WEAR CHARACTERISTICS OF PURE ALUMINIUM, AL-ALLOY & AL-ALUMINA METAL MTRIX NANO COMPOSITE IN DRY CONDITION: PART-II

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Abstract

The aluminium metal matrix was reinforced with 1.5 wt. % of Al2O3 nano particles of 10 nm size using non-contact ultrasonic cavitation method to prepare the metal matrix nano composite. This paper reports wear rate and friction coefficient characteristics of the said composite. The influence of normal load and sliding velocity on both friction coefficient and wear rate was investigated with an unlubricated Multiple Tribo Tester by conducting sliding wear tests of the as-cast MMNC in dry condition, under different test conditions by varying the load and the sliding velocity. It was found that wear rate improved considerably with the addition of alumina nano particles. Wear rate increases with increase in load and sliding velocity. Similarly, it shows improved friction resistance. Worn out surfaces of the specimen were examined under FESEM which shows better wear resistance is offered by MMNC. This study reveals that the addition of the alumina particulates improves the wear rate and friction performance of the MMNC significantly.

Keywords: *Wear rate, Al2O3, MMNC, Duralumin, Coefficient of friction.*

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1. INTRODUCTION

Metal Matrix Nano Composites (MMNCs) and Metal Matrix Composites (MMCs) are special class of advanced materials and have proved their importance over conventional metals and alloys where high strength and stiffness are considered and have captured a large area of application in industries. Most of these high performance materials are metal matrices reinforced with fibres, particulates or whiskers. In recent years, considerable interest has been paid in extending the use of these composite materials in marine environment [1, 2]. These materials diverge from the conventional engineering materials due to their homogeneity [3]. We know that, wear is considered as one of the most commonly encountered problems in industry, leading to frequent replacement of parts, particularly abrasion. Abrasive wear occurs when hard particles or asperities penetrate a softer surface and displace material in the form of elongated chips and slivers [4]. In wear tests, applied load [5-7], sliding speed [8, 9], sliding distance [10, 11] and percentage of reinforcement are identified as important parameters which control the friction and wear performance of composites.

Aluminium is a relatively soft, durable, lightweight, ductile and malleable metal. But, when it is reinforced with Graphite, SiC, Al2O3, etc. [12, 13], it shows encouraging properties. Aluminium based MMNCs possess desirable properties like high specific stiffness, low density, high specific strength controlled coefficient of thermal expansion, increased fatigue resistance and superior dimensional stability at elevated temperatures etc. [14, 15]. Several methods have been developed for the fabrication of MMNCs. But, the non-contact ultrasonic cavitation method [16, 17], is a completely new method for fabrication of MMNCs, as it is inexpensive and offers wide selection of materials and size of the component is not a constraint. It offers better matrix-particle bonding.

2. EXPERIMENTAL PROCEDURE

2.1 Material

Alumina is a high hardened ceramic material. The chemical composition of the composite (Al-Al_2O_3 1.5% by wt. nano particle) is shown in Table 1. The motto to design MMNC is to combine the metals & ceramic i.e. addition of high strength, high modulus refractory particles to ductile metal matrix to get tailor made properties.

Table 1 Composition of Al-Al_2O_3 (1.5 wt. %) MMNC

Element	Fe	Mg	Si	Al	Al_2O_3
Wt. %	1.3	0.43	0.26	96.51	1.5

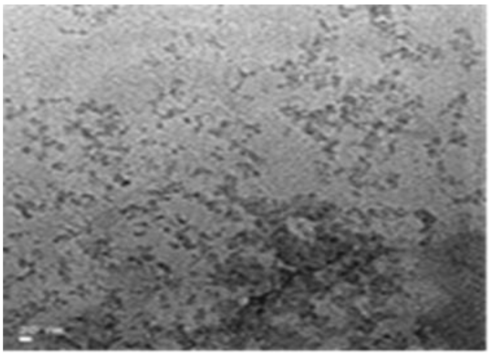

Fig-1 HRTEM micrograph of Al_2O_3 nano powder

The MMNC is prepared by non-contact ultrasonic cavitation method by Padhi et al [16, 21].

