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

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Abstract

In this report, an aluminium metal matrix was reinforced with 1.5 wt. % of Al2O3 nano particles using non-contact cavitation method to prepare the metal matrix nano composite. Microstructural examination conducted on the sample revealed a uniform distribution of alumina particulates. Sliding wear behavior of the as-cast MMNC was studied in dry condition, under different test conditions by varying the load and the sliding velocity, with an unlubricated Multiple Tribo Tester. It was found that sliding wear resistance improved considerably with the addition of alumina nano particles. Microscopic examinations of the worn out surfaces of pure Al, Al-alloy (duralumin) and MMNC reveal that the MMNC has greater resistance to sliding wear compared to pure aluminium and duralumin. Wear increases with increase in load and sliding velocity. Delamination and abrasion are the dominating types of wear observed.

Keywords: *Sliding Wear, Al2O3, MMNC, Duralumin, Delamination and Abrasion.*

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1. INTRODUCTION

With the development of new processing techniques and the demand for lighter materials with high strength and stiffness, high performance composite materials have been developed which show enhanced properties compared to traditional metals and alloys. Most of these high performance materials are metallic matrixes reinforced with fibre, particulate or whiskers. MMNCs are emerging as the most versatile materials for advanced structural, automotive, aviation, aerospace, defense applications because of their excellent combination of properties. In recent years, considerable interest has been paid in extending the use of these composite materials in marine environment [1, 2]. These MMNCs have emerged as the important class of advanced materials giving the prospect to tailor the material properties according to their needs. These materials differ from the conventional engineering materials because of their homogeneity [3]. Aluminium based MMNCs possess desirable properties like high specific stiffness, low density, high specific strength controlled co efficient of thermal expansion, increased fatigue resistance and superior dimensional stability at elevated temperatures etc. [4, 5]. The mechanical and tribological properties of the MMNCs can be improved by reinforcing various materials ranging from very soft materials like Graphite, Talc etc. to high hardened ceramic particulates like SiC, Al2O3, etc., [6, 7]. However, because of their high cost of production, their application in industries is slowed down. Casting Technology plays the key to overcome this problem, although several technical challenges exist. Achieving a uniform distribution of reinforcement within the matrix is a big challenge, which directly influences the properties and quality of the composite materials. The MMNCs possess excellent mechanical and tribological properties and are, therefore, considered as prospective engineering materials for various tribological applications [8-15]. It is reported by many researchers that sliding wear resistance and abrasion resistance of MMCs and MMNCs, reinforced with ceramic particulates like SiC, Al2O3, have improved [8-11]. When nano particles of quantity as small as 2 wt. percent are added, it enhances the hardness and yield strength by a factor as high as 2 [16]. There are several methods for the production of metal matrix nano composites which include mechanical alloying, vertex process, and spray deposition etc. But, the above processes are expensive. Solidification processing is a relatively cheaper route. Nano particulates tend to agglomerate during solidification processing as a result of Van der Waals forces and therefore, proper dispersion of the nano particulates in metal matrix is a challenge. In the present work, a non-contact method, where the ultrasonic probe is not in direct contact with the liquid metal, was attempted to disperse nano sized Al_2O_3 particulates in aluminum matrix. In this method, the mold was subjected to ultrasonic vibration [16-20].

But, no work has ever been reported on the dry sliding wear behavior of MMNCs produced by non-contact cavitation method [16, 21]. Therefore, in the present investigation, an attempt has been made to study the dry sliding wear behavior of Al+1.5% by wt. Al_2O_3 MMNC, prepared by non-contact cavitation method, under different test conditions by varying applying loads and sliding speeds over a predefined time period.

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

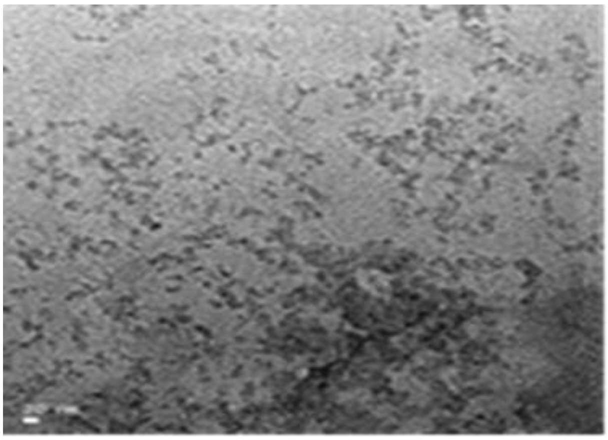

Fig-1. HRTEM micrograph of Al_2O_3 nano powder

The Nano composites are prepared by a non-contact ultrasonic solidification 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.

