

Prediction of Mechanical and Wear Properties of Al-6061/MoS₂ (Molybdenum Disulphide) Composites

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ABSTRACT: This work investigated the influence of Molybdenum disulfide (MoS₂) on the wear and mechanical properties of Aluminium alloy 6061. The investigation reveals the effectiveness of incorporation of Molybdenum disulfide in the composite for gaining wear reduction. The Al 6061 (aluminium alloy 6061) reinforced with MoS₂ was investigated. MoS₂ was used in powder form and mixed with Al 6061. The composites were fabricated using Stir Casting method. The solid lubricating material was incorporated into aluminium alloy matrix to accomplish a reduction in wear volume and increase in wear resistance. The Al 6061 composites were prepared with 5, 10 and 15 wt.% of MoS₂. The composition test, tensile test, Hardness Test, Pin on Disc wear test were performed to check wear and mechanical properties of composites with MoS₂. The investigation revealed that the tensile strength and wear resistance of Al 6061/MoS₂ composite increases at 5 wt.% of MoS₂ and then decline with a further increase in the percentage of lubricant MoS₂ such as 10 or 15 wt.%. The hardness of composites decreases with the increase in the wt.% of MoS₂.

KEYWORDS: Al6061, Molybdenum disulfide (MoS₂), Metal matrix composites, stir casting, Mechanical testing, wear resistance

I. INTRODUCTION

Aluminium and its alloys play a crucial role in various technological fields such as automobile, aerospace, and defense owing to their excellence in strength to weight ratio and other mechanical properties. Due to the nontoxic and easy to recycle nature of aluminum and its alloys, they are widely used in many sectors. However, the adversity of aluminium alloys is that they exhibit low resistance to abrasive wear under deficit lubricating conditions and severe retention of lubricating film over the sliding surface, which becomes abortive to tribological applications. Aluminium alloys are alloys in which aluminium is the predominant metal. The typical alloying elements are copper, manganese, Magnesium, silicon, and zinc. Depending upon the major alloying element aluminium is classified into different grades. Different grades of aluminium are pure aluminium alloys (1xxx series), aluminium-copper alloys (2xxx series), aluminium-manganese alloys (3xxx series), aluminium-silicon alloys (4xxx series), aluminium magnesium alloys (5xxx series), aluminium-magnesium-silicon alloys (6xxx series), aluminium-zinc alloys (7xxx series) and aluminium-lithium alloys (8xxx series). Aluminium alloys typically have an elastic modulus of about 70 Gpa, which is about one-third of the elastic modulus of most kinds of steel and steel alloys. Therefore, for a given load, a component or unit made of an aluminium alloy will experience a greater elastic deformation than a steel part of the identical size and shape. We can achieve stiffer and lighter designs with aluminium alloys than is feasible with steels.

Major characteristics of the Aluminium alloys 6xxx series were high corrosion resistance, extrudability, moderate strength, ultimate tensile strength range: 124-400 MPa, readily welded by GMAW, GTAW. To improve their tribological properties, aluminium alloy with MoS₂ particulate composites are being explored. These self-lubricating composites have accentuated due to their excellent wear properties as compared to pure aluminium. Lubricant particles help in reducing shear strength under sliding conditions to avoid plastic deformation of surface and

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act as a solid lubricant between two sliding surfaces hence reducing friction, wear and improve seizure resistance of the composite.

