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ORIGINAL ARTICLE

Study of tribological properties on $Al/Al_2O_3/MoS_2$ hybrid composite processed by powder metallurgy

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KEYWORDS

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Abstract Aluminium ceramic composites with improved mechanical and chemical properties are essential and needed in aerospace and automotive application. The aluminium matrix composite reinforced with ceramic material of alumina (Al_2O_3) has good tribological properties. However, aluminium based ceramic composites require improvements in their lubrication properties. In this study an attempt is made in the development of a new material through powder metallurgy technique by the addition of molybdenum disulphide (MoS_2), which acts as a solid lubricant. This molybdenum disulphide (MoS_2) based solid lubricant has unique advantage that it can be used in vacuum space, but the same is not applicable in case of graphite. The microstructures, material combination, wear and friction properties were analysed by scanning electron microscopy, EDX, and pin-on-disc wear tester. The newly developed aluminium composite has significant improvements in tribological properties with a combination of 5% alumina (Al_2O_3) and 5% molybdenum disulphide (MoS_2). The test reveals that sliding distance of 1000 m and sliding speed of 1.5 m/s with applied load of 5 N result in minimum wear loss of 0.0102 g and coefficient of friction as 0.117.

1. Introduction

Aluminium Metal Matrix composites (AMC) were identified as good material [1,2] for automobile and space application. The AMC are used in various industries for its lightweight, cost effective, energy efficient and high stiffness. The wear behaviour of aluminium metal matrix composite has been studied [3–5]. It is stated that small amount of reinforcement produces greater amount of wear resistant properties. The MMCs are suggested [6,7] for piston, brake drum and cylinder block for its corrosion resistance and improved wear resistance properties for automobile components. Aluminium-based ceramic composites properties were pointed out by [8] for the good strength, frictional properties and self-lubrication properties and mentioning commonly used lubricants such as MoS_2, BN, Gr and CaF_2. The AMCs possess less frictional and wear resistance property and needs additional reinforcements to improve the properties. Further, addition of ceramic reinforcement enhances tribological properties of the composite material and similarly ceramic materials of SiC, Al_2O_3, B_4C, TiC, and AlN improved wear properties and mechanical strength. The influence of lubricants with wear behaviour and coefficient of friction properties is discussed [9,10]. In the recent work [11,12] effect of SiC on aluminium metal matrix

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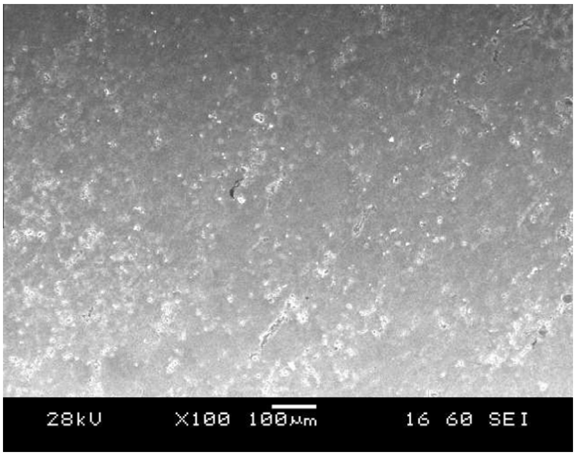

Figure 1 SEM image before wear test – Al.

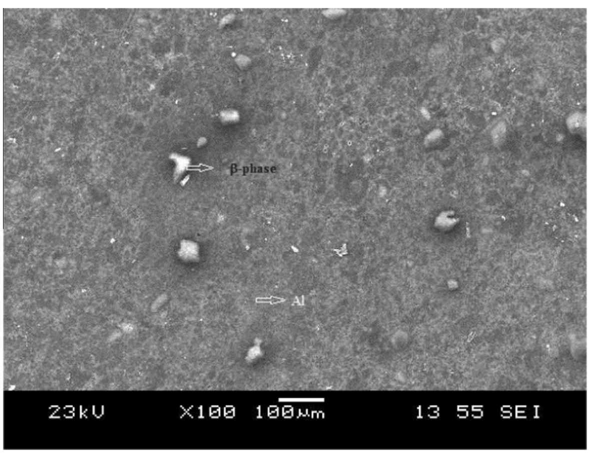

Figure 2 SEM image before wear test – Al + 5% Al_2O_3.