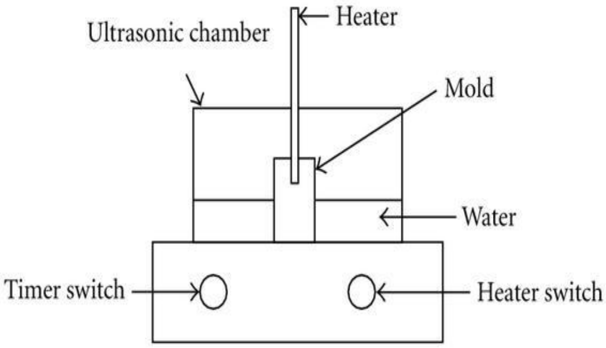

Fig-2: Experimental set up

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.

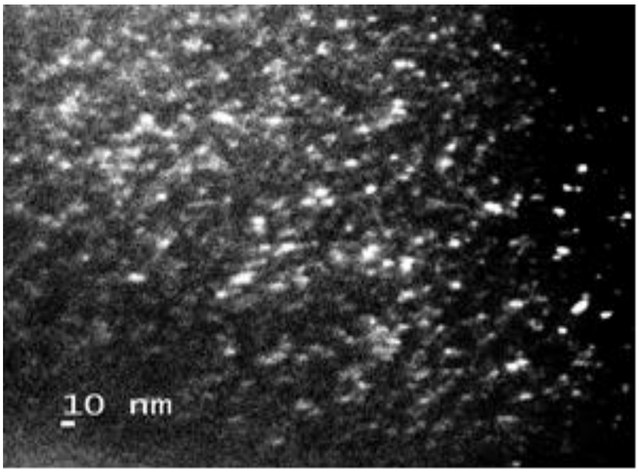

Fig-3: HRTEM micrographs of Al-Al2O3 nano composite showing uniform distribution of nano particles

2.3 Wear Tests

The experiments described here 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).

3. RESULTS AND DISCUSSION

The aluminum, 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.

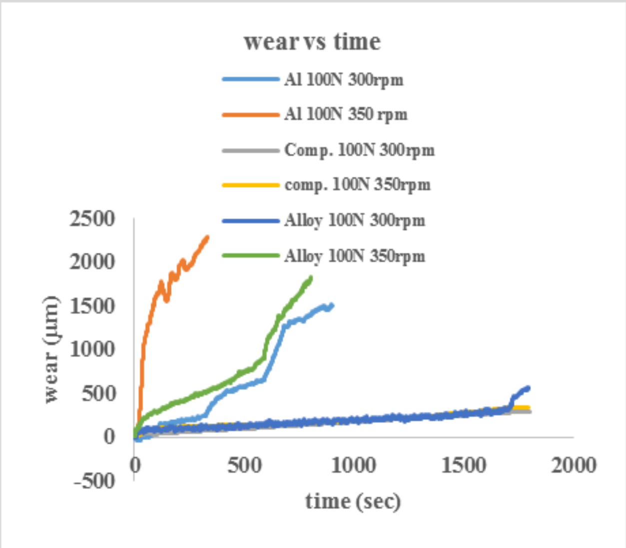

Fig-4: Wear verses time keeping load (100 N) constant at two different speeds 300 and 350 rpm for pure aluminium, duralumin (Al-alloy) and MMNCs.

