

An investigation on dry sliding wear behaviour of AA6061-AlNp composite

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Abstract. This paper studies the effect of load, sliding distance, reinforcement percentage and temperature on dry sliding wear behaviour of Al-AlNp composites by using pin on disc machine. The wear test was conducted at different loads (1,2,3 & 4 Kg), temperatures (30°C, 100°C, 170°C & 240°C) and sliding distances (500m,1000m,1500m and 2000m). Increase in wear rate has been observed by increasing the load and sliding distance, at the same time it has been decreased by increasing the reinforcement percentage and temperature. At the higher loads, temperatures and sliding distances adhesive wear, abrasive wear and oxidation wear are observed to be dominant modes of wear mechanisms in the composite.

1. Introduction

AA6061 originally called 61S Alloy, it is a precipitation hardened alloy. In this alloy, magnesium and silicon are the major constituent elements [1]. Hard ceramic particles are highly stimulating in attaining improved mechanical properties like hardness, tensile strength, yield strength, and young's modulus [2]. Concerning to the mechanical properties of reinforcements results higher strength and hardness but often disbursement of some ductility. AMCs (Aluminium Metal Composites) are maximum conceivable materials for engineering applications because of their outstanding properties like high specific strength, stiffness, wear resistance, electrical and thermal conductivity etc., Due to these properties AMCs have been popularly using in automobile, aerospace, mining and minerals, defence etc. [3-5]. Wear resistance of the aluminium composites are mainly depending on shape, size and type of reinforcement. Apart from the above, wear resistance also depends on interfacial bonding between matrix and reinforcement material. Al-AlNp and Al-SiC composites are popularly used in micro-electronic devices. Thermal conductivity of SiC(250 W/mK) is greater than AlNp(175 W/mK), but AlNp is more stable with aluminium alloys than SiC. Silicon carbide reacts with aluminium and form Al_4C_3 . This causes degradation of mechanical properties of Al-SiC composites [6-13]. Jerome, Ravi Sankar et al were conducted investigation on Al-TiC composites at higher temperatures to know the dry sliding wear behaviour of the composites. They found that wear is increased by increasing the applied load and decreased by increasing the reinforcement percentage. They also found that both the cases i.e. in monolithic and composite offer greater resistance to thermal softening by forming an oxide layer. They also concluded that, due to formation of transfer layer wear rate is less at higher temperatures than room temperatures [14]. Kumar et al studied temperature effect on wear behaviour of Al-7Si-TiB₂ composites, they found that reinforcement material improves the wear resistance of composite at room temperature as well as at higher temperatures. They also found that wear of the alloy changed from mild to severe at the loads of 80N, 60N & 40N with 373K, 423K and 473K respective temperatures. But the addition of 5% reinforcement particles (TiB₂) to the Al-7Si alloy, transition load is 120N at 473K and 80N at 573K [15]. Cui Jar et al conducted the investigation to know the dry sliding wear behaviour of aluminium composites at higher temperatures. They found that with increased sliding velocity, wear rate of the composite was increased up to 0.6 m/s then after wear rate was decreased gradually. But at the temperature 473K, wear rate of the composite is decreased with increased sliding velocity. And also



they found that by increasing the reinforcement percentage wear rate decreases at higher temperatures. In this investigation, they concluded that adhesive, oxidation and abrasive wear are the main motives for wear mechanisms [16]. Ashok Kumar et al developed four factors (Sliding distance, sliding speed, normal load and mass fraction of AlNp reinforcement) five level regression model to predict the dry sliding wear of Al-AlNp composite. They found that with increased load, sliding distance and sliding speed wear rate of the Al-AlNp composite will be decreased. But wear rate was decreased by increasing the reinforcement percentage. At higher sliding velocities, delamination is the principle wear mechanism along with the ploughing and abrasive wear. They concluded that in AA6061 alloy adhesive wear is dominant and in the case of AA6061-AlN composites abrasive wear is dominant [17]. R.N.Rao and S. Das examined the effect of sliding distance on frictional co-efficient and wear of cast and heat treated Al-SiC composite. They acknowledged that heat treated composite gives superlative wear properties than the base alloy. But coefficient of friction varies up and down in narrow range [18].