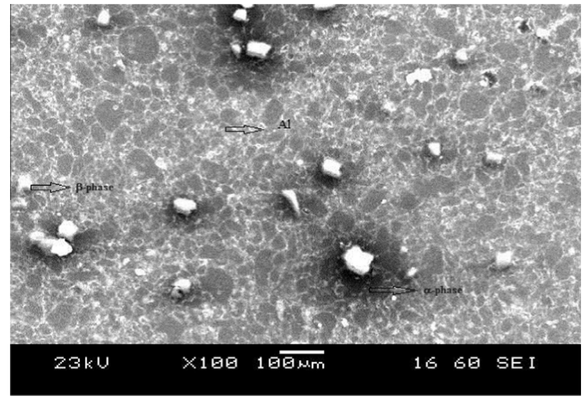

Figure 3 SEM image before wear test – Al + 5% Al_2O_3 + 5% MoS_2.

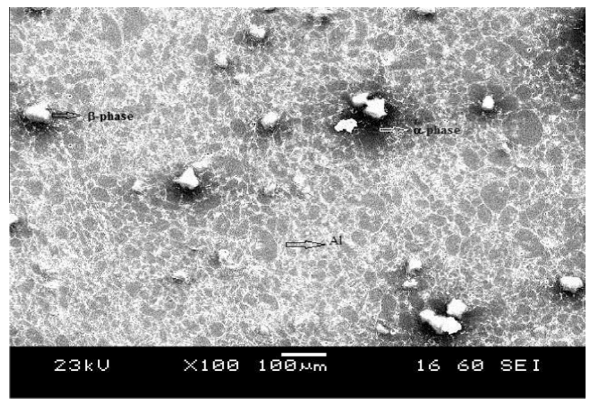

Figure 4 SEM image before wear test – Al + 5% Al_2O_3 + 10% MoS_2.

composites was discussed. The dry sliding wear behaviour of aluminium composites reinforced with various ceramic particles was studied [13,14] and found that the optimum addition of lubricant has attained enhanced to good frictional and wear resistance properties.

Subsequently, [15,16] has discussed the development of SiC/Gr, Al based composites by using stir-casting and other casting techniques. The effect of sliding distance, sliding speed and applied load were taken as parameters to study dry sliding wear behaviour of hybrid composites by [17]. The paper presents the results of experimental research in production of $Al/Al_2O_3/Gr$ powder composites using mechanical alloying [18] technique. The aluminium, alumina and graphite elemental powders have been mixed in a high-energy ball mill RETSCH PM 400. The discussion of [19] has shown the improvement of mechanical properties of hardness and wear resistance as compared with aluminium matrix composite.

Recently, the combination of Al/SiC/Gr [20] has found that the aluminium composite material containing the small volume of graphite produces superior wear and frictional properties over the base alloys. The literature shows that adding of graphite as solid lubricant is not suitable for working under vacuum atmosphere. In this context, introduction of Molybdenum disulphide as solid lubricant is proposed to develop Al/Al_2O_3 and MoS_2 based composite.

Table 1 Wear loss (gm) and Coefficient of friction (μ).

Applied load (N)	Al + 5% Al_2O_3		Al + 5% Al_2O_3 + 5% MoS_2		Al + 5% Al_2O_3 + 10% MoS_2	
	Wear loss (gm)	Coefficient of friction (μ)	Wear loss (gm)	Coefficient of friction (μ)	Wear loss (gm)	Coefficient of friction (μ)
5	0.0155	0.164	0.0137	0.141	0.0152	0.152
8	0.0171	0.183	0.0151	0.156	0.0165	0.174
10	0.0202	0.195	0.0174	0.165	0.0191	0.182
12	0.0216	0.211	0.0187	0.173	0.0201	0.193
15	0.0228	0.231	0.0198	0.183	0.0222	0.215

Table 2 Wear loss (gm) and coefficient of friction.

Sliding speed (m/s)	Al + 5% Al_2O_3		Al + 5% Al_2O_3 + 5% MoS_2		Al + 5% Al_2O_3 + 10% MoS_2	
	Wear loss (gm)	Coefficient of friction (μ)	Wear loss (gm)	Coefficient of friction (μ)	Wear loss (gm)	Coefficient of friction (μ)
0.5	0.0155	0.164	0.0137	0.141	0.0150	0.152
0.7	0.0135	0.156	0.0121	0.136	0.0129	0.146
1.0	0.0131	0.154	0.0115	0.131	0.0125	0.143
1.2	0.0124	0.150	0.0111	0.125	0.0118	0.141
1.5	0.0118	0.142	0.0102	0.117	0.0115	0.128