2.2 Preparation of MMNC

The procedure for preparation of MMNC done by Padhi et al [16, 21] is as follows. The experimental set up is shown in Fig.1. It consists of an ultrasonic generator that generates ultrasonic waves, an ultrasonic chamber and steel mould. The mould was preheated to avoid thermal cracking. The preheated mould was kept in the ultrasonic chamber and the chamber was subjected to vibration at a frequency of 35 KHz. Liquid aluminum and alumina particulate (1.5 wt. %) having average size 10 nm were simultaneously poured into the vibrating mould from the mixing chamber.

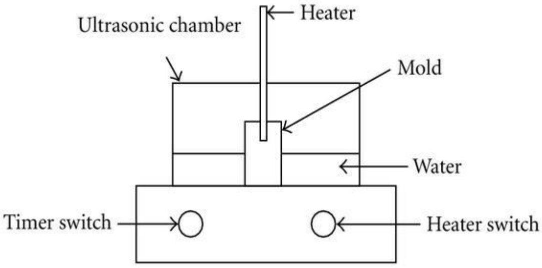

Fig-2: Experimental set up

After the simultaneous pouring, the heating element was immediately brought down above the liquid metal in order to delay the solidification. The vibration was carried out for a period of five minutes to ensure complete mixing. The castings were obtained in both longitudinal and transverse section.

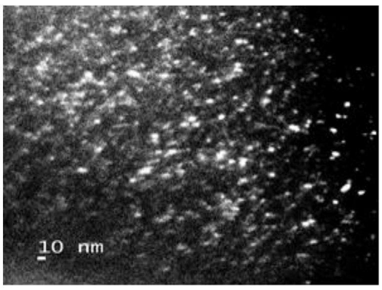

Fig-3: HRTEM micrographs of Al-Al2O3 nano composite showing uniform distribution of nano particles

2.3 Wear Tests

The experiments were carried out on a Multiple Tribo Tester (TR-5), Ducom make. In this Multiple Tribo Tester, the wheel rotates and the specimen, of size 6.35 x 6.35 x 9 mm, is pressed against the wheel .The specimen is held by the fixture. Loads ranging from 0 to 1000 N and speeds up to 2000 rpm can be applied to press the specimen against the periphery of the 20 mm thick, 60 mm diameter wheel. Since the specimen is held stationary and the wheel rotates, the sliding contact occurs between the wheel and the specimen and wear of both takes place as the load is applied for the predefined test duration. Here, the sliding wear tests were carried out under different load conditions and at different speeds for a period of 30 minutes or 1800 seconds. The test conditions are as follows.

1. Constant load of 100 N, constant speed of 300 rpm and test duration of 30 minutes (1800 seconds).
2. Constant load of 100 N, constant speed of 350 rpm and test duration of 30 minutes (1800 seconds).
3. Constant load of 130 N, constant speed of 300 rpm and test duration of 30 minutes (1800 seconds).

Fig-4: Multiple Tribo Tester (TR-5), Ducom make for sliding wear test.

3. RESULTS AND DISCUSSION

The aluminum, al-alloy (duralumin) and MMNC specimens were subjected to the above said test conditions. Duralumin is an aluminum-copper alloy. In addition to aluminium, the main materials constituting duralumin are copper, manganese and magnesium. It is used in aviation and automobile industry. Duralumin is strong, hard and lightweight. Duralumin is relatively soft, ductile, and workable in the normal state. They may be rolled, forged, extruded or drawn into a variety of shapes and products.