II. RELATED WORK (LITERATURE SURVEY)

Much work has been done in developing aluminium composites with different reinforcements. P. Iglesias et al. [1] studied wear behavior of Bakelite resin-matrix composites reinforced with nanocrystalline Al 6061 T6 particles produced by Machining (grain size 70–500 nm). It shows a wear reduction of around 60% on the conventional micro structured reinforcement. Manoj Singla et al. [2] investigate Al–SiC composites containing four different weight percentages 5%, 10%, 20% and 25% of SiC and compared with pure aluminium. Result shows wear rate decreases linearly with increasing weight fraction of silicon carbide, and the average coefficient of friction decreases linearly with increasing normal load and weight fraction of SiC. S. Gopalakrishnan and N. Murugan et al. [3] worked on Aluminium matrix reinforced with titanium carbide (Al–TiCp). Results show that Wear loss increased linearly with the normal load. However, the wear rate increased marginally with increased TiC addition. Similarly, Hulya Katelyn [4], G.B. Veeresh Kumar [5], A. Baradeswaran and A. Malaya Perumal [6] worked on different composites of aluminium. Mahagundappa M. Benal and H.K. Shivanand [7] describes the abrasive wear rate of as-cast and heat-treated Al (6061) alloy reinforced with 9% by weight of SiC particulate and 0, 1, 3 and 5% by weight of E-glassfiber subjected to different aging durations. M. Baki Karamis et al. [8] study friction and wear behaviors of reciprocating extruded Al–SiC composite. Devaraju Arcuri et al. [9] studied the influence of tool rotational speed on wear and mechanical properties of a6061-T6aluminium alloy based surface hybrid composites [(SiC + Gr) and (SiC + Al₂O₃)] fabricated via Friction stir processing (FSP). A. Baradeswaran et al. [10] investigate 7075 aluminium alloy–graphite composites for its tribological and mechanical behaviour under dry sliding conditions. Lin CB et al. [11] showed that increasing the graphite content, observed that wear rate also simultaneously increases due to the decrease in toughness and hardness of composites material. Yang JB et al. [12] analysed that by means of increasing the graphite content in Al/Graphite composites with the effect the wear rate is lowered.

III. MATERIALS AND METHODS

A. Chemicals and Instruments

Aluminum 6061 and MoS₂ were purchased, and casting facility was used from charger foundry, Faridabad. The wear test was performed using a pin on disc apparatus, MNIT, Jaipur, India. The hardness test was conducted at MRCE Faridabad. Tensile test and composition test of materials were performed at Spectro Analytical Labs Limited, Faridabad

B. Material Fabrication

The chemical composition of the Al 6061 alloy and its composites are given in Table 1, Table 2, Table 3 and Table 4. The aluminium alloy 6061 was reinforced with 5, 10, 15 wt.% MoS₂. Al 6061 composites with MoS₂ were prepared by a stir casting process. Aluminium alloy 6061 was preheated for 3-4 hours at 450°C separately. Molybdenum disulphide powder was also preheated at 900°C. Preheated MoS₂ particulates are introduced in the wt.% of 5, 10, and 15 in molten aluminium alloy 6061. Aluminium alloy 6061 and MoS₂ were mixed mechanically with the help of stirrer, and the final matrix is kept in the pit furnace at 750°C. The stirring is continued to ensure a proper mixing and slurry. The slurry of the composites thus prepared was poured into sand molds.

C. Wear Test

Pin on disc test apparatus shown in Figure 1 was used to investigate the dry sliding wear behaviour of Al 6061, Al 6061/5 wt.%, Al 6061/10wt.% and Al 6061/15wt.% MoS₂ composites. Pin specimens of 6 mm diameter and 20 mm height for wear test were prepared from the above composites were machined.

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Fig 1: Pin on Disc machine
[Courtesy: MNIT, Jaipur]

Table 1: Chemical composition of Al 6061 (After Casting)

Element	Symbol	Composition% in Al 6061
Copper	Cu	0.024
Magnesium	Mg	0.092
Silicon	Si	0.392
Iron	Fe	0.485
Nickel	Ni	0.002
Manganese	Mn	0.168
Zinc	Zn	0.02
Lead	Pb	<0.001
Tin	Sn	0.009
Titanium	Ti	0.016
Chromium	Cr	0.003
Vanadium	V	<0.01
Aluminium	Al	98.78

Table 2: Chemical composition of Al 6061/5wt.% MoS₂ Composite

Element	Symbol	Composition% in Al 6061
Copper	Cu	0.02
Magnesium	Mg	0.043
Silicon	Si	0.35
Iron	Fe	0.429
Nickel	Ni	0.004
Manganese	Mn	0.161

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Zinc	Zn	0.021
Lead	Pb	<0.001
Tin	Sn	0.01
Titanium	Ti	0.018
Chromium	Cr	0.002
Vanadium	V	<0.01
Aluminium	Al	98.93