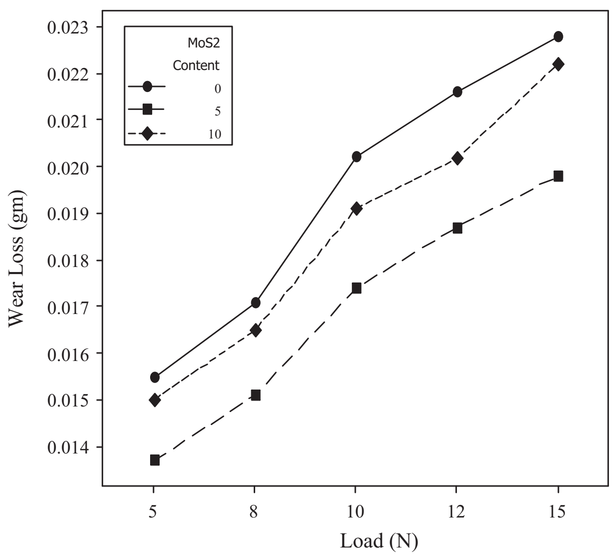

Figure 5 Wear loss vs applied load.

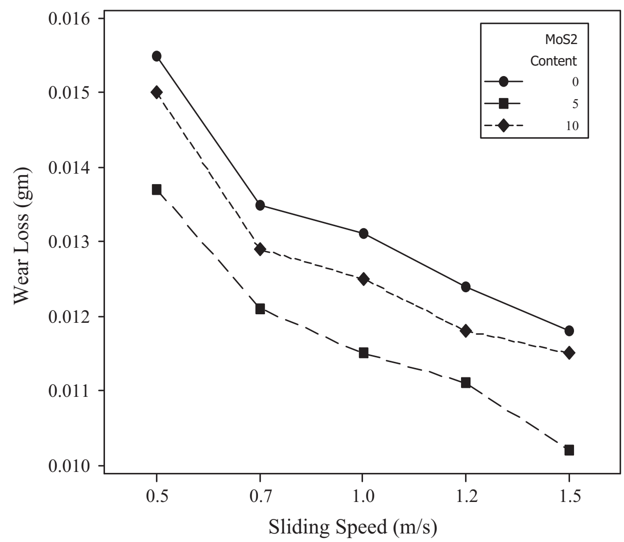

Figure 7 Wear loss vs sliding speed.

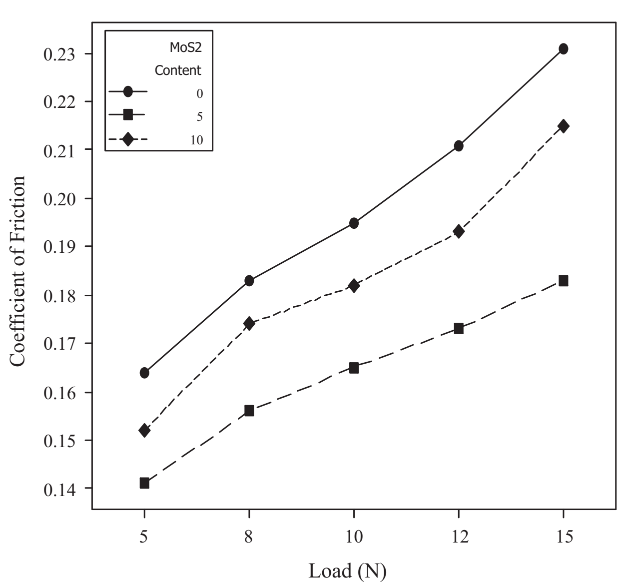

Figure 6 CoF vs applied load.

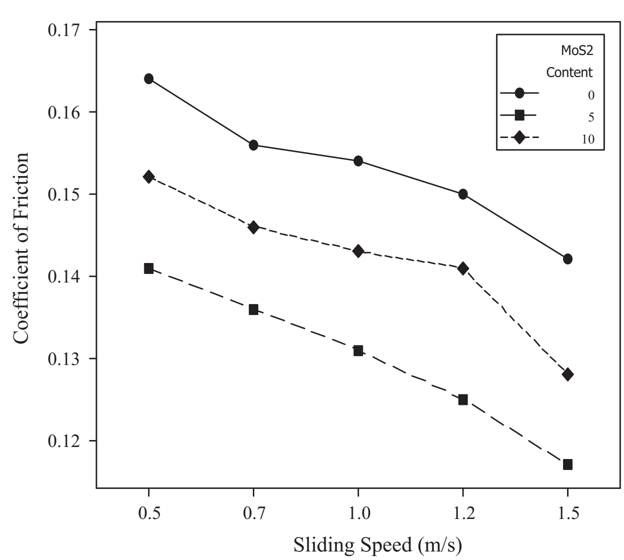

Figure 8 CoF vs sliding speed.