2. Experimental procedures

2.1 Fabrication

A prepared and immaculate aluminium alloy (AA6061-T6) of diameter 50.8 mm and 200 mm long bars and 2 μ m size AlNp particles (reinforcement) were used as crude materials. In present research, Al-AlNp composites were fabricated through stir casting route. During fabrication aluminium alloy rods (AA6061) were placed in electric stir casting furnace which contains the stainless crucible. The stir casting machine also contains stainless stirrer (coupled with electric motor) to stir the melted aluminium. Initially temperature of the electric furnace set to 1000°C, when temperature of the stir casting furnace reaches to 650°C argon gas had been supplied to the crucible to avoid reactions between molten aluminium and atmospheric gases. And when the temperature of melted aluminium reaches to 1000°C, the melt was stirred with the help of stirrer to form vortex. Proper stirring of melted aluminium with constant speed (500 rpm) is essential to ensure uniform distribution of AlNp. When the vortex forms, a measured amount of preheated AlNp at 700°C was added to the melted aluminium at the periphery of the vortex. AlN particles were added into the melt for 210 s. The blend of the molten aluminium and AlN particles were further stirred for 900 s before it is supplied into the moulds while the mould's temperature is by 350°C. After this, the composite was permitted to cool in atmospheric air and should be taken out from the moulds after solidification. Similarly, different weight percentage of AA6061-AlNp composites were fabricated.

Table 1: Chemical composition of AA6061 alloy

Element	Mg	Si	Cu	Fe	Cr	Ti	Mn	Zn	Al
Weight (%)	0.92	0.70	0.238	0.18	0.062	0.038	0.005	0.003	97.854

2.2 Wear Test

Pin on Disc machine (Model: DUCOM TR20-LE) was used to conduct the wear test at a constant sliding velocity against the steel disc hardness 500 HV.

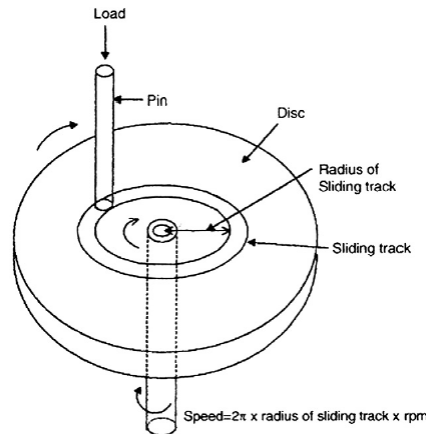


Fig.1 Schematic diagram of pin-on-disc set up

The pins were formed by cutting the fabricated AA6061-AlNp composite comprising various weight percentages of reinforcement with a dimension of 8mm in diameter and 35mm in length. Before starting of each test, the pin surface and the disc were grounded by using emery paper with grit size 320, 600, 1000 and 1200 to get the effective contact. The wear tests were conducted at different loads, sliding distances and temperatures on different reinforcement percentage of pins.

Table 2: Input factors and levels

	Level1	Level2	Level3	Level4	Units
Load	1	2	3	4	Kg
Temperature	303	373	443	513	⁰ K
Reinforcement	0	10	20	30	%
Sliding distance	500	1000	1500	2000	m

A four factor, four level design was considered as shown in figure above. According to full factorial design, total number of experiments are $4 \times 4 \times 4 \times 4 (=256)$. By using Taguchi's L16 orthogonal array we have abridged the experiments. During the testing, through cantilever mechanism load was applied on the pin and the track radius of the disc is 100mm. Height of the pin was measured before and after each test. Wear rate was calculated by using height loss of the pin and expressed in volume loss per sliding distance. Coefficient of friction also computed by using following formulae.

$$\text{Coefficient of friction} = \frac{\text{Frictional force}}{\text{Applied load}}$$



Fig. 2a AA6061-AlNp Pins after testing



Fig. 2b Specimens used for SEM Imaging

3. Results and Discussions

3.1 Microstructure examination

Fig.3 exhibits the microstructure of AA6061 alloy and AA6061-AlNp composite. Fig. 3a reveals the formation of α -Aluminum dendritic structure because of super cooling of the molten metal. Fig. 3b-d shows the various weight percentages of homogenous distribution of AlNp particles in Al alloy. These figures also evident that, there is no casting defects like cracks, shrinkage porosity etc., In the

solidification phase, AlNp particles are abjured in the direction of refined α -Aluminum grains. During the solidification AA6061-AlNp composite AlNp acts as nucleus due to this refinement of α -Aluminum taken place. At the same time AlNp offer the resistance to formation of α -Aluminum.