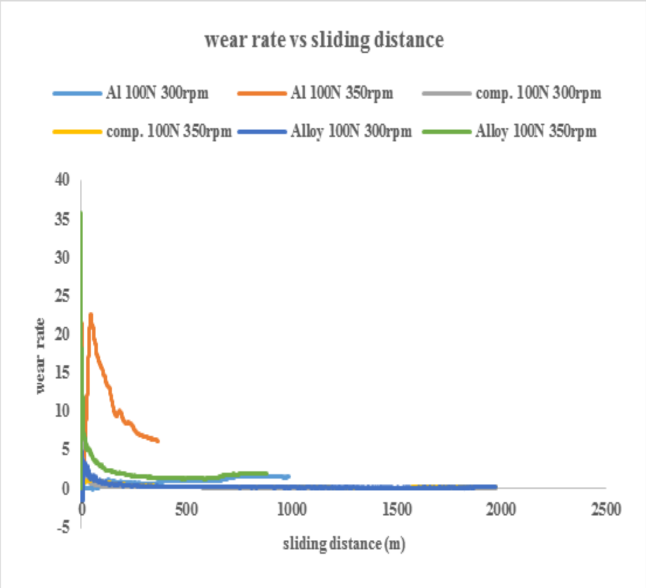

Fig. 5: Wear rate verses sliding distance keeping load (100 N) constant at two different speeds 300 and 350 rpm for MMNCs and pure Aluminium.

The characteristic curves between wear rate and sliding distance for pure Aluminium, Al-Alloy and MMNC specimens with constant load of 100N and at two different speeds of 300 and 350 rpm are shown in Fig 5. For pure aluminium specimen, when speed is 300 rpm, the wear rate increases suddenly up to 24 µm/sec within few seconds and then falls to around 1 µm/sec and continues up to 1000 meters of sliding distance. But when speed increases to 350 rpm, the wear rate goes up to 23 µm/sec and then falls and continues up to the sliding distance of 400 meters to get completely worn out. In case of Duralumin, when speed is 300 rpm, the wear rate becomes negative due to sticking of the specimen to the wheel, then it rises to 6 µm/sec and then it falls to 0.5 µm/sec and continues up to 2000 meters of sliding distance. But when speed increases to 350 rpm, wear rate rises to 36 µm/sec initially and then falls to 1 µm/sec approximately and continues up to 900 meters of sliding distance. Further, in case of MMNCs, though rpm varies from 300 to 350 rpm, no significant variation in the sliding distance occurs as both the specimens covered 2000 meters. The maximum wear rate in case of MMNC is 9.5 µm/sec that occurs within few meters of sliding distance when speed is 300 rpm. When speed increases to 350 rpm, the maximum wear rate comes down to 2.25 µm/sec. We may conclude that the wear resistance of MMNC is significantly increased compared to pure aluminium and alloy.

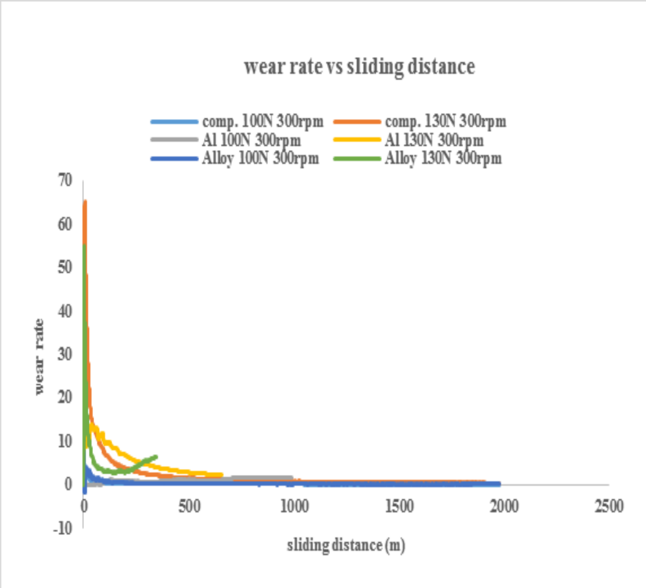

Fig. 6: Wear rate verses sliding distance keeping speed constant (300 rpm) at two different loads 100 and 130 N for pure Al and MMNCs.

The characteristic curves between wear rate and sliding distance for pure Aluminium, Al-Alloy and MMNC specimens with constant speed of 300 rpm and at two different loads of 100 and 130 N are shown in Fig 6. It is observed that wear rate of MMNCs first increases suddenly registering a maximum value of 9.5 µm/sec within few meters of sliding distance and then falls and continues up to 2000 meters of sliding distance. But when load increases from 100 N to 130 N, wear rate increases to maximum 67 µm/sec suddenly and then falls and covers the entire sliding distance of 2000 meters. In case of alloy, under 300 rpm, the curve shows negative initially due to the sticking of the material to the wheel and then rises up to 10 µm/sec. it then falls to 0.5 µm/sec approximately and continues up to 2000 meters of sliding distance. But when load rises to 130 N, wear rate goes up to 55 µm/sec and then falls to 4 µm/sec approximately and continues up to 350 meters of sliding distance. In case of pure aluminium, the wear rate increases to 25 µm/sec suddenly during 130 N load and then falls and continues up to 700 meters, but when load comes down to 100 N, the wear rate increases to 14 µm/sec and then falls and continues up to 1000 meters. It shows that wear rate is significantly improved in case of MMNC. This happens because of the strengthening mechanism due to nano particles embedded in the aluminium matrix uniformly.