The composites were fabricated through powder metallurgy process method. Pure aluminium was used as the matrix material. Further, to increase the strength and wear properties of the composites, 5% of alumina is added and then Molybdenum disulphide is used as solid lubricant varying from 0 to 10 wt%. The principal objective of this investigation was to fabricate hybrid aluminium matrix composites by powder metallurgy and evaluate their wear and frictional properties using pin-on-disc wear tester. Furthermore, the SEM morphology and EDS testing of the combination were taken. The newly developed aluminium composite has significant improvements

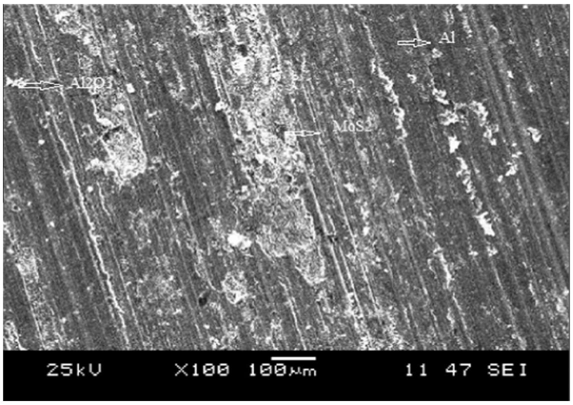

Figure 9 Worn surface SEM image of Al + 5% Al_2O_3 + 5% MoS_2.

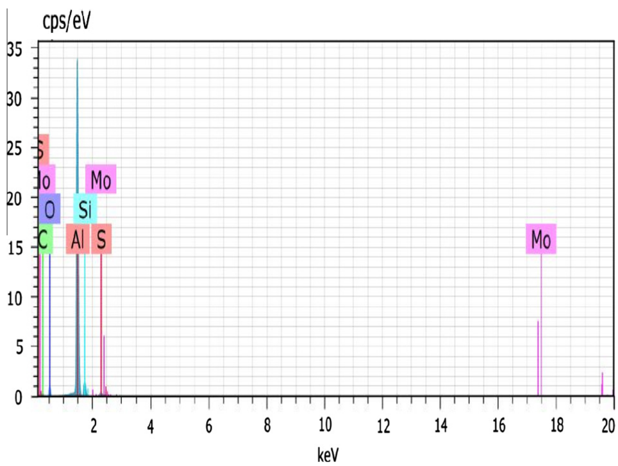

Figure 10 EDS image Al + 5% Al_2O_3 + 5% MoS_2.

in tribological properties for combination of 5% alumina (Al_2O_3) and 5% molybdenum disulphide (MoS_2). The results reveal that sliding distance of 1000 m and sliding speed of 1.5 m/s with applied load of 5 N produce minimum wear loss of 0.0102 g and coefficient of friction of 0.117.

2. Experimental procedure

The aluminium hybrid composite is developed by powder metallurgy technique. The hybrid composite contains elements of aluminium (Al), Alumina (Al_2O_3) and Molybdenum disulphide (MoS_2). Initially, the elemental powders were dried at 110 °C for one hour and mixture of Aluminium, alumina and MoS_2 powders was milled in planetary tumbler mixer using stainless steel balls with a diameter of 10 mm, in order to produce hybrid aluminium composite. In the planetary tumbler mixer ball to powder weight ratio of 10:1 is maintained with the collaborating time of six hours. The mechanical mixing is executed at 50 rpm using a toluene medium to avoid the oxidation or penetrating of powders on the wall of the vial.

Three combinations of specimens were developed in this process as Al + 5% Al_2O_3, Al + 5% Al_2O_3 + 5% MoS_2 and Al + 5% Al_2O_3 + 10% MoS_2. The green compacts were processed by uniaxial press under a constant pressure of 800 MPa at room temperature and zinc stearate acts as die wall lubrication. Subsequently, sintering process was performed at a thoroughly controlled temperature of 530 °C for 60 min in muffle furnace to increase the strength of the green compact. The specimen is further cooled in atmospheric air for 72 h. The specimen dimension is maintained as diameter of 10 mm and height of 30 mm. The pin-on-disc equipment (Winducom 2010 software), AISI 52 100 (EN31) disc based on ASTMG99-05 is used to analyse the dry sliding wear property of the specimen. All tests were performed with various testing parameters of applied loads of 5–15 N, varying sliding distance of 1000–3000 m and sliding speeds of 0.5–1.5 m/s. The specimen was weighed before and after testing to determine the amount of wear loss with an accuracy of 0.1 mg weight balance machine. The SEM image is captured before and after the wear test to examine the image pattern and subsequently energy dispersive spectroscopy was performed to analyse the hybrid presences of composite elements.

