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

Vyjainto Kumar Ray[1], **Payodhar Padhi**[2], **B. B. Jha**[3], **Tapas Kumar Sahoo**[4]

[1]*Student of Ph.D., Mechanical Engineering Department, B.P.U.T., Bhubaneswar, Orissa, India*
[2]*Principal, Mechanical Engineering Department, K.I.S.T., Bhubaneswar, Orissa, India*
[3]*Chief Scientist, Metallurgical Engineering, Surface engineering department, I.M.M.T., Bhubaneswar, Orissa, India*
[4]*Technical Assistant, Metallurgical Engineering, Surface engineering department, I.M.M.T., Bhubaneswar, Orissa, India*

Abstract

In this report, the 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 samples 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 resistance to sliding wear 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. Wear is more when load and speed are increased in steps. 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

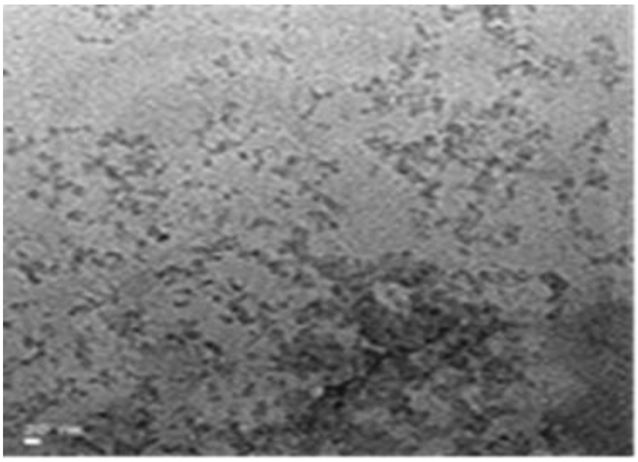

Fig-1 HRTEM micrograph of Al_2O_3 nano powder

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.

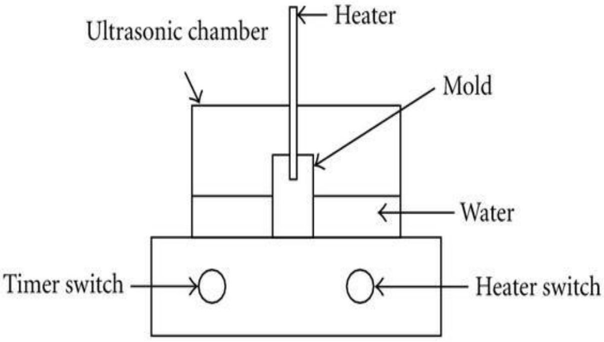

Fig-2: Experimental set up

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.

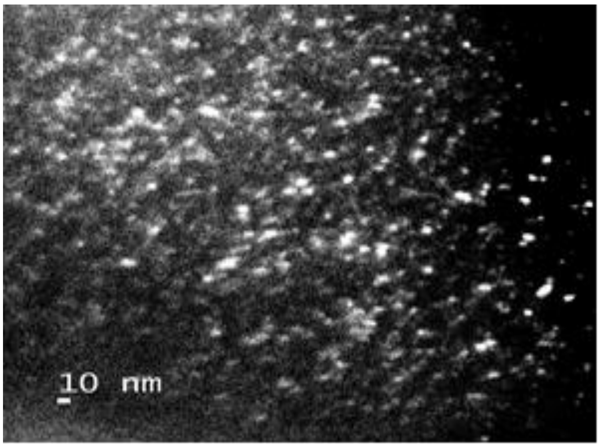

Fig-3: HRTEM micrographs of Al-Al2O3 nano composite showing uniform distribution of nano particles

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. Load of 100 N (constant), speed of 300 rpm (constant) and test duration of 30 minutes (1800 Seconds).

2. Step load of 50 N with step load 10 N, 5 minutes duration step, speed of 300 rpm (constant) and test duration of 30 minutes (1800 Seconds).
3. Load of 130 N (constant), step speed of 100 rpm with step of 100 rpm, time variation 10 minutes and test duration of 30 minutes (1800 seconds).
4. Load of 130 N (constant), speed of 300 rpm (constant) 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.