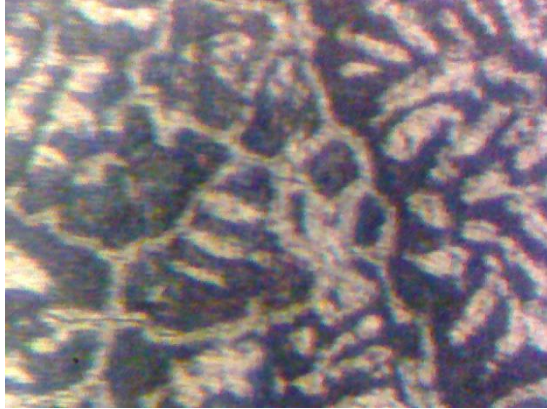


Fig. 3a AA6061 Alloy (0% AlNp)

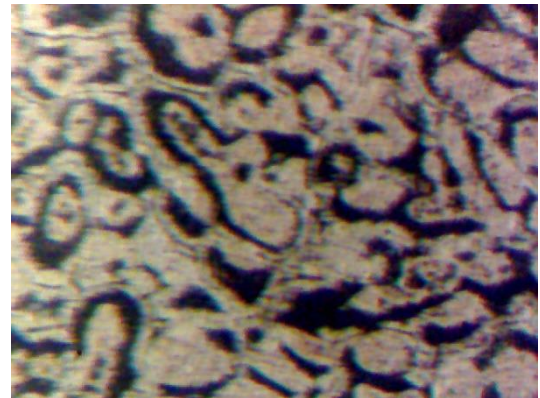


Fig. 3b AA6061 Alloy (10% AlNp)

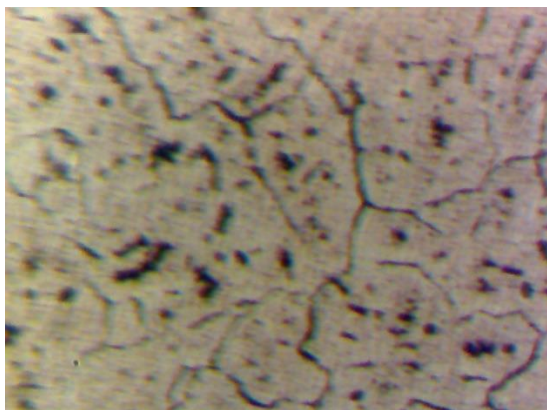


Fig. 3c AA6061 Alloy (20% AlNp)