3. Results and discussion

The polished specimen images were captured in the scanning electron microscopy with various magnification and scale. Fig. 1 shows the microstructure of pure aluminium with ×100 magnification and 100 μm scale. Similarly, Figs. 2–4 represent the SEM image of ×100 magnification and 100 μm scale for hybrid composite of Al + 5% Al_2O_3, Al + 5% Al_2O_3 + 5% MoS_2 and Al + 5% Al_2O_3 + 10% MoS_2 respectively. The image reveals uniform mixture of aluminium, alumina and the evenly distributed molybdenum disulphide over aluminium matrix. The matrix phase is α-phase that is Al/alumina composition and covers high fraction area in the hybrid composite. The secondary phase is β-phase; it corresponds to MoS_2 content and occupies minimum fractional area. The image with minimum dark zone reveals the minimum porosity formation level in the specimen.

The wear and coefficient of friction properties were analysed by pin-on-disc equipment with the testing parameter ranges of applied loads of 5–15 N, varying sliding distance of 1000–3000 m and sliding speeds of 0.5–1.5 m/s. The pin-on-disc equipment was operated with constant sliding speed of 0.5 m/s and constant sliding distance of 1000 m to calculate the wear loss. The wear loss and coefficient of friction were calculated for Al + 5% Al_2O_3, Al + 5% Al_2O_3 + 5% MoS_2 and Al + 5% Al_2O_3 + 10% MoS_2 for five ranges of applied load listed in Table 1.

The wear loss increased with respect to the applied load for all the three combinations of specimen. The minimum wear loss of 0.0137 g and minimum coefficient of friction of 0.141 are attained by Al + 5% Al_2O_3 + 5% MoS_2 specimen at applied load of 5 N.

Fig. 5 indicates specimen behaviour for wear loss versus applied load, and the wear loss increases with applied load for all three combinations. Similarly, Fig. 6 shows the relationship between coefficient of friction and applied load, and the coefficient of friction increased correspondingly with applied load. The wear loss and coefficient of friction results under constant applied load of 5 N and sliding distance of 1000 m are presented in Table 2. The wear loss and coefficient of friction were found minimum in high sliding speed and graphs and are mentioned in Figs. 7 and 8 respectively. The minimum wear loss of 0.0102 g and minimum coefficient of friction of 0.117 are found for Al + 5% Al_2O_3 + 5% MoS_2 specimen at sliding speed of 1.5 m/s.

The SEM image of worn surface of composite specimen Al + 5% Al_2O_3 + 5% MoS_2 is shown in Fig. 9. The surface of the composite sample seems to be crossed by grooves, generated by the steel disc surface contact. The grooves were formed by detachment of particles from specimen surface due to abrasion. The scratches found on the composite surface are lesser and the abrasion develops parallel grooves and scratches in the sliding direction. In higher sliding velocity, the adhesion wear is found and at minimum sliding distance, protective layer for the composite is formed by oxide layer on the surface which develops high cohesive forces to the contact surfaces.

Heat generation increased with increasing sliding speed during friction contact. The aluminium matrix tends to plastic deformation and leads to form an oxide surface at the elevated temperature, it permits smooth sliding on the disc surface and wear loss is reduced at higher speed. The oxide development in the worn surface of hybrid Al/5% Al_2O_3/5% MoS_2 composite is shown by the O, Al, Mo, S and C peaks in Fig. 10 of Energy Dispersive Spectroscopic analysis.

4. Conclusion

The three types of Aluminium hybrid composites developed by powder metallurgy are studied in this article. The introduction of MoS_2 as solid lubricant has produced significant tribological performance. In the studied three combinations of Al + 5% Al_2O_3, Al + 5% Al_2O_3 + 5% MoS_2 and Al + 5% Al_2O_3 + 10% MoS_2, wear and friction properties depended up on the percentage of MoS_2. The combination of Al + 5% Al_2O_3 + 5% MoS_2 has minimum wear and coefficient of friction at constant sliding speed of 0.5 m/s and constant sliding distance of 1000 m. Similarly, the minimum wear and coefficient of friction were observed at sliding speed of 1.5 m/s with content applied load of 5 N and sliding distance of 1000 m. The study reveals that further addition of 10% MoS_2 in the hybrid composite does not help to improve the tribological property. The design of experiment may be extended to optimise the composition and tribological property as the scope of work in future.

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