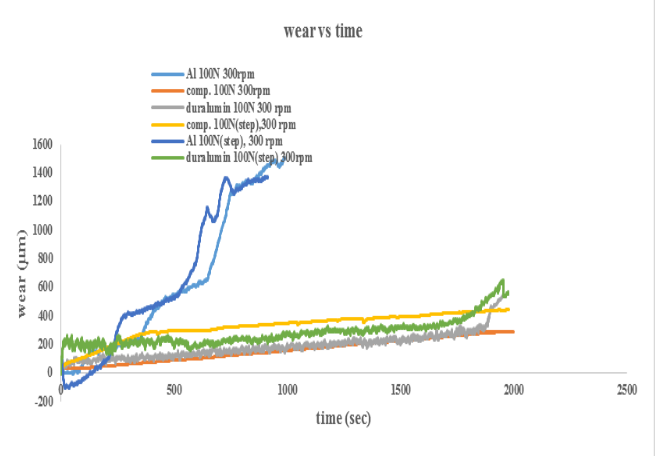

Fig-4: Wear verses time keeping speed constant at 300 rpm at two different load conditions of 100 N (constant) and 100 N (step load) for pure aluminium, duralumin (Al-alloy) and MMNCs.

Figure-4 shows the graph between wear in (µm) verses ime in seconds for pure Aluminium, alloy and MMNC keeping speed constant at 300 rpm at two different load conditions of 100 N (constant) and 100 N (step load) . The sliding wear of commercially pure Aluminium, in both the conditions, shows that the wear increases w.r.t. time. In case of MMNCs, in both the cases, no significant variation of wear occurs. Also the maximum wear in case of MMNC is 300 µm under 100 N step load whereas it is reduced to 200 µm under 100 N constant load which occur after 1800 seconds i.e. entire time duration. In case of pure aluminium, wear increases drastically up to 1500 µm within 1000 seconds approximately under 100 N constant load, but it is reduced to 1350 µm within 900 seconds approximately under 100 N step load. Initially pure aluminium is sticking to the wheel under step load which indicates negative. In case of duralumin, the maximum wear is 500 µm under 100 N constant load and 600 µm under 100 N (step load). In all the cases, wear is more under step load condition. Hence it is concluded that the wear properties of composite is significantly increased compared to pure aluminium and alloy.

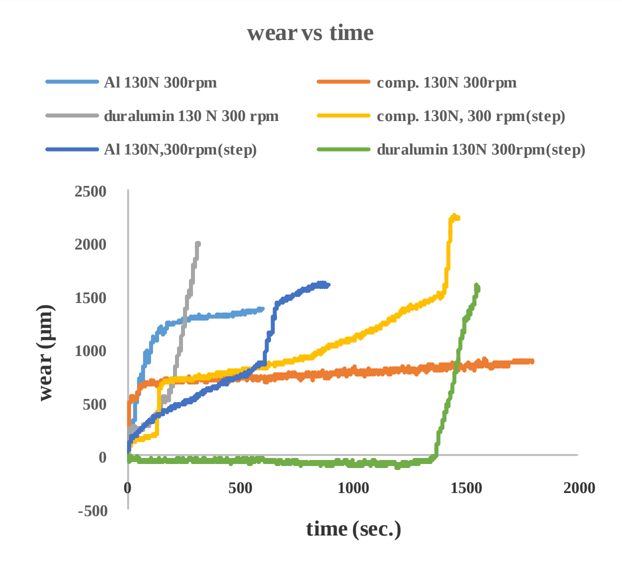

Fig-5: Wear verses time keeping load constant at 130 N at two different speeds of 300 rpm (constant) and 300 rpm (step) for pure Al, duralumin and MMNC.