Table 3: Chemical composition of Al 6061/10wt.% MoS₂ Composite

Element	Symbol	Composition% in Al 6061
Copper	Cu	0.03
Magnesium	Mg	0.001
Silicon	Si	0.415
Iron	Fe	0.98
Nickel	Ni	0.348
Manganese	Mn	0.152
Zinc	Zn	0.335
Lead	Pb	0.025
Tin	Sn	0.73
Titanium	Ti	0.012
Chromium	Cr	0.013
Vanadium	V	0.063
Aluminium	Al	96.89

Table 4: Chemical composition of Al 6061/15wt.% MoS₂ Composite

Element	Symbol	Composition% in Al 6061
Copper	Cu	0.62
Magnesium	Mg	0.023
Silicon	Si	3.47
Iron	Fe	0.85
Nickel	Ni	0.082
Manganese	Mn	0.325
Zinc	Zn	0.445
Lead	Pb	0.096

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Tin	Sn	0.164
Titanium	Ti	0.024
Chromium	Cr	0.018
Vanadium	V	0.019
Aluminium	Al	93.86

A hardened steel disc of 100 mm diameter of 58HRC was used as the counter surface in the wear test. The test was conducted with various sliding velocity of 0.5, 1.0, 2.0, 3.0 m/s for the sliding distance of 100, 200, 300 and 400 m for the constant load of 10N. This test was also conducted at various load of 10, 20, 30N at the constant sliding speed and sliding distance of 1.0 m/s and 100 m respectively. The test was conducted at room temperature.

The initial weight of the specimen was measured in an electronic weighing machine with a least count of 0.0001 g. A strain gauged friction detecting arm holds and loads the pinned specimen vertically on a rotating hardened steel disc. In each test after running the fixed sliding distance, the specimen was removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The wear rates were determined using the weight loss method.

D. Hardness test

The hardness tests were carried out using Rockwell hardness testing machine (Specification of m/c) with a 1/16" (1.588 mm) steel ball indenter and 100 kg load for 30 s. The test was conducted at room temperature (30°C), and the measurement of hardness was taken at four different places on each sample to obtain an average value of hardness.

E. Tensile test

The tensile strength was evaluated on the cylindrical tensile specimen of casted composites. The tensile test was conducted on Universal Testing Machine (UTM) at Spectro Analytical Labs, New Delhi. Figure 2 represents the specimen for tensile and composition test. Figure 3 shows picture of cylindrical pins used for the wear test on pin on disc machine.

Fig. 2: Specimens for Tensile and Composition test

Fig. 3: Cylindrical pins used for wear test



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IV. RESULTS AND DISCUSSION

A. Effect of Reinforcements

The effect of MoS₂ on the hardness and the tensile strength of the composite obtained from hardness test and tensile test are shown in Figure 4 and 5. The hardness measurements were carried out on a Rockwell hardness-testing machine.

From figure, it is observed that the hardness of the Al 6061/MoS₂ composite decreases with the addition of MoS₂. It was lower than that of base alloy. The hardness of all the composites was significantly lower than that of the base alloy characterized by the lubricant nature of MoS₂ particles.

