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Influence of tool rotational speed on microstructure and sliding wear behavior of Cu/B_4C surface composite synthesized by friction stir processing

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Abstract: An attempt was made to synthesize Cu/B_4C surface composite using friction stir processing (FSP) and to analyze the influence of tool rotational speed on microstructure and sliding wear behavior of the composite. The tool rotational speed was varied from 800 to 1200 r/min in step of 200 r/min. The traverse speed, axial force, groove width and tool pin profile were kept constant. Optical microscopy and scanning electron microscopy were used to study the microstructure of the fabricated surface composites. The sliding wear behavior was evaluated using a pin-on-disc apparatus. The results indicate that the tool rotational speed significantly influences the area of the surface composite and the distribution of B_4C particles. Higher rotational speed exhibits homogenous distribution of B_4C particles, while lower rotational speed causes poor distribution of B_4C particles in the surface composite. The effects of tool rotational speed on the grain size, microhardness, wear rate, worn surface and wear debris were reported.
Key words: surface composite; friction stir processing; rotational speed; wear rate; microstructure

1 Introduction

Higher strength and wear resistance are essential properties desirable for industrial applications such as electrical sliding contacts, bearings, bushes and antifriction materials. Copper matrix composites (CMCs) have high potential for such applications [1,2]. But the reinforcement of hard, non deformable ceramic particles into the copper matrix results in the loss of ductility and toughness of CMCs. The nature and properties of component surface play a crucial role in determining its lifespan. If the surface of the components alone is modified by reinforcing with ceramic particles, the inner matrix will retain its ductility and toughness. Surface composite is the term used to denote such modified surfaces [3,4].

Friction stir processing (FSP) is a novel solid state technique to synthesize surface composites. MISHRA et al [5] developed FSP based on the principles of friction stir welding (FSW). One of the methods to produce surface composite using FSP is to make a groove of required depth, compact with ceramic particles, plunge the tool and traverse along the groove [6]. The frictional heat softens the matrix alloy and the ceramic particles distribute within the plasticized matrix alloy due to the stirring action of the tool. FSP has been effectively explored by several investigators to synthesize the surface composite on aluminum, magnesium, steel and titanium alloys [7]. BARMOUZ et al [8−11] successfully applied the FSP technique to synthesize Cu/SiC surface composites in recent times.

Some studies on the effect of tool rotational speed on the properties of surface composites synthesized by FSP were reported in literatures [8,12−17]. BARMOUZ et al [8] produced Cu/SiC surface composite by FSP and noticed insignificant change in the grain size with an increase in tool rotational speed. MAHMOUD et al [12] synthesized AA1050/SiC surface composite by FSP and reported the formation of defects at higher tool rotational speeds. LIM et al [13] prepared AA6111/CNT surface composite by FSP and found enhanced distribution of carbon nanotubes at higher tool rotational speeds. ASADI et al [14] produced AZ91/SiC surface composite

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using FSP and observed a decrease in the grain size with an increase in tool rotational speed. KURT et al [15] developed AA1050/SiC surface composite by FSP and concluded that increasing tool rotational speed affected the thickness of the surface composite, grain size, distribution of the precipitates and reinforcing particles. ASADI et al [16] fabricated AZ91/SiC surface composite using FSP and recorded an increase in grain size and a decrease in hardness when the tool rotational speed increased. AZIZIEH et al [17] produced AZ91/Al_2O_3 surface composite by FSP and observed an enhanced distribution of particles at high tool rotational speeds.

In the present work, an attempt is made to synthesize Cu/B_4C surface composite by FSP and study the effect of tool rotational speed on the microstructure and sliding wear behavior of the surface composites. Boron carbide (B_4C) has excellent chemical and thermal stability, high hardness and low density and is used for manufacturing of armor tank, neutron shielding material etc [18,19]. B_4C coating is applied on copper and steel by various methods and is extensively used in nuclear industries [20].

2 Experimental

Commercially available pure copper plates with 100 mm in length, 50 mm in width and 6 mm in thickness were used in this work. The optical micrograph of as-received copper plate which was etched with a color etchant containing 20 g chromic acid, 2 g sodium sulphate, 1.7 mL HCl (35%, mass fraction) in 100 mL distilled water is shown in Fig. 1(a). A groove of 0.7 mm in breadth and 2.5 mm in depth was cut in the middle of the plate using wire EDM and compacted with B_4C powders. The SEM image of B_4C particles is shown in Fig. 1(b). The average size of B_4C particles is 4 μm. A pinless tool was initially employed to cover the top of the groove after filling with B_4C particles to prevent the particles from scattering during the FSP. A tool made of double tempered hot working steel as shown in Fig. 2 was used in this work. The tool had a shoulder diameter of 20 mm, pin diameter of 5 mm and pin length of 3 mm. The FSP was carried out on an indigenously built FSW machine. The traverse speed (40 mm/min) and axial force (10 kN) were kept constant. The tool rotational speed was varied from 800 to 1200 r/min in step of 200 r/min. The FSP procedure to produce the surface composite is schematically shown in Fig. 3. The theoretical and actual volume fractions of B_4C particles were calculated using the following expressions:

$$\varphi_t=(S_g/S)\times 100\% \quad (1)$$

$$\varphi_a=(S_g/S_c)\times 100\% \quad (2)$$

$$S_g=W_g H_g \quad (3)$$

$$S_t=D_p L_p \quad (4)$$

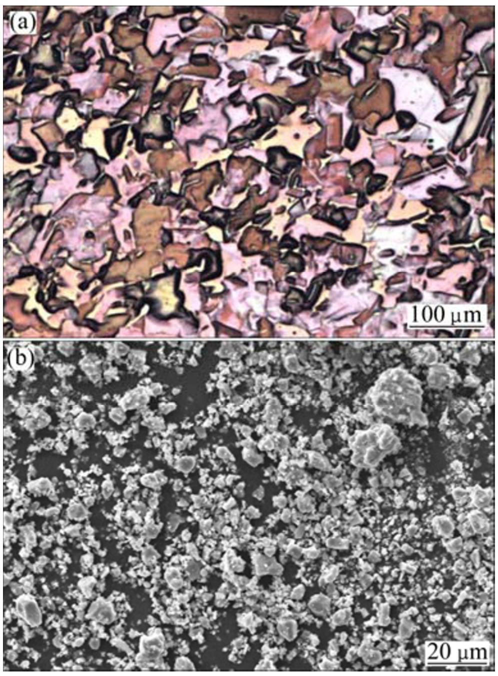

Fig. 1 Optical micrograph of copper (a) and SEM image of B_4C particles (b)

Fig. 2 Fabricated friction stir processing tool

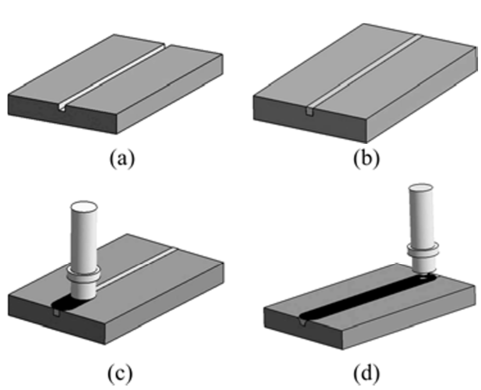

Fig. 3 FSP procedure to fabricate surface composite: (a) Cutting groove; (b) Compacting groove with ceramic particles; (c) Processing using pinless tool; (d) Processing using tool with pin