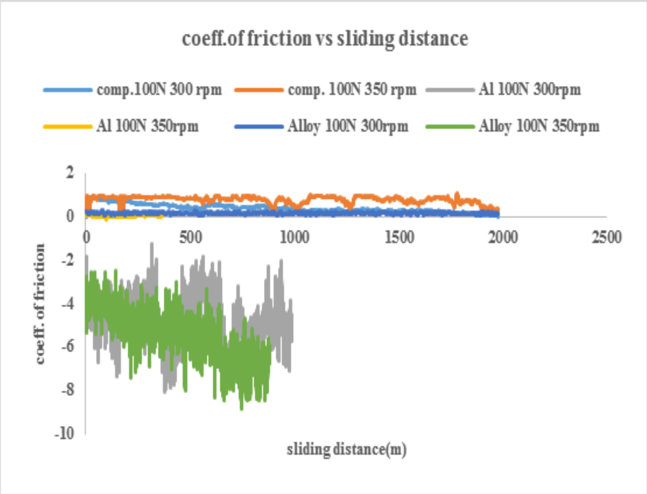

Fig. 7: Coeff. of friction verses sliding distance keeping load (100 N) constant at two different speeds 300 and 350 rpm for MMNCs and pure Aluminium.

The characteristic curves between coeff. of friction and sliding distance for pure Aluminium, Al-Alloy and MMNC specimens with constant load of 100N and at two different speeds of 300 and 350 rpm are shown in Fig 7. For MMNCs, the coeff. of friction is almost constant over the entire sliding distance of 2000 meters but at 350 rpm, with little fluctuations or drops within 20 meters and between 100 to 200 meters and 900 to 1200 meters. Again at 300 rpm, the MMNC curve first rises and then falls uniformly over the entire sliding distance. In case of alloy, under 300 rpm, the coeff. of friction is registering lower value compared to MMNC, but is uniform over the entire sliding distance. But when speed rises to 350 rpm, alloy curve shows negative due to sticking of the material to the wheel. In case of pure aluminium, coeff. of friction is zero when speed is 300 rpm. As the material is sticking to the wheel, the characteristic curve shows negative throughout 1000 meters of sliding distance. But when speed increases to 350 rpm, coeff. of friction becomes more. Friction is more in case of MMNCs compared to pure Al and hence, resistance to wear is more in case of MMNCs.

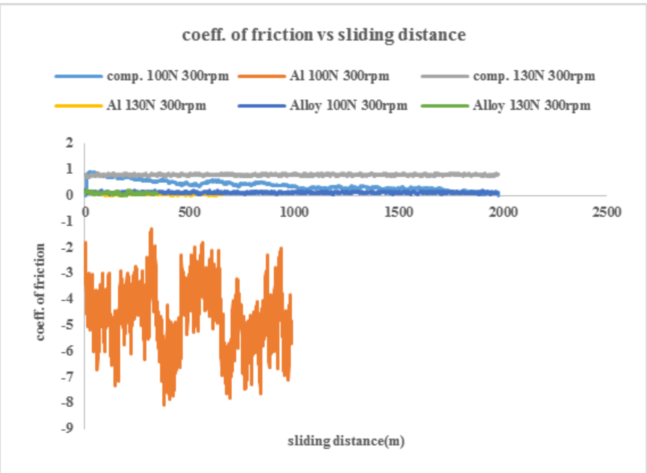

Fig. 8: Coeff. of friction verses sliding distance keeping speed constant (300 rpm) at two different loads 100 and 130 N for pure Al and MMNC.