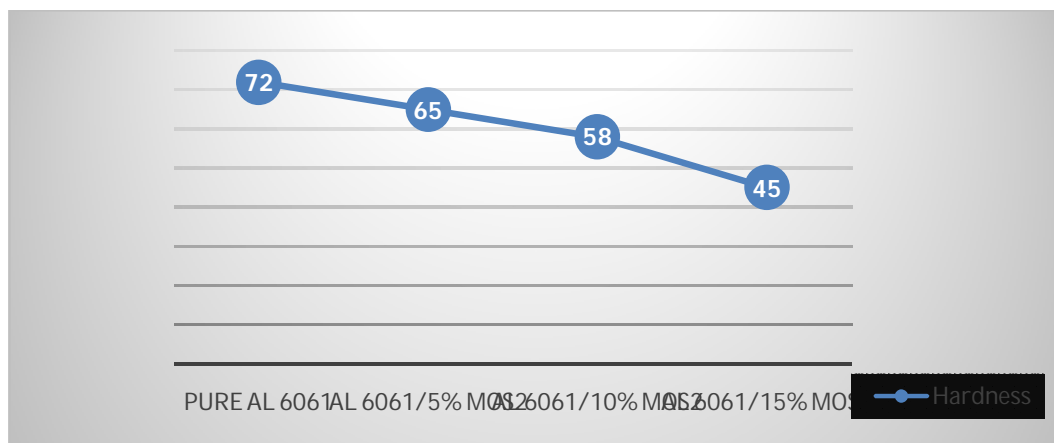


Fig.4:Rockwell hardness of Aluminium Composites

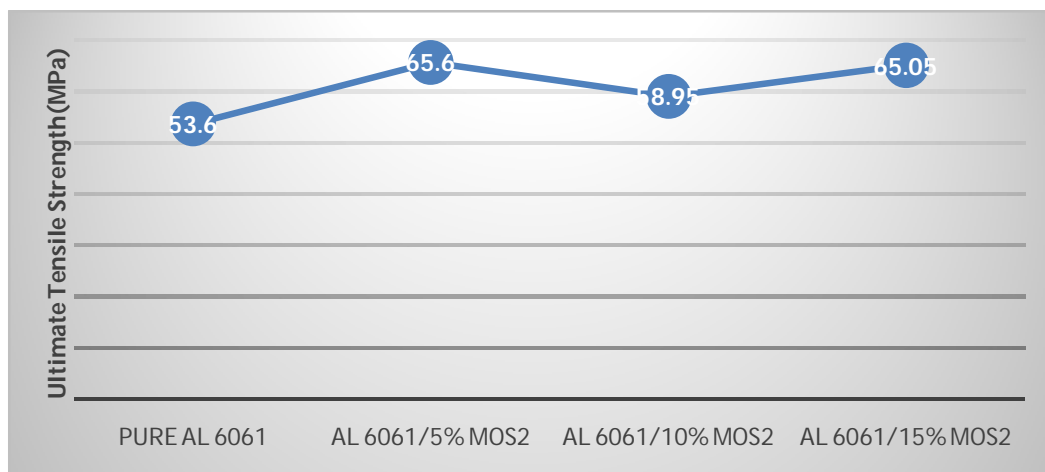


Fig. 5:Ultimate tensile strength of Al 6061 Composites

The variation of the ultimate tensile strength of aluminium and its composites with the addition of MoS₂ is shown in Figure 5. Ultimate tensile strength of composites increases with the addition of MoS₂. There is a slight decrement in the UTS of 10wt.% Aluminium composites due to some casting defects in composites. Figure 6 and Figure 7 shows variation in the yield stress and elongation of the pure metal and its composites during a tensile test. Yield stress and percentage elongation of material first increases and then decreases with the further addition of MoS₂.

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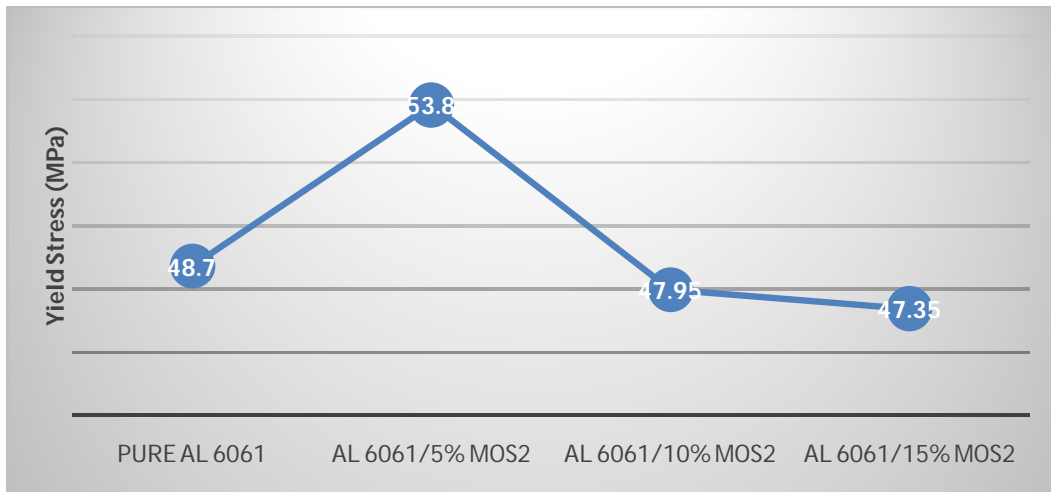