Fig 4 shows the graph between wear in (µm) verses time in seconds for pure aluminium, duralumin and MMNC keeping load constant i.e. 100N, at two different speeds of 300 and 350 rpm. The sliding wear of commercially pure aluminium in both the conditions shows that under 100N load and 300 & 350 rpm, the wear increases w.r.t. time in both the cases. But when speed increases to 350 rpm from 300 rpm within a short span of time i.e. 300 seconds, the material gets completely worn out. In case of duralumin, as it is harder than pure aluminium, it covers the total time duration i.e. 1800 seconds under 100N and 300 rpm, but registers more wear compared to MMNC. When speed goes up to 350 rpm, it gets complete worn out within 800 seconds. Further, in case of MMNC, in both the cases, though rpm varies from 300 to 350 rpm, no significant variation in the time occurs. Also the maximum wear under 300 rpm, in case of MMNC is 300 µm which occurs after 1800 seconds whereas, in case of duralumin it is 500 µm after 1800 seconds and in case of pure aluminium, it is 1500 µm at 900 seconds approximately. When speed increases to 350 rpm, the wear in case of pure aluminium increases to 2300 µm and the complete worn out takes place at 300 seconds.

Hence it is concluded that the wear properties of MMNC is significantly increased compared to both alloy pure aluminium.

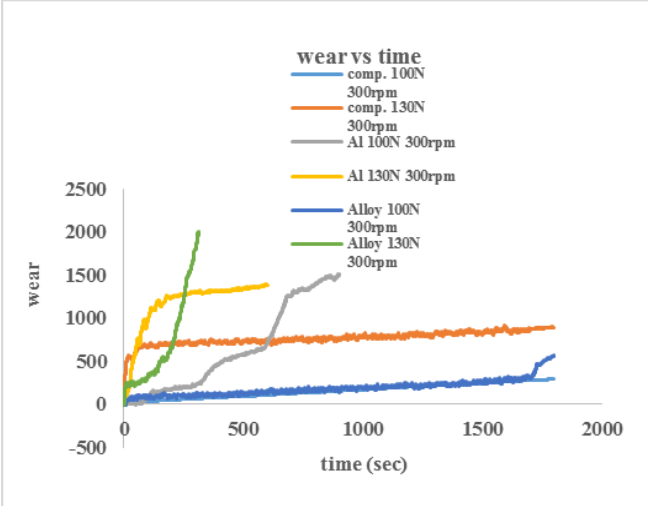

Fig-5: Wear verses time keeping speed constant (300 rpm) at two different loads 100 and 130 N for pure Al, duralumin and MMNC.

Fig. 5 shows the wear verses time keeping speed constant at 300 rpm under 100 N and 130 N load. It is observed that wear of MMNCs increases gradually and linearly (under 100N) as time increases up to 1800 seconds. But when load increases from 100N to 130 N, wear increases to 600 µm (under 130N) from 300 µm (under 100N) suddenly and then remains nearly constant up to 1800 seconds. In both the load conditions, MMNC covers 1800 seconds. In case of duralumin, the wear is 500 µm under 100N load covering 1800 seconds and 2000 µm under 130N load covering only 300 seconds, whereas, in case of pure aluminium, the wear increases to 1400 µm under 100N load covering 900 sec and 1200 µm under 130 N load covering 600 seconds. This happens because of bonding of nano particles embedded in the aluminium matrix uniformly.

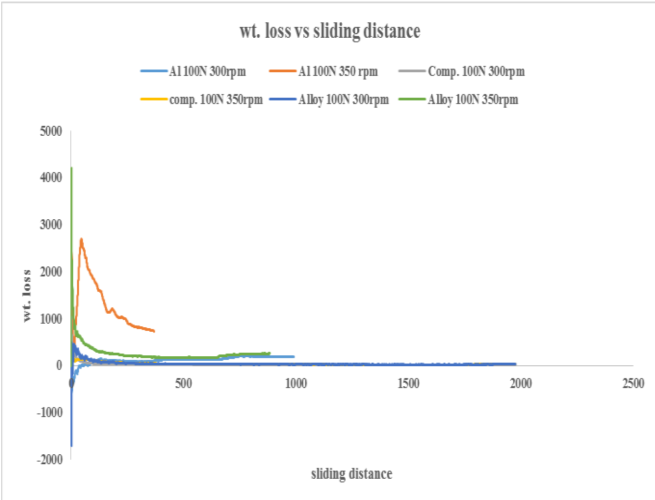

Fig-6: Weight loss verses sliding distance under constant load (100 N) at two different speeds 300rpm and 350 rpm for pure Al, duralumin and MMNC.

