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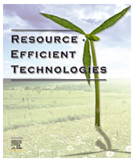

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Research paper

Dry sliding wear studies of aluminum matrix hybrid composites

V.V. Monikandan *, M.A. Joseph, P.K. Rajendrakumar

Department of Mechanical Engineering, National Institute of Technology, Calicut 673601, Kerala, India

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Abstract

In the present work, hybrid composites are fabricated with self-lubricating characteristics to make them as resource-efficient materials. AA6061-10 wt. % B_4C–MoS_2 hybrid composites reinforced with 2.5, 5 and 7.5 wt. % concentration of MoS_2 particles are produced using stir casting technique, and mechanical and tribological properties are evaluated. Microstructural characterization of the hybrid composites revealed the uniform distribution of reinforcement (B_4C and MoS_2) particles in the matrix material. Hardness and fracture toughness of the hybrid composites are decreased monotonously with an increase in the addition of MoS_2 particles. Dry sliding tribological studies conducted using a pin-on-disk tribotester under atmospheric conditions revealed the formation of MoS_2-lubricated tribolayer on the worn pin surface which significantly influenced the tribological properties. The addition of MoS_2 particles decreased the friction coefficient and wear rate of the hybrid composites. Delamination and abrasion are observed to be the controlling wear mechanisms and material in the form of platelet-shaped debris, and flow-type chip debris is formed, and a long and shallow crater on the worn pin surface of the hybrid composite is also observed.

Keywords: AA6061-B_4C–MoS_2 composites; Solid lubrication; Stir casting; Tribological studies

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1. Introduction

Aluminum alloys are broadly used in the automotive sector because of their high strength to weight ratio, suitability to cast into leak proof parts, ability to resist mechanical forces at temperatures near 145 °C and high thermal conductivity [1]. Monolithic aluminum alloys exhibit poor wear behavior compared to the particle reinforced Aluminum Matrix Composites (AMCs) [2,3]. The literature on B_4C reinforced Metal Matrix Composites (MMCs) is sparse because of the higher cost of B_4C particles compared to the conventional ceramic particles such as SiC particles [4] and Al_2O_3 particles [5]. Kennedy [4] observed that large specific property improvements of MMCs could be attained by using B_4C particles as the reinforcement phase. Hence, an AA6061-10 wt. % B_4C mono composite was produced using liquid metallurgy stir casting technique, and its tribological properties were studied [6]. Solid lubrication property was imparted by reinforcing the mono MMC with solid lubricants such as molybdenum disulfide (MoS_2), graphite (Gr) and tungsten disulfide (WS_2). In dry environmental conditions, the use of MoS_2 particles as a solid lubricant was shown to be far more suitable than Gr particles [7]. During stir casting, the addition of 4% Mg to improve the wettability of MoS_2 and SiC particles with the aluminum matrix material resulted in considerable improvement in ultimate tensile strength and hardness of the Al–SiC–MoS_2 hybrid composites [8].

Literature was reviewed to observe the influence of MoS_2 particles on the mechanical properties of MoS_2 reinforced composites. Deng et al. [9] observed that the hardness, flexural strength and fracture toughness of Al_2O_3–TiO_2–MoS_2 hybrid composites are decreased with increase in MoS_2 addition due to the formation of pores generated by the melting and escaping of MoS_2 particles during the hot pressing process. The sintering temperature employed for hot pressing of the hybrid composite specimen was 1700 °C. Kato et al. [10] studied the hardness and bending strength of Cu–Sn–MoS_2 composites and observed that both the hardness and bending strength were increased while the concentration of MoS_2 particles was up to 5 vol. %. However, as the concentration was increased beyond 5 vol. %, both the hardness and bending strength were decreased.

Several studies were conducted to assess the role of MoS_2 particles in the tribological properties of MoS_2 reinforced composites. Dharmalingam et al. [11] statistically analyzed the

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* Corresponding author. Department of Mechanical Engineering, National Institute of Technology, Calicut 673601, Kerala, India. Fax: +91 495 228 7250.
E-mail addresses: saai.manikandan@gmail.com, p110059me@nitc.ac.in (V.V. Monikandan).

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tribological properties of Al–Al_2O_3–MoS_2 composites that were slid against EN 32 counterface and observed that the specific wear rate and friction coefficient were significantly influenced by the addition of MoS_2 particles. Also, Dharmalingam et al. [12] studied the abrasive wear behavior of Al–Al_2O_3–MoS_2 composites and reported that both the wear rate and friction coefficient were decreased with increased content of MoS_2 particles. In both the studies, the Al–Al_2O_3–MoS_2 composites were fabricated through stir casting technique. Dry sliding tribological tests of Ag–Cu–MoS_2 composites mated against Ag–Cu counter disc revealed the formation of MoS_2-rich transfer layer which reduced the wear loss and friction coefficient of the composites. Delamination and abrasion were stated to be the dominant wear mechanisms that influenced the tribological behavior of the Ag–Cu–MoS_2 composites within the applied load range of 1–4 N [13]. A study of the tribological properties of Cu–MoS_2 and Cu–$MoSe_2$ composites that were mated against Cu counterface revealed the incurrence of adhesive wear. It was also observed that the solid lubrication becomes more significant for the composites having MoS_2 or $MoSe_2$ concentration greater than 5 wt. % [14]. Dhanasekaran and Gnanamoorthy [15] studied the tribological properties of Fe–Cu–C alloy containing MoS_2 particles, and it was observed that the composites exhibit better tribological properties up to 3 vol. % of MoS_2 particles addition. However, the composites exhibit poor tribological properties as the concentration of MoS_2 particles is increased to 5 vol. %.