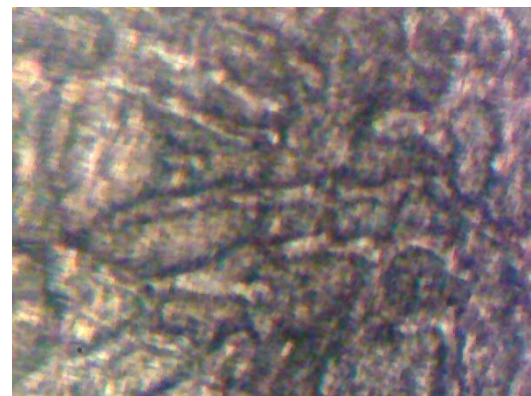
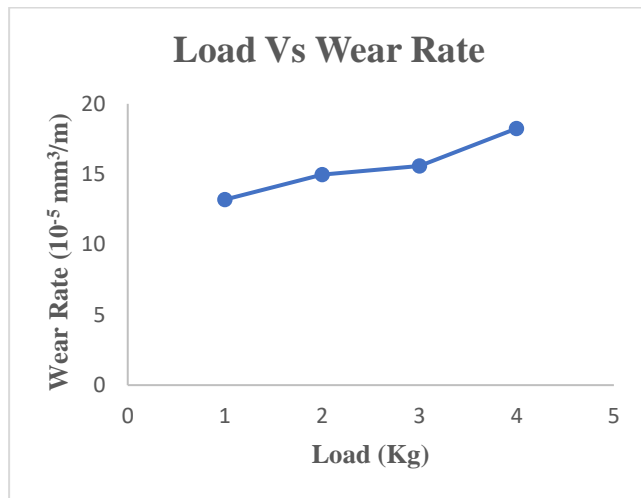
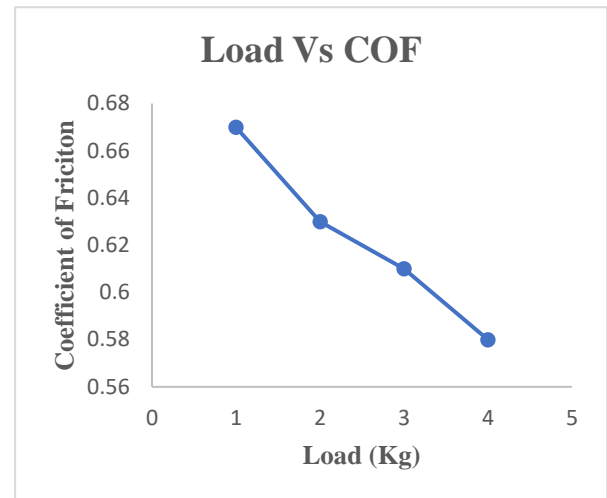


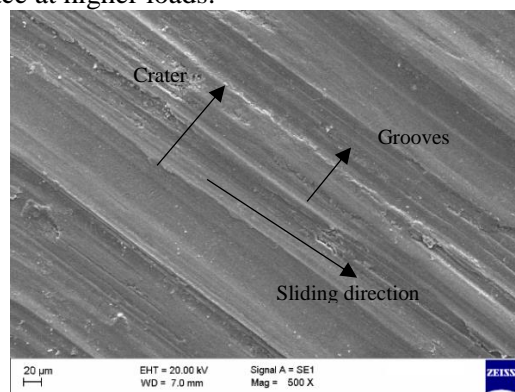
Fig. 3d AA6061 Alloy (30% AlNp)

3.2 Wear: Effect of applied load

Fig. 4a shows that wear rate is increased by increasing the applied load by following the Archard's principle [19]. According to this principle wear rate of the material depends on the applied pressure. The applied pressure is increased by either increasing normal load per contact area or by decreasing the contact area. During dry sliding test pin and counter face (Steel Plate) asperities are contacted. Due to the relative motion between pin and disc shear stress is developed in asperities. When the developed shear stress is higher than the yield strength of the asperities plastic deformation taken place hence asperities detached from the matrix. The separated asperities will fill the valleys of both pin and counter face. At lower applied loads asperities of the steel disc may plough the soft pin. Therefore, at lower loads abrasive wear taken place. By increasing applied load on the pin, frictional heat is generated between the pin and counter face increases. This frictional heat makes the matrix material soft, at the same time shear stress is developed in the reinforcement particle. And also exceeds its fracture strength which causes to fracture (brittle fracture) and fragmentation. Because of this fracture, new sharp edges are formed. These newly formed edges and counter face asperities penetrate into the matrix and causes ploughing the pin. Due to delamination and abrasive wear the material is removed from the pin. Coefficient of friction (COF) can replicate the integrate properties of the wear pair. Fig. 4b Evident that Coefficient friction (COF) values were decreased by increasing the applied load. Because at higher loads wear mechanism can change due to thermal softening of the beneath of worn out surface.

**Fig. 4a** Effect of load on wear rate**Fig. 4b** Effect of load on COF

The Fig. 5 shows the SEM image of worn out surface of cast AA6061-30% AlN composite at the sliding velocity 3.0 m/s and load is 2 Kg. Frictional heat generated during the sliding leads to generation of craters and grooves. Plastic deformation is very high at the edges of the grooves. Reason for development of craters is delamination and surface tearing of the pin. These craters are further enhanced due to shear force. Because of micro cutting and delamination, the material is removed from the pin at the higher loads. It is concluded that the delamination and micro-cutting are motives for removing the material from the work surface at higher loads.