The characteristic curves between coeff. of friction and sliding distance for pure Aluminium and MMNC specimens with constant speed of 300 rpm and at two different loads of 100 and 130 N are shown in Fig 8. For MMNCs, at 130 N, the coeff. of friction is constant over the entire sliding distance and at 100 N, the curve initially rises and then reduces almost uniformly over the entire sliding distance of 2000 meters. However, friction is more when load is 130 N which indicates more resistance to wear at higher load. In case of alloy, under 100 N, the coeff. of friction is registering lower value compared to MMNCs and is uniform over the entire sliding distance. But when load rises to 130 N, coeff. of friction for alloy shows even lower value and frictional resistance continues up to 350 meters approximately. In case of pure aluminium, coeff. of friction is zero when load is 100 N. As the material is sticking to the wheel, the characteristic curve shows negative throughout 1000 meters of sliding distance. But when speed increases to 350 rpm, coeff. of friction becomes more. Friction is more in case of MMNCs compared to pure Al.

To determine the coefficient of friction in case of dry sliding wear, Peter J Blau [19] used a rule of mixture approach. The coefficient of friction for the composite μ_{mix} is given by the following equation:

$$\mu_{mix} = \alpha_{mat}\ \mu_{mat} + \alpha_{ren}\ \mu_{ren}$$

Where α_{mat} = Area fraction of matrix
μ_{mat} = coefficient of friction of matrix.
α_{ren} = area fraction of reinforcement
μ_{ren} = coefficient of friction of reinforcement

From the above equation, it is seen that the coefficient of friction of composite is greater than that of pure aluminium. Again Al_2O_3 is a hard material whereas aluminium is a soft material and is sticky for which coefficient of friction for pure aluminium is negligible i.e. almost zero in some cases as evident from the characteristic curves. Al-Alloy Duralumin is relatively soft, ductile, and workable in the normal state. It is also evident, from some characteristic curves, that the Al-Alloy (Duralumin) has zero coeff. of friction. When load increases significantly, coeff. of friction decreases as sliding distance increases.

4. EVALUATION OF MICROSTRUCTURE

The microstructure of the worn out samples were examined under FESEM. The FESEM images are shown in the following figures.