Fig. 6: Yield Stress of Al 6061 Composites

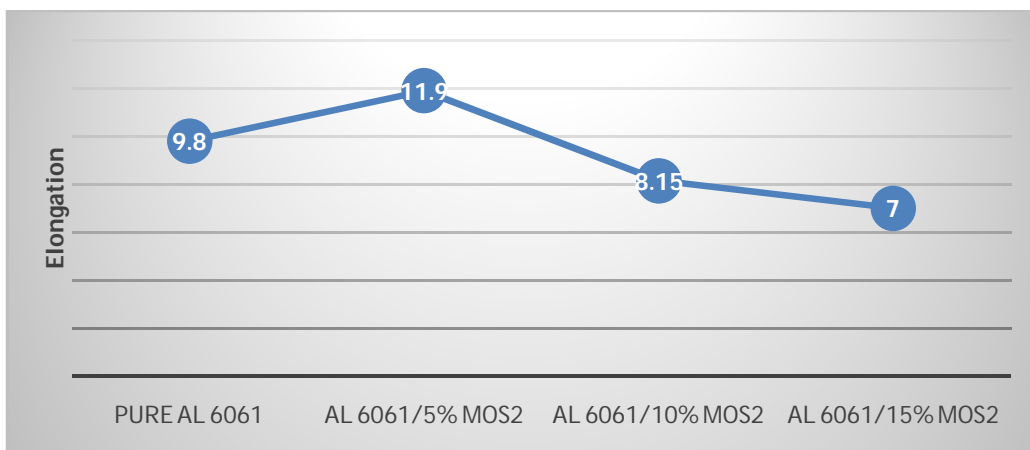


Fig. 7: Percentage elongation of Al 6061 Composites

B. Wear behavior of the composites

The wear behaviour of aluminium composites is analyzed under dry sliding conditions on a pin on disc machine. Figure 8 to Figure 12 show variation in wear volume of composites with the addition of solid lubricant at different parameters (sliding speed, sliding distance, and load). There is a significant effect of MoS₂ on the wear volume of aluminium composites. Wear volume decreases with the addition of solid lubricant and minimum at 5wt.% of MoS₂.

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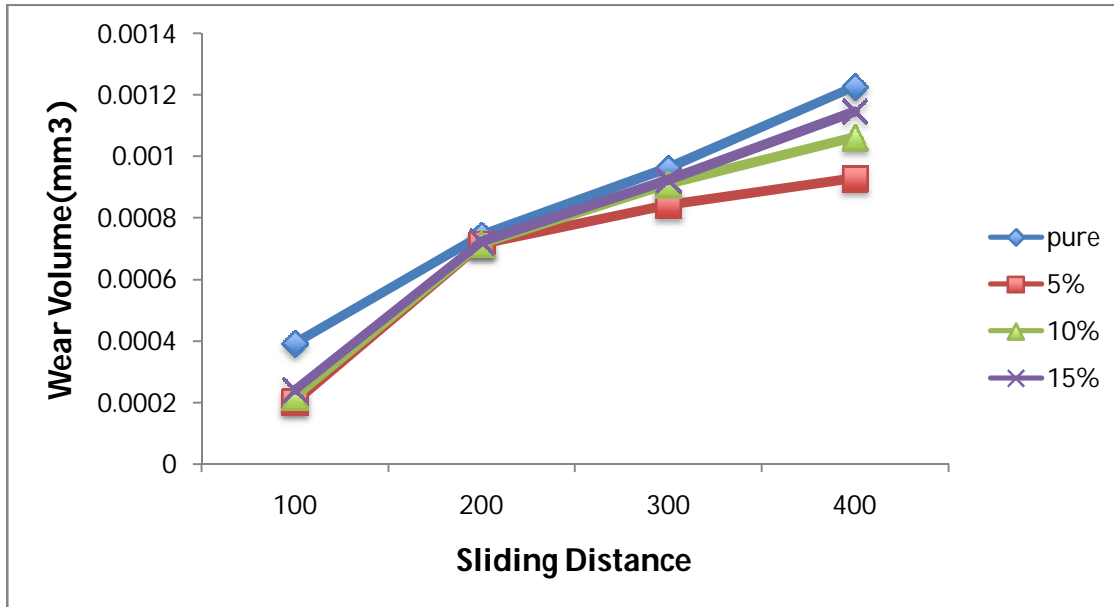