Figure 6 shows weight loss verses sliding distance keeping load constant at two different speeds. Weight loss for MMNC at 100N is nearly zero at 300 and 350 rpm though there is a little difference which is not so significant where as in case of duralumin, wt. loss rises first within few meters of sliding distance and then becomes uniform over the whole sliding distance. When speed increases to 350 rpm, initially wt. loss rises severely and then falls and continues almost uniformly up to 900 meters of sliding distance. For duralumin, wt. loss is significantly varying under both the conditions. In case of pure aluminium, when rpm varies from 300 rpm to 350 rpm, weight loss of material varies significantly as shown. Initially the material is sticking to the wheel which indicates negative.

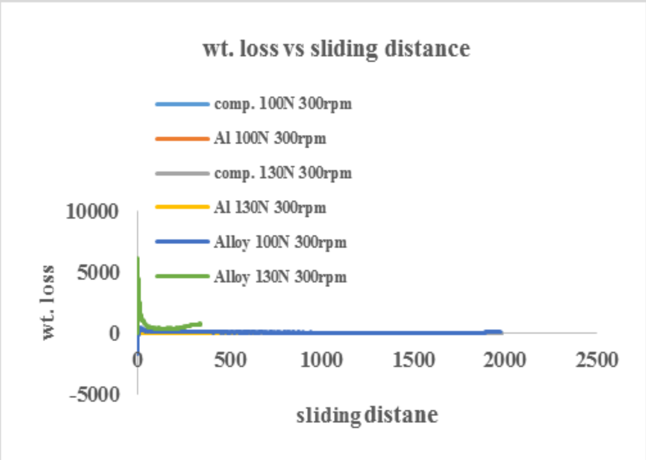

Fig-7: Weight loss verses sliding distance keeping speed constant (300 rpm) at two different loads 100 and 130 N for pure Al, duralumin and MMNC.

Figure 7 shows weight loss verses sliding distance keeping speed constant at two different loads. Weight loss for MMNC at 300 rpm is nearly zero at100N and 130N rpm though there is a little difference which is not so significant whereas in case of both duralumin and pure aluminium, when load varies from 100N to 130N, weight loss of material varies significantly as shown. Initially duralumin and pure aluminium is sticking to the wheel which indicates negative.

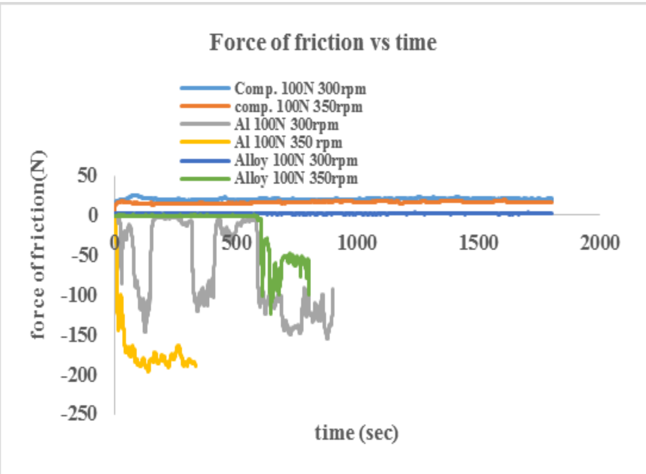

Fig-8: Force of friction verses time keeping load (100 N) constant at two different speeds 300 and 350 rpm for MMNC, duralumin and pure aluminium.

The characteristic curves between force of friction and time for pure aluminium, duralumin and MMNC specimens with constant load of 100N and at two different speeds of 300 and 350 rpm are shown in Fig 8. For MMNC in both the conditions, the force of friction is constant over the entire time period of 1800 seconds. When speed rises to 350 rpm from 300 rpm, the force of friction reduces. In case of pure aluminium, force of friction is zero under both he speeds of 300 rpm and 350 rpm. As the material is sticking to the wheel, the characteristic curves in both the cases show negative throughout 900 seconds (under 100 N) and 300 seconds (under 130 N) of time periods they covered respectively. At 300 rpm, in case of duralumin, the force of friction curve is uniform throughout the entire sliding distance of 1800 seconds with little frictional resistance whereas under 350 rpm, the alloy material is sticking to the wheel for which the characteristic curve shows negative throughout 800 seconds of time period it covered. Friction is more in case of MMNC compared to pure Al and alloy and hence, resistance to wear is more in case of MMNC.