Literature mentioned above makes it clear that the environment of testing, concentration of MoS_2 particles and the formation of MoS_2-lubricated tribolayer influence the tribological properties of the materials added with MoS_2 particles. It is understood that the mechanical properties are also influenced by the concentration of MoS_2 particles. In this work, particle-reinforced AA6061-B_4C–MoS_2 hybrid composites with various MoS_2 concentrations are fabricated, and their tribological and mechanical properties are studied. Also, the mechanical and tribological properties of the hybrid composites are compared with those of the AA6061-10 wt. % B_4C mono composite [6] to understand the influence of MoS_2 particles addition. Due to their self-lubricating properties, Al–B_4C–MoS_2 hybrid composites can be possible materials to fabricate different automotive components and also their self-lubricating characteristics can eliminate the need for external lubrication system during sliding.

2. Fabrication of hybrid composites

The casting method used to fabricate the hybrid composites, as well as the materials used for the fabrication, is detailed in the following sections.

2.1. Materials

AA6061 (Mg – 0.86, Si – 0.67, Fe – 0.19, Cu – 0.21, Ti – 0.018, Mn – 0.04, Cr – 0.05, Zn – 0.004, B – 0.003, Pb – 0.001, and the rest Al by wt. %), supplied by M/s. Hindalco Ind. Ltd., India, is selected as the primary phase. B_4C particles (supplied by M/s. Bhukhanvala Ind. Pvt. Ltd., India) of 30 μm Average Particle Size (APS) and MoS_2 particles (supplied by M/s. Otto Chemie Pvt. Ltd., India) of 130 μm APS are selected as the secondary phase.

2.2. Stir casting

Fig. 1(a) shows the macrograph of the stir casting equipment that is used to fabricate AA6061-10 wt. % B_4C–MoS_2 hybrid composites reinforced with 2.5, 5, and 7.5 wt. % MoS_2 particles through stir casting. The crucible and stirrer are made of stainless steel, and the permanent mold and skimmer are made of mild steel. The stir casting process is carried out in a step by step procedure. The crucible, stirrer, permanent mold, and skimmer are coated with coatings that have water as carrier and vermiculite and refractory pigments as concentrates. The coating prevents the reaction between the melt and the metallic components that come into contact with the melt. The coated components are heated to 180 °C to evaporate the carrier (water) after coating. Time (10 min) is given for the evaporation to complete, and then the argon gas is supplied continuously to the crucible to prevent the reaction of matrix material with the atmospheric air. AA6061 alloy bars cleaned with acetone are placed inside the crucible, and the electric furnace is heated to 800 °C that is higher than the melting point (621 °C) of the AA6061 alloy to compensate for the heat loss incurred due to stirring [6]. The temperature at which the addition of the reinforcement particles, stirring, and pouring are carried out, is above the liquidus temperature of the melt [6]. The melt temperature is maintained at a precision of ±2 °C throughout the casting process. 1 wt. % of magnesium (Mg) is added to the melt in the form of Al–Mg master alloy to enhance the wettability of the reinforcement particles with the matrix material [16]. Hydrogen has significant solubility in molten aluminum, and high concentration of hydrogen causes porosity defects in the cast specimen.

Hexachloroethane (C_2Cl_6) tablets are used to remove hydrogen from the melt. Dried tablets are held with tongs and immersed in the melt inside the crucible. The tongs are held just above the crucible bottom and 5 min (approx.) is given for the decomposition of the tablet that ensures efficient hydrogen removal throughout the melt. The tablet decomposes and forms aluminum chloride ($AlCl_3$) bubbles in the melt that entraps the hydrogen gas and rises to the melt surface to expel the hydrogen gas to the atmosphere [17]. Granular cleaning flux is then added into the melt to remove the other non-metallic inclusions and oxides from the melt. The melt surface is then skimmed by using a skimmer. The reinforcement particles (B_4C and MoS_2) are mixed in an aluminum agate mortar and pestle, and the particles mixture is preheated and maintained at 300 °C. A detachable stainless steel stirrer is fixed over the furnace and immersed into the melt. The stirrer is run at the speed of 450 rpm to form a vortex [18]. The predetermined amount of reinforcement particles is added into the vortex of the melt. The stirring holds the reinforcement particles in suspension throughout the melt that helps to attain a homogenous distribution of the reinforcement particles in the matrix material. After the addition of particles, stirring is further continued for 1500 sec. The composite melt is then poured into the mold by

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