Figure-5 shows the wear verses time keeping load constant at 130 N at two different speeds of 300 rpm (constant) and 300 rpm (step) for pure aluminium, duralumin and MMNC. It is observed that wear of MMNC, which is 750 µm under 300 rpm constant speed, increases gradually and linearly as time increases up to 1800 seconds. But under 300 rpm step speed, wear increases linearly up to 1500 µm approximately till 1400 seconds are covered and then to 2300 µm suddenly and gets worn out after 1550 seconds. In case of pure aluminium, the wear increases to 1500 µm at 1000 seconds during 300 rpm step speed condition and under 300 rpm constant speed condition, the wear comes down to 1300 µm approximately at 700 seconds. Similarly, in case of alloy, the maximum wear is 2000 µm under constant speed condition within 400 seconds and the maximum wear is 1600 µm under step speed condition within 1600 seconds. Initially the alloy is sticking to the wheel under step load which indicates negative. In all the cases, wear is more under step speed condition. Again, it is concluded that the wear properties of composite is significantly increased compared to pure aluminium and alloy.

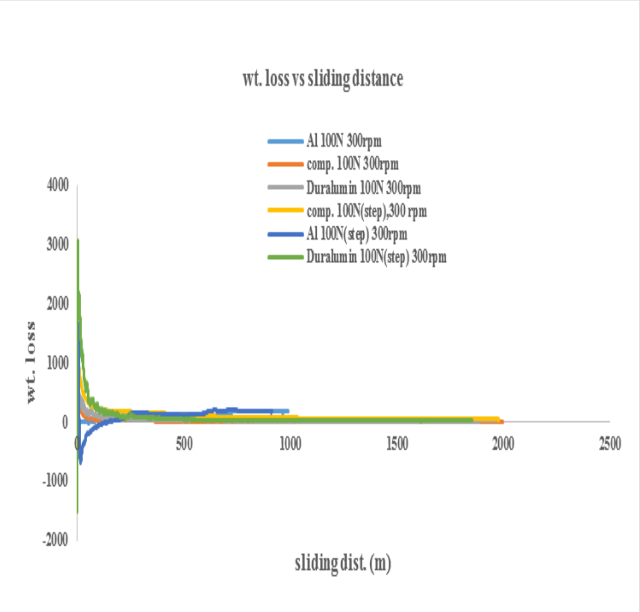

Fig-6: Weight loss verses sliding distance keeping speed constant at 300 rpm at two different load conditions of 100 N (constant) and 100 N (step load) for pure Al, duralumin and MMNC.

Figure-6 shows weight loss verses sliding distance keeping speed constant at 300 rpm under two different load conditions 100 N constant and 100 N step. At constant load, for MMNC, weight loss is initially high and gradually decreases to nearly zero and maintains a steady state till sliding distance 2000 meters. This happens due to the embodied of nano particles in the aluminium matrix. Weight loss for MMNCs at step load conditions is initially more and gradually decreases to very small amount till 600 meters of sliding distance then again decreases to almost zero and continues to 1800 meters sliding distance. This is due to the application of step load because during the transition period, the wear rate decreases and subsequently it maintains steady state. In case of pure aluminium, at constant load, weight loss of material varies significantly as shown in the Figure 6. Initially the material loss is very high (2800 µm), then decreases to negative value due to sticking to the wheel, then again increases and at 1000 meters of sliding distance, complete worn out takes place. During the step load condition, when sliding distance exceeds 50 meters, weight loss increases to 1700 µm, then drastically decreases to negative value due to sticking to the wheel, then again increases and at 1000 meters of sliding distance, complete worn out takes place. The weight loss for composites, in both the cases, is initially high and then decreases to almost zero as sliding distance increases up to 2000 meters. This happens due to increase of hardness as alumina nano particles embedded in the aluminium matrix. But still here is a difference of weight loss between constant load and step load. During step load, weight loss is more compared to constant load. This is due to the frequent increase of load. Weight loss increases at each step, which is very less. In case of duralumin, under constant load 100 N, wt. loss increases up to 900 µm, then falls to negative value for sticking to the wheel, then rises and continues up to 2000 meters at almost constant rate. But under step load condition, the alloy specimen sticks to the wheel initially showing negative wt. loss. The wt. loss then rises up to 3000 µm, then falls to negligible value and continues up to 1850 meters of sliding distance. Weight loss is more when speed is increased in steps.

