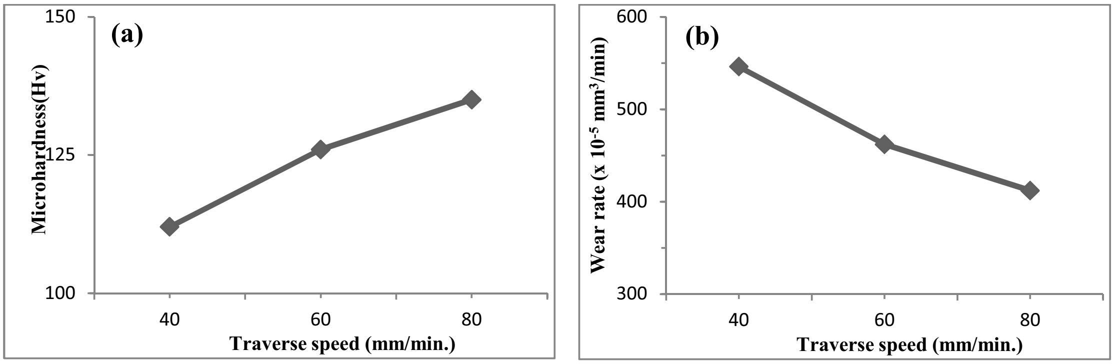

Fig. 4. Effect of Traverse speed on; (a) microhardness and (b) wear rate of AA6082/TiC AMCs.

The hardness and wear rate are correlated by the established Archard's law. According to this law, volume loss is inversely proportional to the hardness of the AMC. Higher the hardness of the material, lower will be the wear rate because, the resistance to remove the material during sliding increases. The effect of traverse speed on wear rates of AA6082/TiC AMCs is shown in Fig. 4 b. It is evident from the figure that the wear rate decreases with increase of traverse speed. The thermal mismatch and differential deformation produces dislocations in the surface AMC. The increased dislocation density raises the resistance to the motion of dislocation across the material. The excellent interfacial bonding between aluminum matrix and TiC particle brings the load transferring the mechanism into operation. The effective transfer of load from aluminum matrix to TiC particles strengthens the surface composite.

4.Conclusions

In the present study, AA6082/TiC AMC was fabricated. The following conclusions are derived from the present work.

- The traverse speed significantly influenced the area of the surface composite. The area of the FSP zone was computed to be 48 mm^2 at 40 mm/min and 30 mm^2 at 80 mm/min.
- The traverse speed influenced the TiC particles distribution in the surface composites. Higher traverse speed resulted in poor distribution of TiC particles and vice versa.
- The microhardness and wear rate of the surface composites were influenced by traverse speed. The microhardness was found to be 112 HV at 40 mm/min. and 135 HV at 80 mm/min. The wear rate was measured to be 546 x 10^{-5} mm^3/m at 40 mm/min. and 412 x 10^{-5} mm^3/m at 80 mm/min.

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