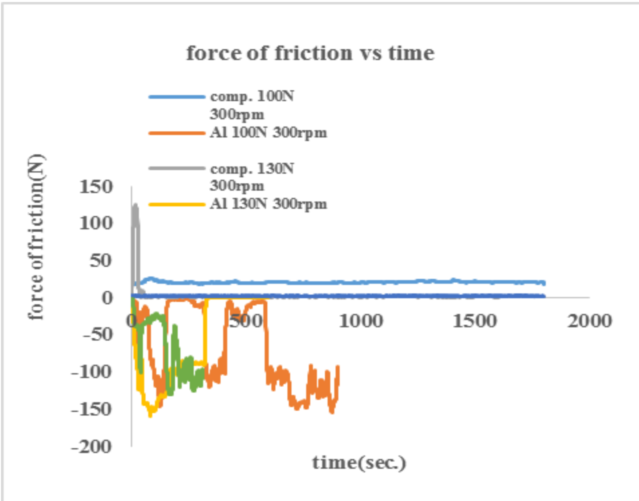

Fig-9: Force of friction verses time keeping speed constant (300 rpm) at two different loads 100 and 130 N for pure Al, duralumin and MMNC.

The characteristic curves between force of friction and time for pure aluminium, duralumin and MMNC specimens with constant speed of 300 rpm and at two different loads of 100 N and 130 N are shown in Fig 9. For MMNC, at 100 N, the coeff. of friction is constant over the entire time period of 1800 seconds and at 130 N, the curve initially rises and then reduces and moves almost uniformly over the entire time period of 1800 seconds. When load rises to 130 N, the force of friction reduces. In case of duralumin, under 100 N load, the curve is uniform over the entire time period, but when load rises to 130 N, the material is sticking to the wheel and hence, the characteristic curve shows negative. It covers only 300 seconds. In case of pure aluminium, force of friction is zero under both 100 N and 130 N. As the material is sticking to the wheel, the characteristic curves show negative throughout 900 seconds (under 100 N) and 600 seconds (under 130 N) of time periods respectively. Friction is more in case of MMNC specimen compared to pure Al and alloy.