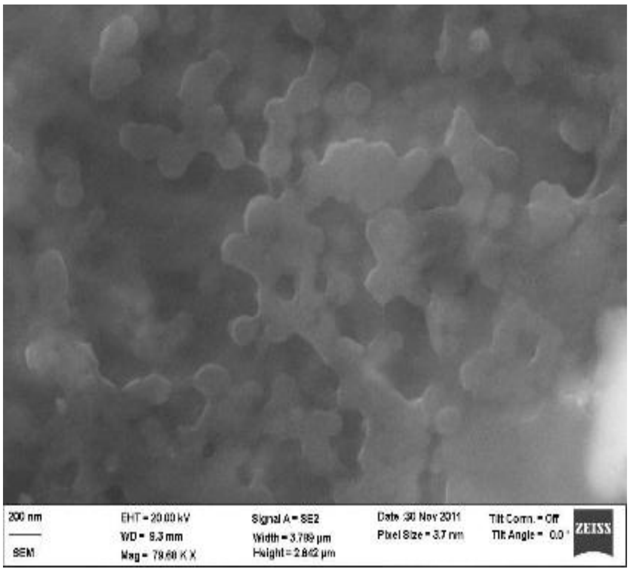

Fig-9 Microstructure of pure Al at 100N and 300 rpm

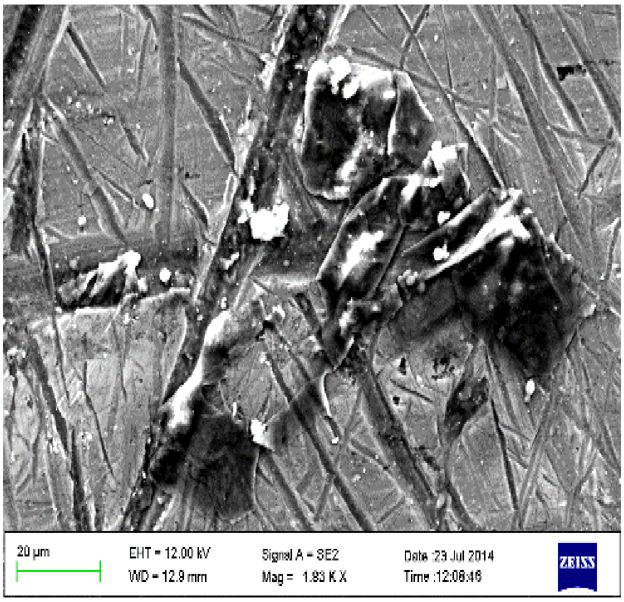

Fig-10 Microstructure of alloy at 100N and 300 rpm

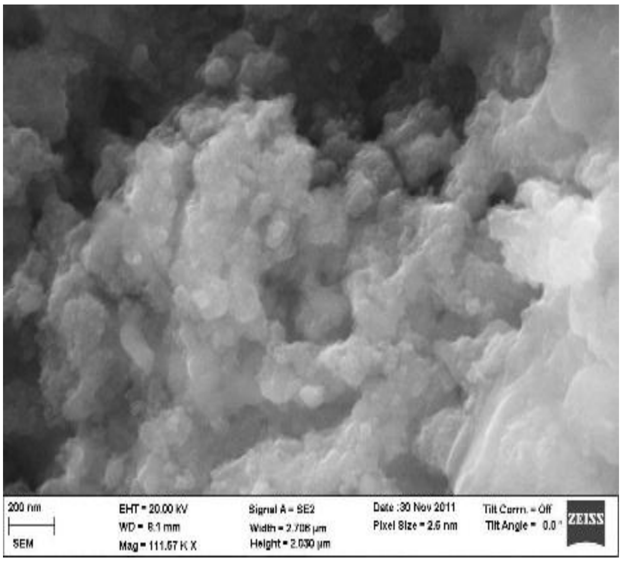

Fig-11 Microstructure of MMNC at 100N and 300 rpm

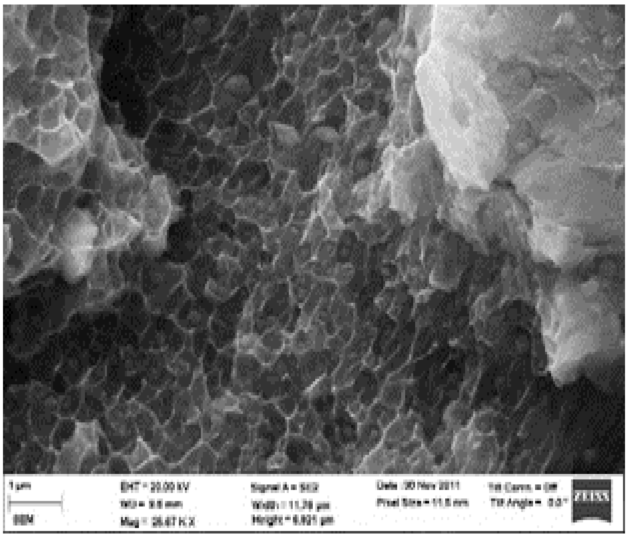

Fig-12 Microstructure of pure Al at 100N and 350 rpm

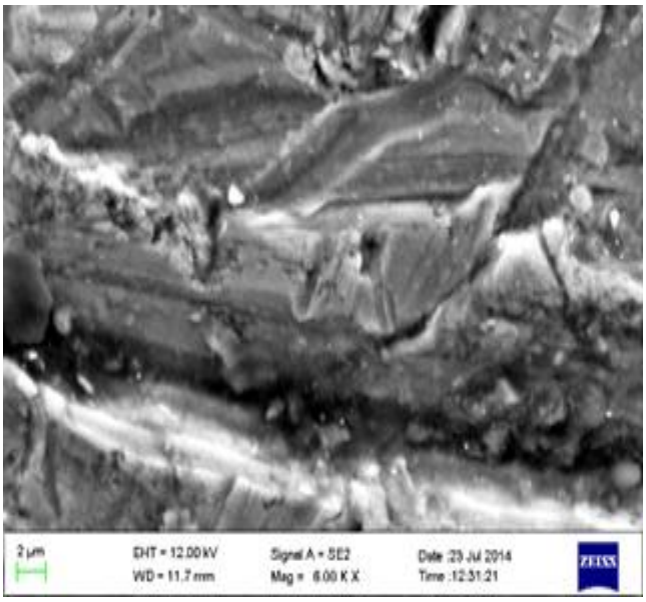

Fig-13 Microstructure of alloy at 100N and 350 rpm

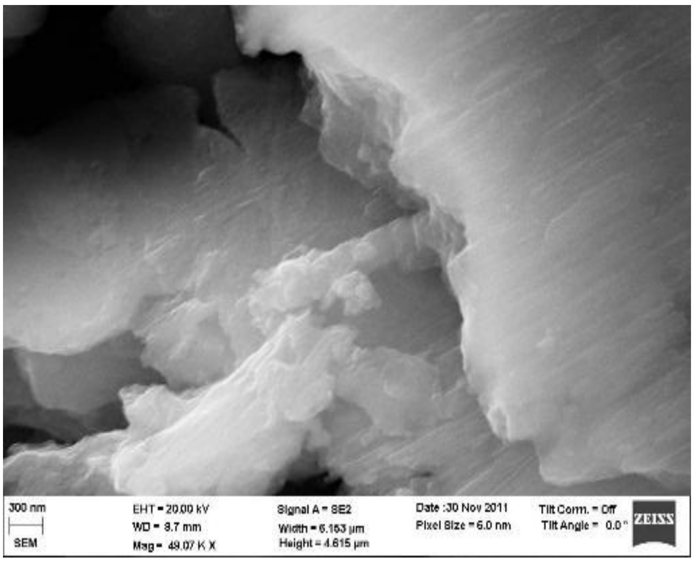

Fig-14 Microstructure of MMNC at 100N and 350 rpm

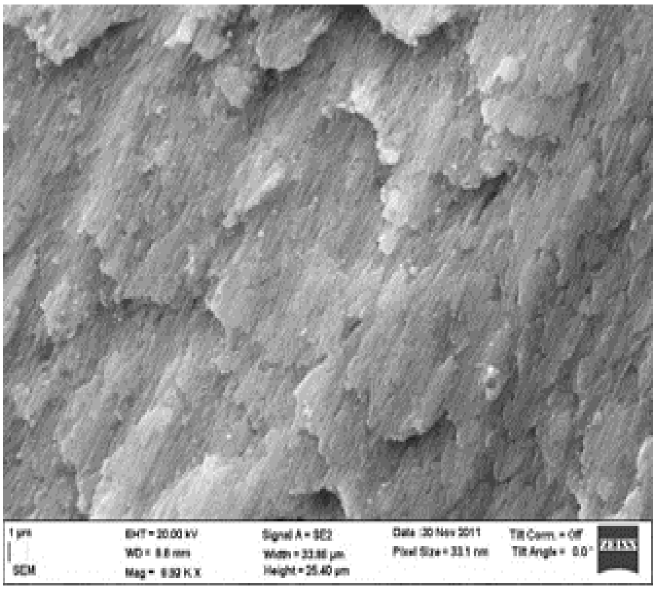

Fig-15 Microstructure of pure Al at 130N and 300 rpm

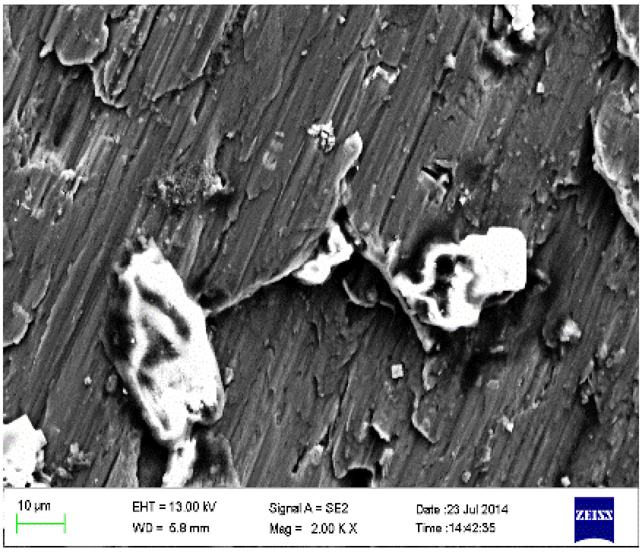

Fig-16 Microstructure of alloy at 130N and 300 rpm

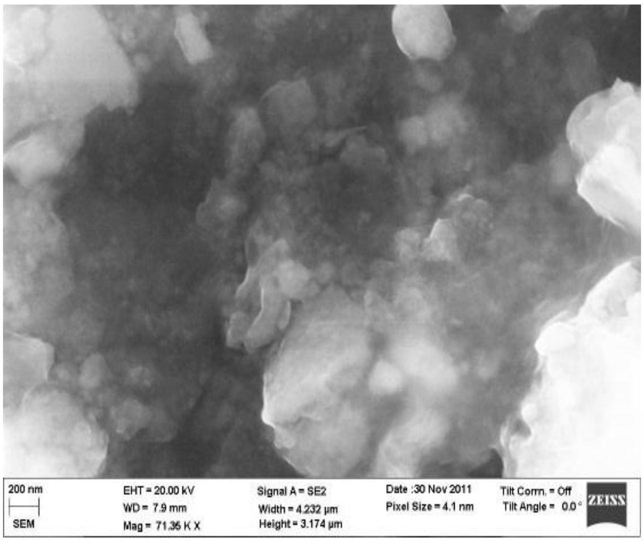

Fig-17 Microstructure of MMNC at 130N and 300 rpm

The FESEM micrograph pics of worn out surfaces of pure aluminium, al-alloy (duralumin) and MMNC under the test condition of 100 N load and sliding speed of 300 rpm are shown in figure 9, 10 and 11 respectively. They show the following:

(1) Because of heat generation and localized welding, a nodular surface is observed in case of pure aluminium. Since aluminium is sticky, material loss is more compared to MMNC, due to sticky surfaces.