**Fig. 5** SEM image of worn out surface of AA6061- 30% AlN composite at load 2 Kg

3.3 Wear: Effect of the reinforcement

Fig. 6a demonstrates the impact of reinforcement percentage on wear of AA6061-AlN composite. It reveals that, when the reinforcement percentage increases, the wear of the composite decreases. This occurs due to the uniform distribution and good wetting of reinforcement particles with matrix gives higher load bearing capacities because of good interfacial bonding. This is attributed to the higher hardness of AlN phase and work hardening tendency of matrix with AlN. Incorporation of AlN particles into aluminium matrix grain refinement takes place and causes reduction in the grain size of aluminium (α -Al). It also enhances the load bearing competency of the composite, because of the larger difference in thermal coefficient of expansion of AA6061 and AlN increase dislocation density around the AlN during solidification. The interactions between AlN and dislocations improves the wear resistance of the composite. Fig. 6b unveils the Coefficient friction (COF) decreases with increased reinforcement percentage of AlN. Reason for this is improvement of anti-frictional behaviour of reinforcement

particles. This also attributed to improved dispersion of AlN particles and good interfacial bonding with base matrix.

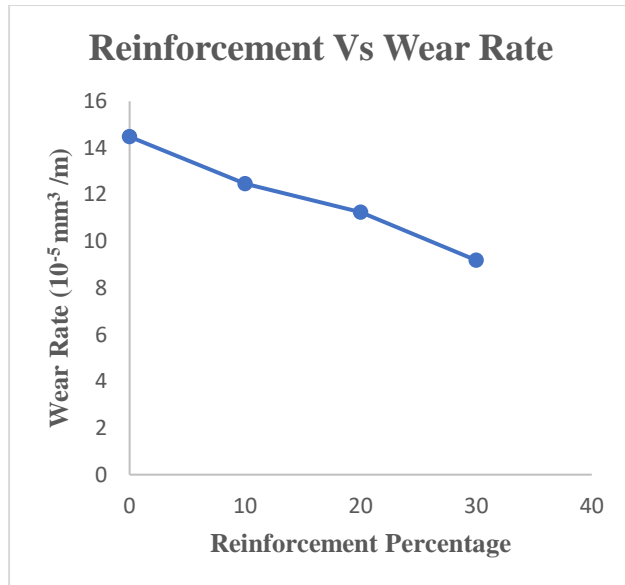


Fig. 6a Effect of reinforcement on wear rate

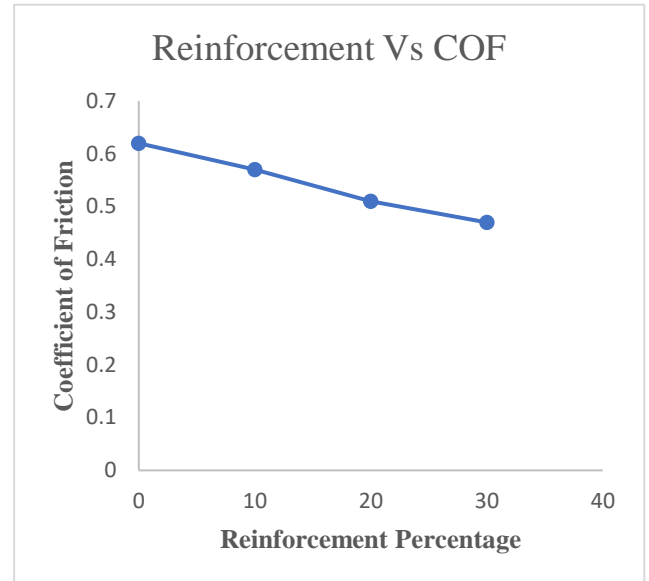


Fig. 6b Effect of reinforcement on COF

The Fig. 7 show SEM image of worn out surface of the AA-6061- 20% AlN composite. It is evident that the shallow grooves and plastic deformation. It is also evident that by detached and non-adherent AlN with matrix as shown in the image. The SEM reveals that abrasive wear is dominant in composites.