Fig. 8: Wear at different sliding distance at constant load (10N) and speed (0.5 m/s)

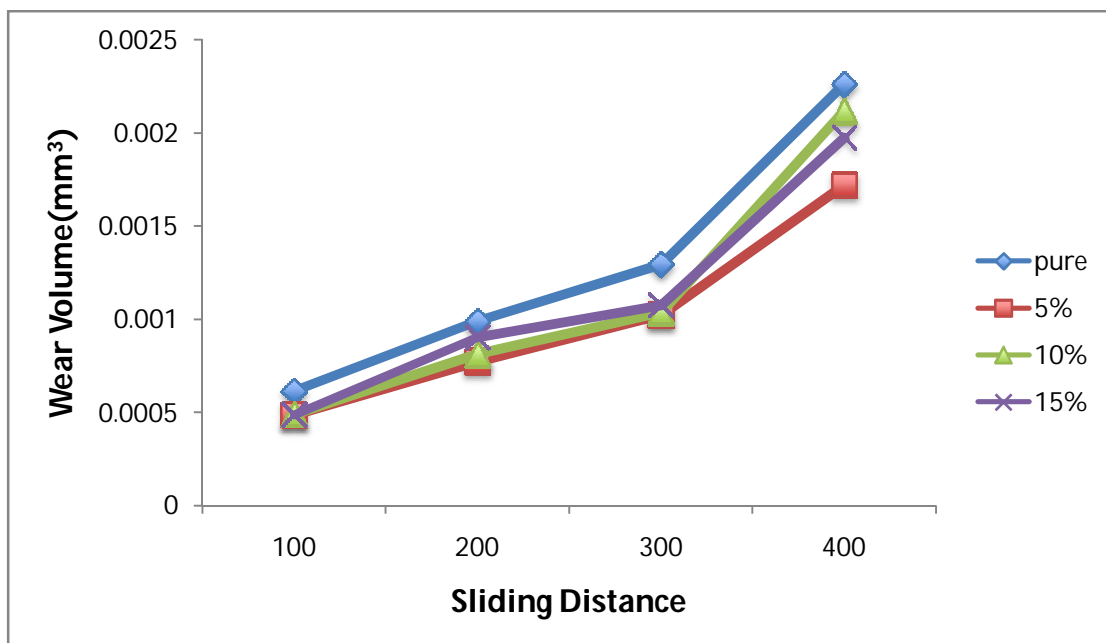


Fig. 9: Wear at different sliding distance at constant load (10N) and speed (1.0 m/s)

Above Figure 8 shows variation in the wear volume of aluminium composites at different sliding distance i.e. 100, 200, 300, 400 mm respectively at constant load condition of 10 N and constant speed of 0.5 m/s. wear volume increases with the sliding distance. The variation in the wear volume of aluminium composites at different sliding distance i.e. 100, 200, 300, 400 mm respectively at constant load condition of 10 N and constant speed of 1.0 m/s as shown in Figure 9.