4. MICROSCOPIC EVALUATION

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

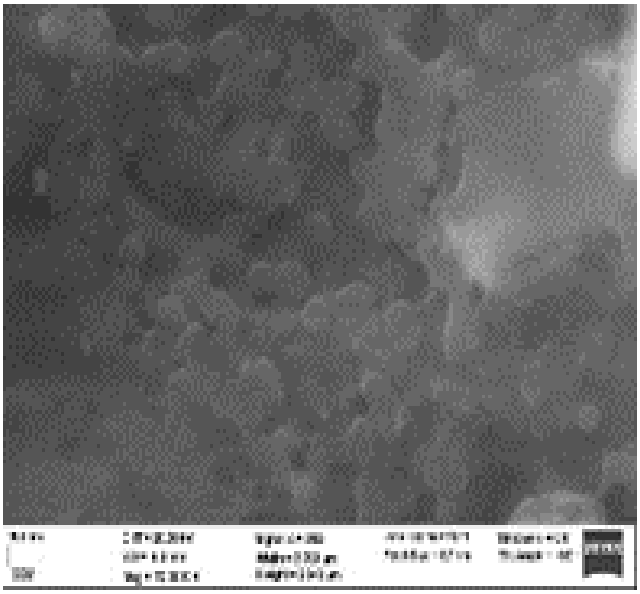

Fig-10 Microstructure of pure Al at 100N and 300 rpm

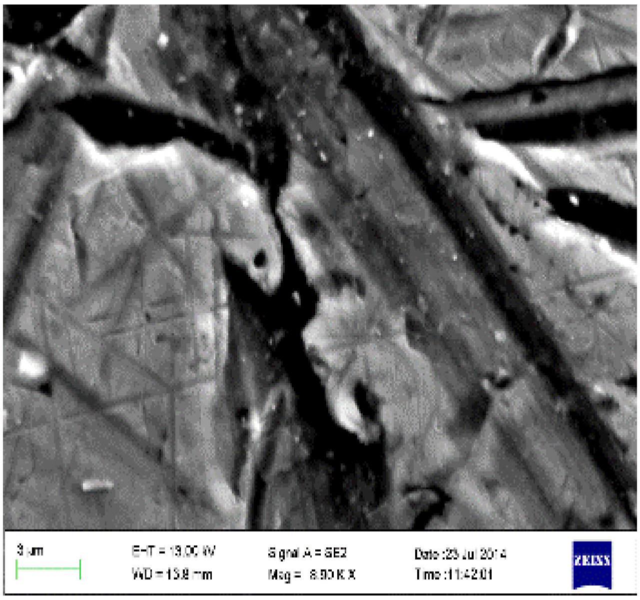

Fig-11 Microstructure of alloy at 100N and 300 rpm

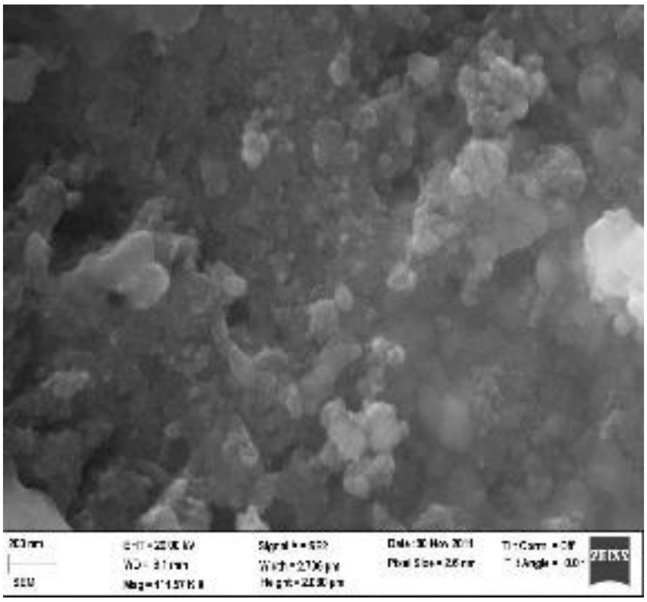

Fig-12 Microstructure of MMNC at 100N and 300 rpm

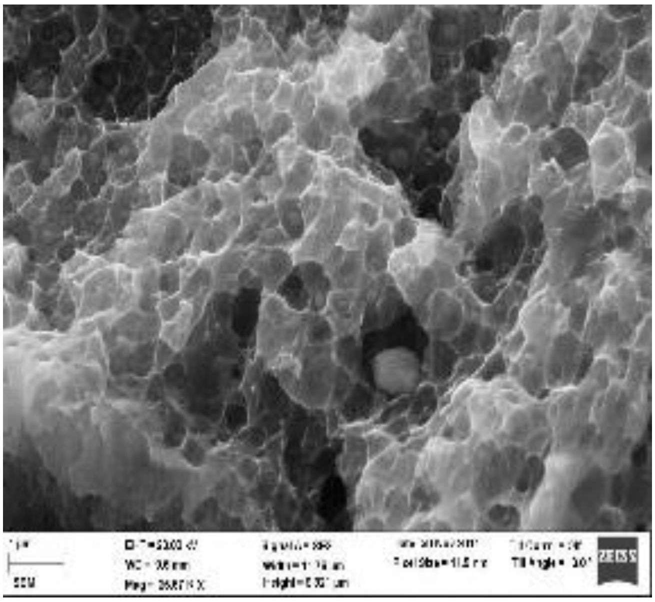

Fig. 13 Microstructure of pure Al at 100N and 350 rpm

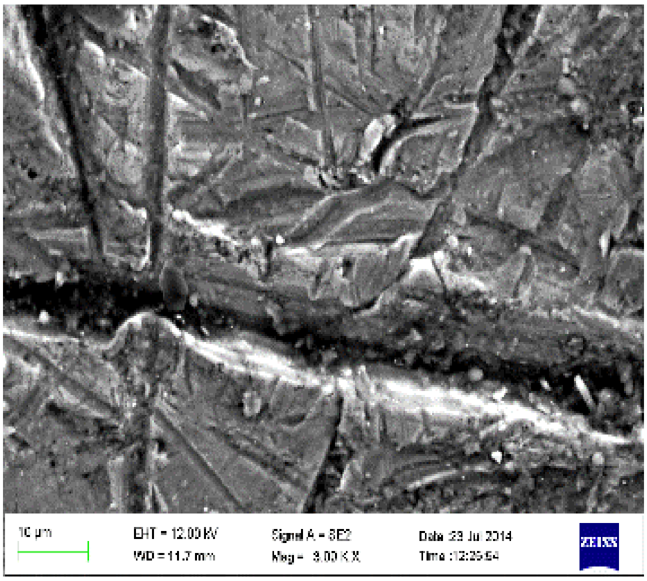

Fig. 14 Microstructure of alloy at 100N and 350 rpm

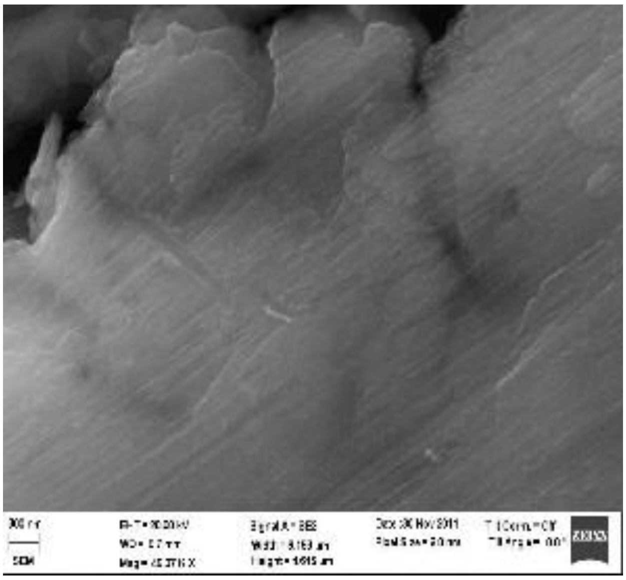

Fig. 15 Microstructure of MMNC at 100N and 350 rpm

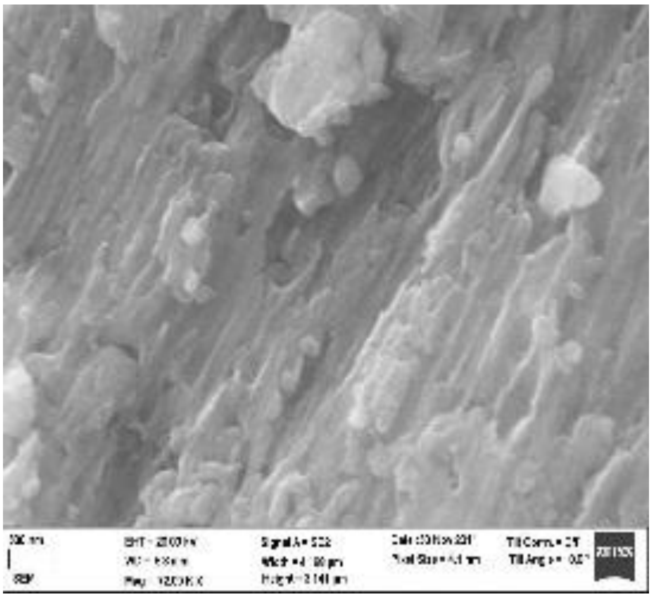

Fig. 16 Microstructure of pure Al at 130N and 300 rpm

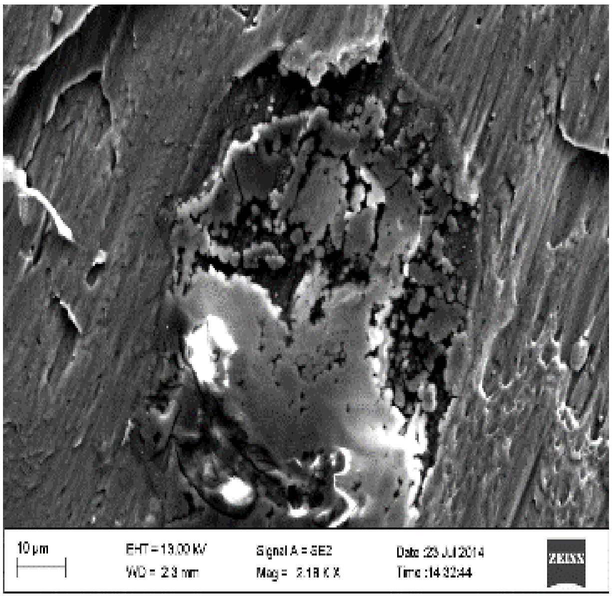

Fig. 17 Microstructure of alloy at 130N and 300 rpm

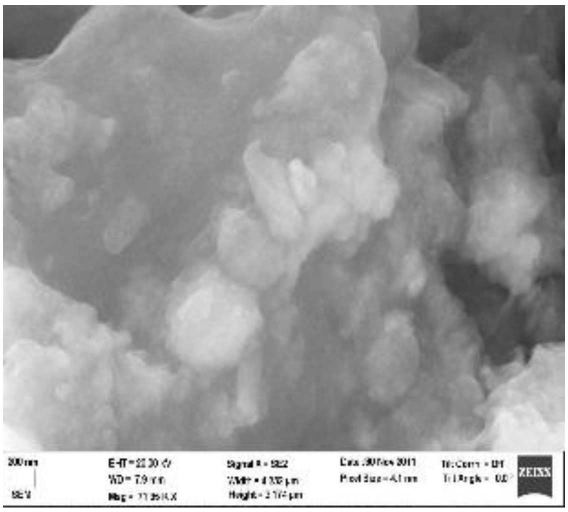

Fig. 18 Microstructure of MMNC at 130N and 300 rpm

Figure 10, 11 and 12 show the FESEM micrographs of worn out surfaces of pure aluminium, alloy and MMNC respectively. From the worn out surface of pure Al in figure 10, a nodular surface is observed due to heat generation and localized welding. The metal worn out becomes more because of the sticky surfaces. From the worn out microstructure of alloy shown in fig. 11, scratches are observed and the microstructure is not that smooth for which the wear is more than MMNC. From the worn out surface of MMNC in figure 12, the morphology of worn out microstructure is nearly smooth because of which wear rate is almost negligible keeping wear constant.