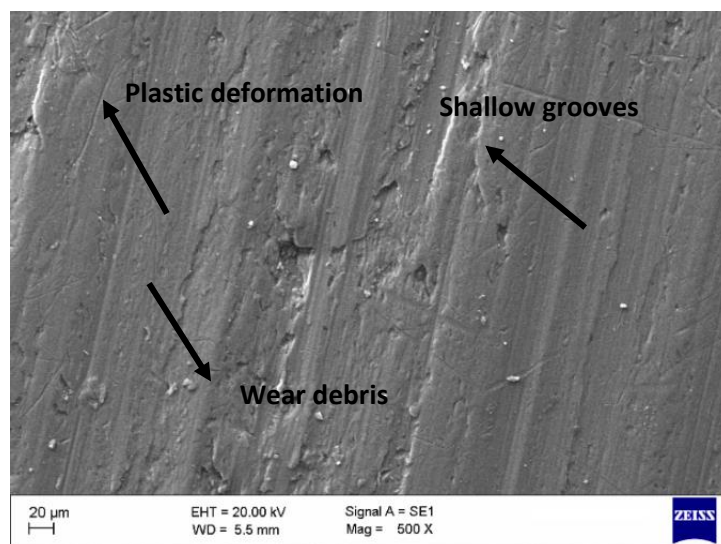


Fig.7 SEM image of worn out surface of AA6061-20%AlN

3.4 Wear: Effect of the temperature

Fig. 8a shows the effect of temperature on wear rate. It reveals that by increased temperature wear rate was decreased. Reason for this is that, by increasing the temperature matrix materials gets softer, asperities of pin and counter disc undergo deformation i.e., adhesion because wear rate is high. As the temperature increases wear rate of the composite decreases, and is attributed by formation of oxide protective layer (Mechanical Mixed Layer) on worn out surface. At higher temperatures, critical thickness of the oxide layer attains more quickly because of oxide regeneration is too high. COF values of the composite at 30°C, 100°C, 170°C and 240°C are 0.62, 0.64, 0.67 and 0.70 respectively. By

changing COF values at temperatures from 170°C to 240°C is high when compared to other temperatures because 240°C is the higher than the recrystallization temperature of the matrix material.