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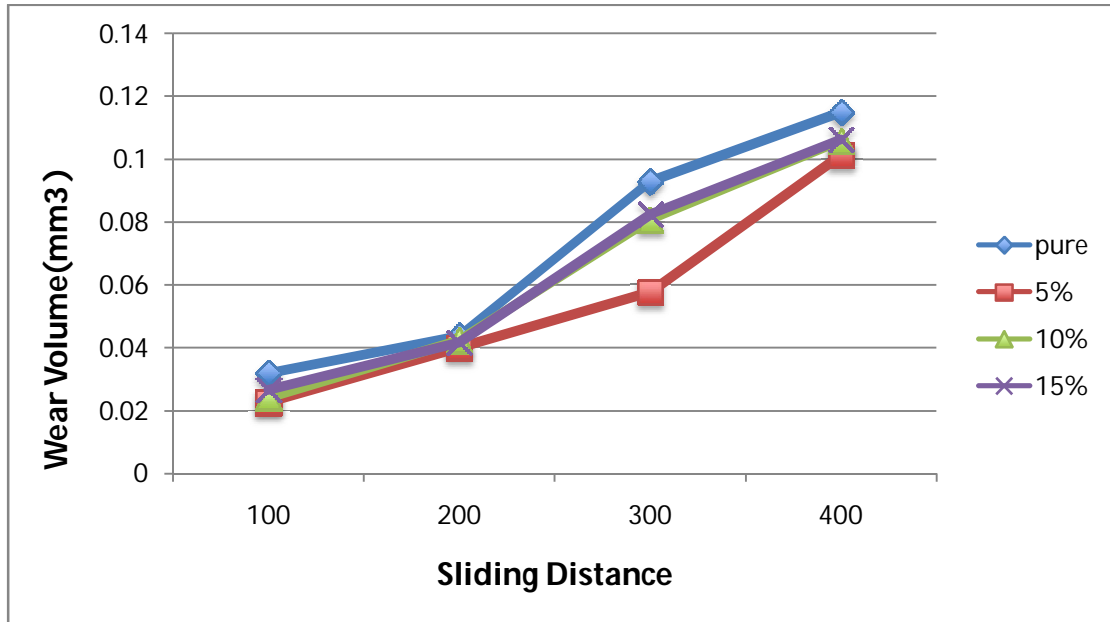


Fig. 10:Wear at different sliding distance at constant load (10N) and speed (2.0 m/s)

In figure 10 shows variation in the wear volume of aluminium composites at different sliding distance i.e. 100, 200, 300, 400 mm respectively at constant load condition of 10 N and constant speed of 2.0 m/s. In figure 11 shows variation in the wear volume of aluminium composites at different sliding distance i.e. 100, 200, 300, 400 mm respectively at constant load condition of 10 N and constant speed of 3.0 m/s. The variation in the wear volume of aluminium composites at different load i.e. 10, 20 and 30N respectively in figure 12. It concluded that wear volume increases with the increase in applied load.

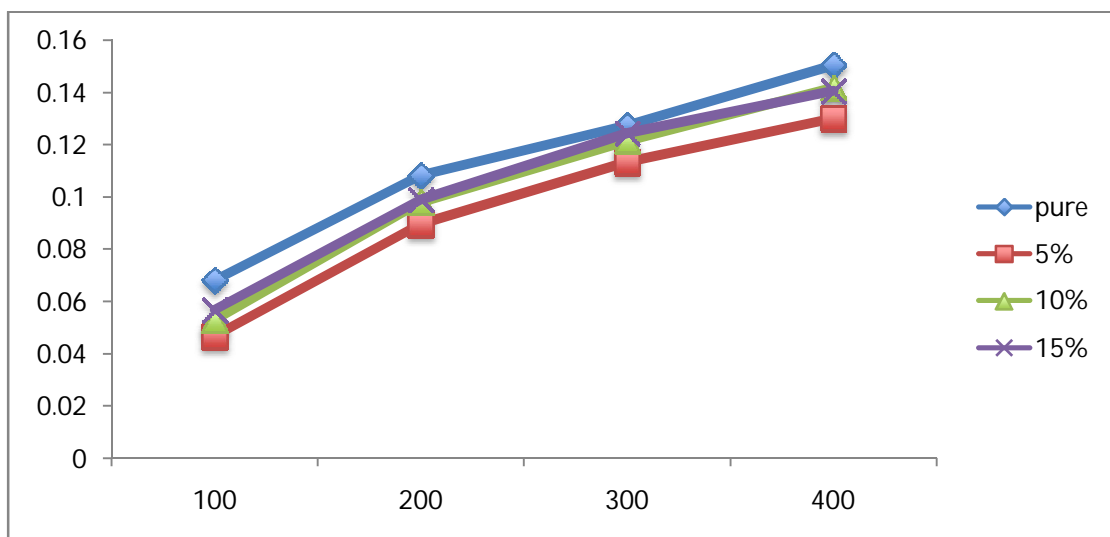


Fig. 11:Wear at different sliding distance at constant load (10N) and speed (3.0 m/s)

