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Tensile, compressive and wear behaviour of self-lubricating sintered magnesium based composites

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Abstract: The graphite (Gr)/MoS_2 reinforced Mg self-lubricating composites were prepared through powder metallurgy. The composites were characterized for microstructure, physical, mechanical and wear properties. Gr/MoS_2 phase in the composites was identified by XRD analysis. Microstructural observation showed that the Gr/MoS_2 particles were homogeneously dispersed within the magnesium matrix. Micro-hardness was measured using an applied load of 5 g with a dwell time of 15 s at room temperature. Hardness of all the composites was measured to be in the range of VHN 29−34. The mechanical properties were studied using micro-hardness, tensile and compression tests. A fractographic analysis was performed using scanning electron microscope. The highest values of hardness, compressive strength and tensile strength were attained using Mg−10MoS_2 composite. A pin-on-disk tribometer was used to measure the friction coefficient and the wear loss of the sintered composites. In addition to that, the friction and wear mechanism of the composites were systematically studied by worn surface characterization and wear debris studies using SEM analysis. The reduced friction coefficient and wear loss were achieved in MoS_2 rather than Gr.

Key words: magnesium composites; self-lubricating; powder metallurgy; sliding wear; microstructure; mechanical properties

1 Introduction

Magnesium is the sixth most abundant element in the earth's crust (2%) and the third most dissolved minerals in seawater (1.1 kg/m^3) [1]. Magnesium is the lightest of all engineering metals with a density of 1.74 g/cm^3, which is two-thirds the density of aluminium and over four times lighter than steel [2]. This property attracts automobile manufacturers to change from denser materials, not only steel, cast iron, copper and titanium but even aluminium, to magnesium [3]. Magnesium has excellent specific strength and stiffness, exceptional dimensional stability, high damping capacity and high recyclability [4]. Based on these superior properties, the research and development of magnesium alloys for practical industrial applications in automotive, aircraft and electronic consumer products have increased worldwide during the past decade [5,6]. The major advantage of magnesium composites lies in the tailorability of their mechanical and physical properties to meet specific design criteria [7].

Wear is one of the most commonly encountered industrial problems that leads to the replacement of components and assemblies in engineering. When two solid surfaces are placed in solid-state contact, it is not easy to envision the absence of some wear even in the most efficiently lubricated systems because of asperity contact [8].

Graphite (Gr) and molybdenum disulphide (MoS_2) are important solid lubricants, and they have a layered structure [9,10]. The layer consists of flat sheets of atoms or molecules, which is called a layer-lattice structure. An important effect is that the materials can shear more simply parallel to the layers than across them. Therefore, they can support relatively heavy loads at right angle to the layers while still being able to easily slide parallel to the layers. This property is being effectively used in lubrication process. The friction coefficient is more or less equal to the shear stress parallel to the layers divided by the yield stress or hardness perpendicular to the layers [11,12]. Because

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low friction only occurs parallel to the layers, it follows that these solid lubricants will only be effective when their layers are parallel to the direction of sliding. It is also significant that the solid lubricant should adhere strongly to the bearing surface; otherwise it would be easily rubbed away and give very short service life.

Solid lubricants are used as a powder or thin film to give protection from smashing during relative movement and to decrease friction and wear. Solid lubrication can be implemented where unusual circumstances exist which make lubrication oils and greases unsuitable. For example, in space applications, lubricating oils are shunned due to their out gassing under vacuum and high temperature conditions [13]. Other application areas include the food and textile industries and in tablet manufacturing, where products are likely to become contaminated with oils and greases. According to the scientific periodicals on tribology, graphite is the most widely used solid lubricant in powder materials, followed by molybdenum disulphide. They are important solid lubricants, and have a layered structure [14,15].

Significant efforts have been made to improve the wear resistance of aluminum alloy matrices by the addition of lubricating particles. Aluminium alloy−graphite particulate composites have importance as a self-lubricating material through the enhancement of the wear resistance, machinability and delayed onset of severe wear and seizure. The reduction in wear resistance happens with the addition of graphite, assistances in the formation of a solid lubricating film. This lowers the friction coefficient and increases the anti-seizure quality of the matrix alloy [15,16].

When using copper matrix under unlubricated conditions, it is important to note that copper is more likely to scuff because it is significantly softer and more ductile than common steel. Scuffing may be avoided by using a solid lubricant, which can separate the sliding metallic surfaces [17,18]. Solid lubricants may be delivered to the friction contact if they are included in the copper as the second structural phase. Thus, the coefficient of friction and wear rate depend on the amount of the solid lubricant particles present in the copper matrix. Copper–graphite sintered materials combine the effective electrical conduction of the copper matrix with the self-lubricating ability of graphite to produce good friction and wear performance. These materials can potentially be used as sliding electrical contacts. Higher quantities of solid lubricants, however, contribute to the reduction of wear resistance. The MoS_2 particles, which serve as a lubricant during dry sliding processes, decrease wear loss [19]. There are far fewer studies of molybdenum disulfide with copper and aluminium matrix powder compositions than those of graphite containing materials.

In manufacturing metal matrix composites, the dispersion of the reinforcement particles is a challenge. However, a uniform mixture of metal and non-metal compositions is impossible to obtain by traditional casting methods. Powder metallurgy overcomes the negative effects of liquid state processing methods such as stir casting [20]. Powder metallurgy processing may be used to obtain metallic composite materials containing solid lubricants. In powder metallurgy, the reinforcement is homogeneously dispersed in the matrix for the fabrication of composites [21].

Only a very few researchers have attempted to study the effects on the tribological properties of magnesium self-lubricating composites [22]. Therefore, magnesium matrix composites reinforced with solid lubricants are promising materials that should have good performance in tribo-mechanics, but lead to a reduction in hardness of the composites. An attempt has been made to estimate the dry sliding friction and wear behaviour of Mg−Gr and Mg−MoS_2 self-lubricating composites over a range of loads. The function of solid lubricants (Gr/MoS_2) in dry sliding conditions at room temperature was discussed. In addition, the self-lubricating composites were tested for uniaxial tensile and compressive strength.

2 Experimental

2.1 Powder preparation

The composites were prepared using the powder metallurgy route. To conduct the present study, different types of self-lubricating composites were prepared (Table 1).

Table 1 Details of composition and density values

Composition/%	Theoretical density/(g·cm^3)	Actual density/(g·cm^3)
Pure Mg	1.73	1.65
Mg−5Gr composite	1.77	1.67
Mg−10Gr composite	1.79	1.68
Mg−5MoS_2 composite	1.91	1.81
Mg−10MoS_2 composite	2.07	1.97

In this experiment, magnesium powders with mean particle size of 55 μm were used as the matrix material, and the graphite and molybdenum disulfide powders had mean particle sizes of 25 μm of 99.8% purity and 15 μm of 99.2% purity, respectively. The SEM images of the received magnesium, graphite, and molybdenum disulphide powder particles are shown in Fig. 1, respectively. The Mg particles had spherical and ellipsoidal shapes. The graphite was in the shape of flakes, and the MoS_2 particles had a layer shape. The powders were mixed in a planetary ball mill using

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