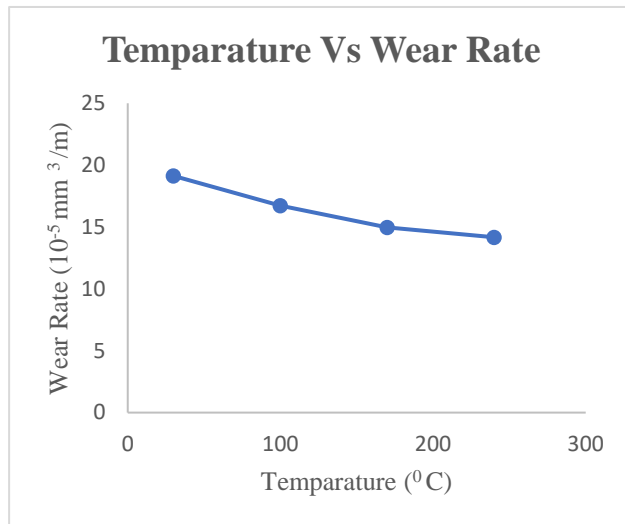


Fig. 8a Effect of temperate on wear rate

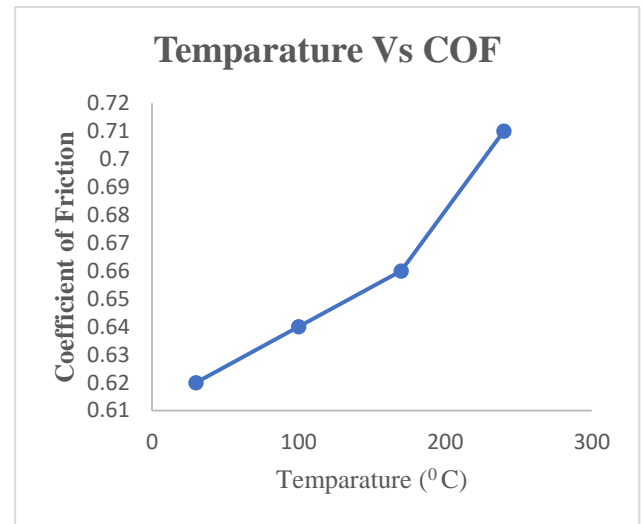


Fig. 8b Effect of temperate on COF

Fig.9a shows the SEM image of worn out surface of AA6061-AlN composite at the temperature of 170°C. At the room temperature metal is removed from the pin mainly due to the fracture of the reinforcement particles. As the temperature increases strength of the matrix decreases by thermal effect. With the help of reinforcement fracture and thermal effects, a smooth glaze is formed at higher temperatures and is called as tribo-oxidation. Due to this layer wear rate of the pin decreases by increasing the test temperature. Fig.9b shows the EDX analysis of worn out surface.

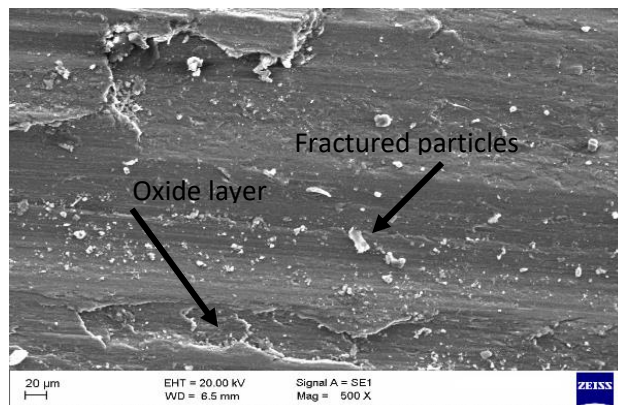


Fig. 9a SEM image of worn out surface of surface of AA6061-AlN composite at 170°C

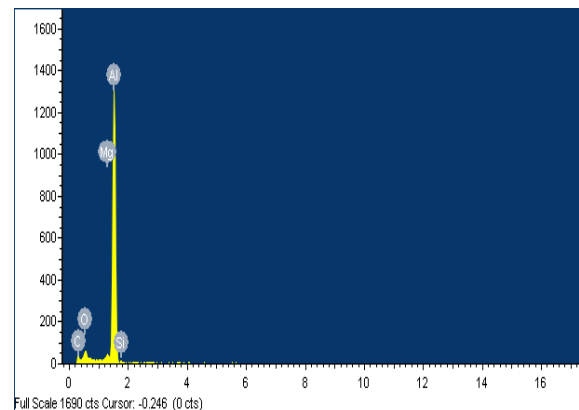


Fig. 9b EDX analysis of worn out AA6061-AlN composite at 170°C

3.5 Wear: Effect of sliding distance

Fig. 10a demonstrates the impact of the sliding distance on wear rate. It is evident that wear rate increases by increasing sliding distance. Sliding wear is related to asperity to asperity contact. At the early stages of sliding, some of the asperities detached from the pin which are unable to resist the share force at the same time some are separated from the matrix because of hard asperities and shear force of the counter face. All these separated asperities were seal the valleys and some may be fragmented also added to wear debris. Apart from this some AlN particles may be detached from the composite, cracked and

added to the wear debris. All these wear debris presented in sliding surfaces and act as abrasive medium. Due to this three-body wear mechanism produced instead of two body mechanism. The wear debris and hard asperities plough the pin. Further growths of sliding distance frictional heat is generated between the sliding parts due to this shear force and rate of deformation increases. Apart from this pull out of the reinforcement particles also increases. As a result, wear rate was increased. Fig.10b reveals that Coefficient of friction (COF) values are increases with sliding distance. In the initial stage as distance increases heat generated between sliding bodies is more but it is a lower thermal gradient as a consequence higher frictional force will occur. As time passes temperature gradient increases and it lowers the frictional force. Further increased sliding distance temperature between sliding bodies increases, test pin softens and causes to higher COF.