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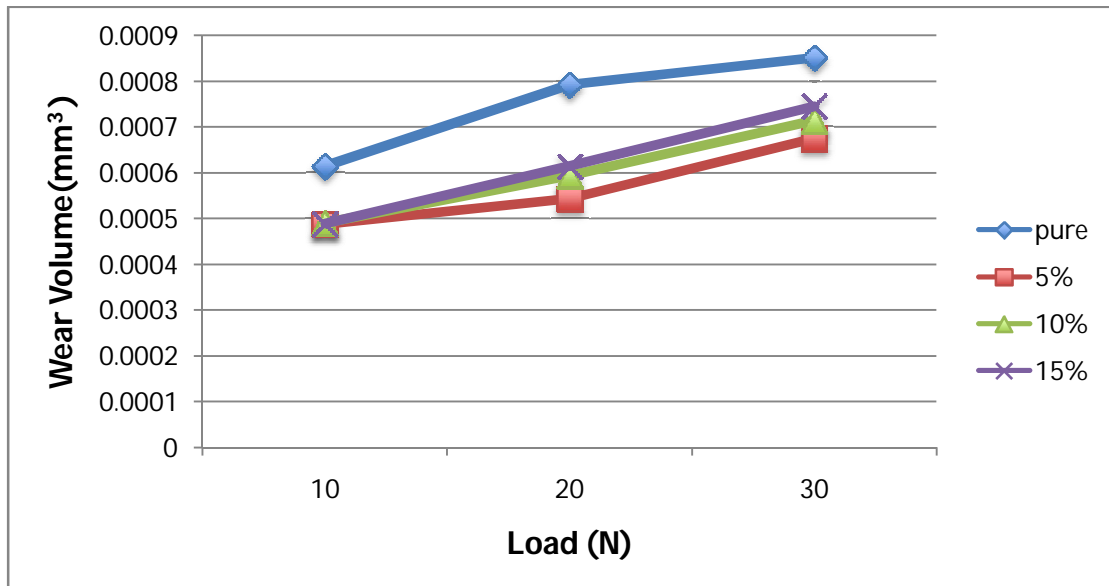


Fig.12:Wear at different load

V. CONCLUSIONS

In this research work, Al 6061/ MoS₂ composites are fabricated using the stir-casting technique and the mechanical and wear behaviour of the metal matrix composites were studied. The significant conclusions of the studies carried out on Al6061–MoS₂ MMCs are as follows:

1. The Liquid metallurgy technique (stir casting route) was successfully adopted in the preparation of Al6061–MoS₂ composites containing the reinforcement up to 15wt.%.
2. From composition test, we analyze that there are some little bit changes in the percentage of elements in the composites with the addition of MoS₂. Percentage of copper, silicon, manganese, lead, titanium, and chromium increases with the addition of MoS₂. Similarly, the percentage of Aluminium, Magnesium decreases with the increase in wt. % of MoS₂.
3. The hardness of composites decreases with the increasing percentage of MoS₂.
4. Tensile properties of Al 6061/ molybdenum disulfide composites improve at 5% addition of MoS₂ and decreases with the further addition of molybdenum disulfide i.e. 10%, 15%.
5. 5wt % MoS₂ composite shows minimum wear volume with increasing sliding speed as compared to Al 6061 alloy and its composites (10%, 15% MoS₂).
6. The studies conducted to see the effect of applied load on wear rate revealed that wear rate increases continuously with aload in a linear manner and this is due to the pull out of the molybdenum disulfide from the matrix material.
7. Wear volume of the pure aluminium 6061 alloy and its composites increases with the increase sliding distance.
8. Wear volume of aluminium composites was significantly influenced by sliding distance, sliding speed and applied load.
9. Above results show that the wear volume was optimum with the 5wt.% MoS₂ addition to the base alloy as compare to other weight percentage.

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