Figure 13, 14 and 15 show the FESEM images of worn out samples at 100N load and 350 rpm of pure aluminium, alloy and composite respectively. Figure 13 shows an irregular honey comb structure because of ploughing action whereas fig. 14 shows deep scratches on the surface of alloy because of rise in speed and figure 15 has smooth microstructure showing worn out surface of MMNC uniform. But if the FESEM of fig. 12 is compared with that of fig. 15, wear in this case is found to be more.

Similarly when load increases to 130 N, the FESEM shown in figure 16, 17 and 18 show the severe wear in case of pure aluminium and alloy compared to composite. This happens due to strengthening mechanism of the nano particles embedded in the matrix. Since particles are very small and when embedded in the matrix, no projections are coming out of the surfaces. Hence, no ploughing action takes place thus keeping the wear uniform in case of MMNC.

The average surface roughness value of pure Al, alloy and MMNC are Ra 10.5 µm, Ra 4.2 µm and Ra 5.04 µm respectively under 100 N load and 300 rpm speed. Similarly, it is Ra 8.4 µm, Ra 5.0 µm and Ra 6.52 µm for pure Al, alloy and MMNC respectively under 100 N load and 350 rpm speed. Again, it is Ra 3.0 µm, Ra 5.2 µm and 3.8 µm for pure Al, alloy and MMNC respectively under 130 N load and 300 rpm speed.

5. CONCLUSION

As this paper reports the dry sliding wear behaviour of pure aluminium, alloy and MMNC, the following conclusions can be drawn.

(a) Wear decreases as the time duration increases.
(b) Wear increases with the increase in load.
(c) Wear increases with the increase in speed.
(d) Force of friction reduces with rise in load and speed.

The results shown by MMNC are encouraging in comparison to pure aluminium and duralumin as far as wear, material loss and friction are concerned. This is because of the strengthening mechanism due to uniform dispersion of Al_2O_3 nano particles in the matrix. Addition of nano alumina powder to aluminium increases the mechanical and tribological properties of MMNC. It also improves the hardness, yield strength, wear and abrasion resistance of the composite [24]. Again this is light in weight.

FUTURE SCOPE

More tests are required to study all the parameters varying the load, speed, time as well as weight percentage of reinforcements. MMNCs can be prepared by varying the weight percentage of alumina and by reinforcing alumina in the matrix of duralumin. Even hybrid MMNCs can be prepared using non-contact ultrasonic cavitation method and tribological properties can be studied.

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