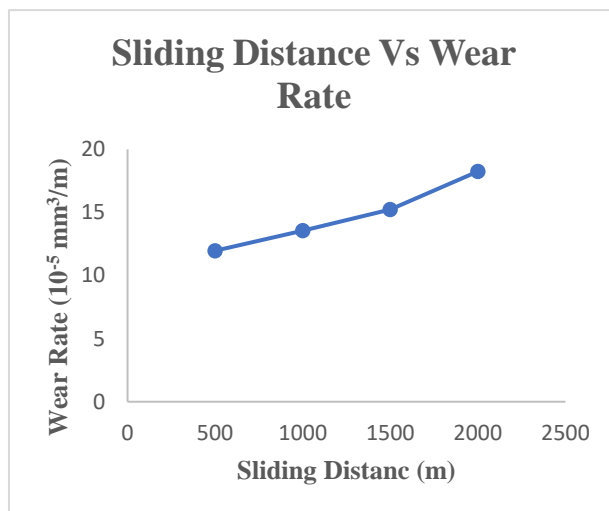


Fig. 10a Effect of sliding distance on wear rate

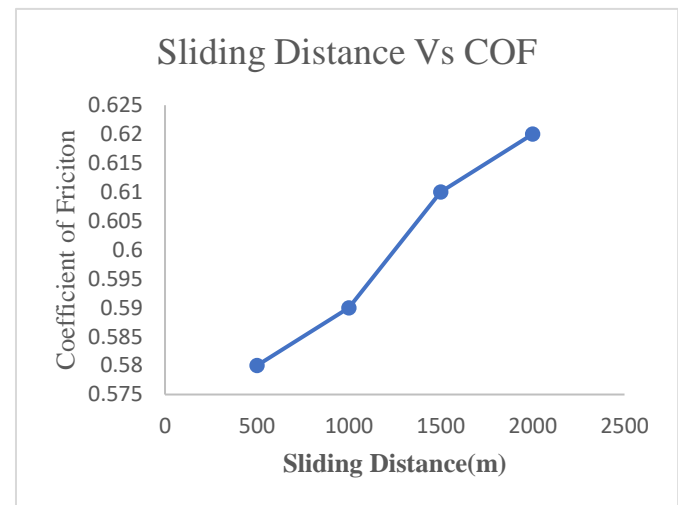


Fig. 10b Effect of sliding distance on COF

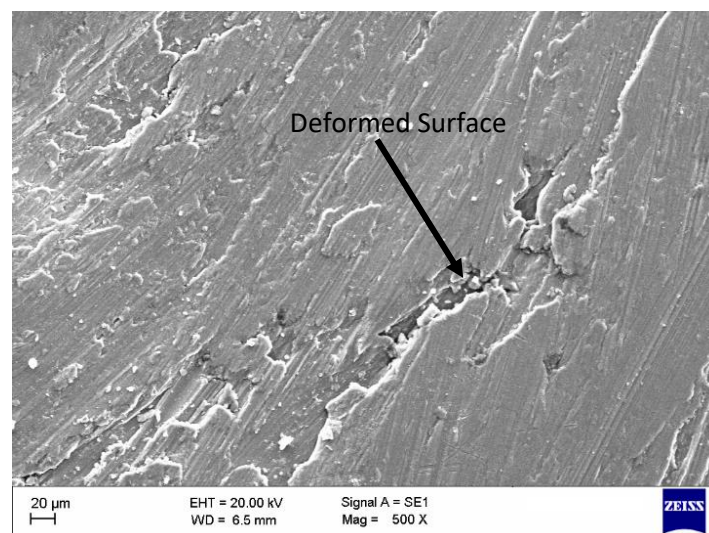


Fig. 11 SEM image of worn out surface of AA6061- 30%AlN composite at sliding distance 1500m

4. Conclusions

1. Wear rate of the composite increases by increasing load, sliding distance and decreases by increasing reinforcement percentage and temperature.

2. Coefficient of friction increases by increasing temperature but decreases by load, reinforcement and sliding distance.
3. Adhesive wear is dominant in AA6061-AlN composite.
4. At the higher loads, temperatures and sliding distances adhesive wear, abrasive wear and oxidation wear are the modes of wear mechanisms of the composites.

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