(2) Scratches are observed in case of alloy. But the surface is nearly smooth and hence, the wear rate is negligible.
(3) The surface is almost smooth in case of MMNC and hence, the wear rate is negligible keeping the wear rate constant.

Similarly, the FESEM micrograph pics of worn out surfaces of pure aluminium, al-alloy (duralumin) and MMNC under the test condition of 100 N load and sliding speed of 350 rpm are shown in figure 12, 13 and 14 respectively. They show the following:

(1) As a result of ploughing action, an irregular honey comb structure is observed in case of pure aluminium. Material loss is significant.
(2) Deep scratches are observed in case of alloy which indicates material loss is more in comparison to MMNC. A non-uniform surface is observed.
(3) A smooth microstructure is observed in case of MMNC. Wear rate is more due to higher sliding speed, but a uniform surface is observed.

Again, the FESEM micrograph pics of worn out surfaces of pure aluminium, al-alloy (duralumin) and MMNC under the test condition of 130 N load and sliding speed of 300 rpm are shown in figure 15, 16 and 17 respectively. They show the following:

(1) For pure aluminium, wear rate is severe in comparison to MMNC due to increased load.
(2) For alloy, material loss in comparison to MMNC is severe due to increase in load which is evident from the pic.
(3) A smooth microstructure is observed in case of MMNC. No ploughing action takes place and hence, wear rate is uniform.

5. CONCLUSION

This experimental work reveals the wear and friction characteristics of pure Al, Al-Alloy (duralumin) and Al-Al_2O_3 MMNC. The MMNC is prepared using liquid metallurgy route. Following conclusions may be drawn.

(a) The wear rate is controlled by load and sliding distance.
(b) Wear rate increases with the increase in load and speed.
(c) Wear rate decreases as the sliding distance increases.
(d) The coefficient of friction is affected by load and sliding speed. Increase in load and sliding speed increases the Coefficient of friction.

The MMNC shows encouraging results in comparison to pure aluminium and al-alloy as far as wear rate and coefficient of friction are concerned. This is because of the strengthening mechanism due to uniform dispersion of Al_2O_3 nano particles. The nano particles are embedded with the aluminium matrix which strengthens the composites. Again this is light in weight. The experiment is required to be extended to study all the parameters varying the load, speed and time as well as weight percentage of reinforcements.

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