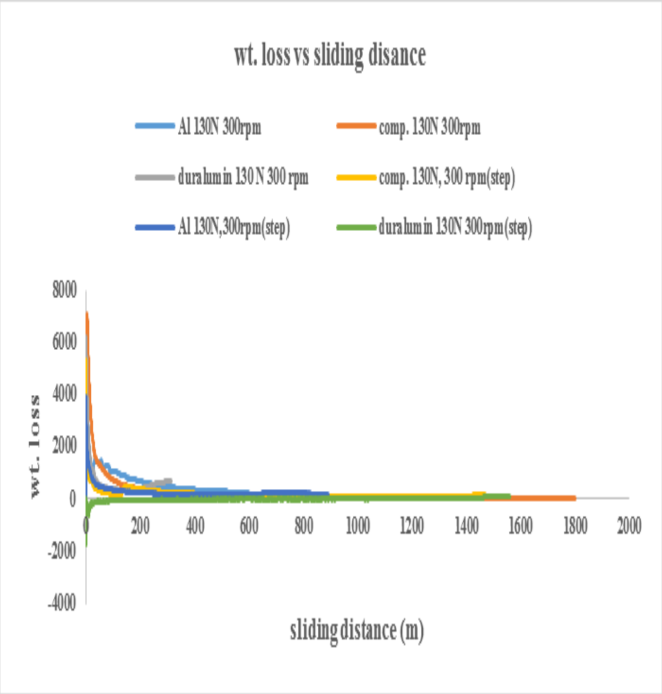

Fig-7: Weight loss verses sliding distance keeping load constant at 130 N at two different speeds of 300 rpm (constant) and 300 rpm (step) for pure Al, duralumin and MMNC.

Figure-7 shows weight loss verses sliding distance keeping load constant at 130 N under constant and step speed conditions. Weight loss for MMNC specimen at both speed conditions is nearly zero though there is a little difference which is not so significant where as in case of pure aluminium, weight loss of material varies significantly as shown. Initially the material is sticking to the wheel which indicates negative. For duralumin, under 130 N constant load and 300 rpm constant speed, wt. loss rises to 6500 µm initially, then falls to around 500 µm and continues up to 300 meters of sliding distance. Under 300 rpm step speed and 130 N constant load, alloy initially sticks to the wheel showing negative wt. loss and then continues up to 1600 meters.

In all the cases, weight loss is more during step speeds. This happens when speed changes step wise, at each step the wt. loss increases and stabilizes after certain time. This phenomena continues till the end. At constant speed, initially weight loss is high and decreases to negligible amount after few sliding distance and then maintains the same.

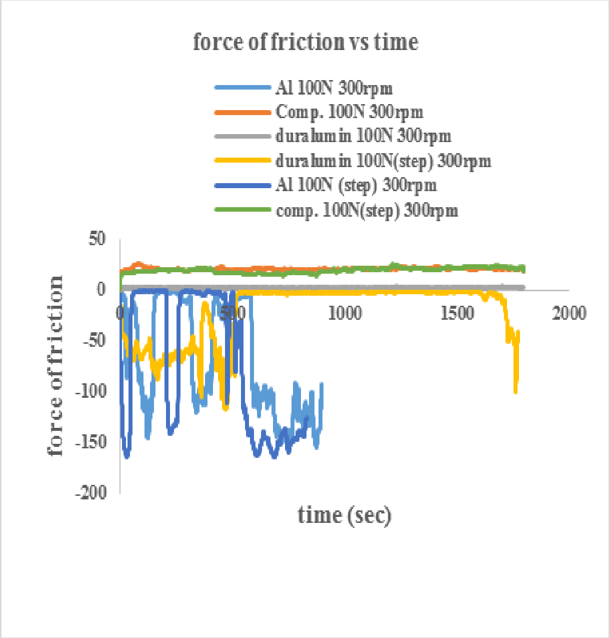

Fig-8: Force of friction verses time keeping speed constant (300 rpm) at two different load conditions of 100 N constant and 100 N step for pure Al, duralumin and MMNC.

Figure-8 shows the graph between force of friction verses time keeping speed constant at two different load conditions. For MMNC, the force of friction is almost constant in two loading conditions, over the entire time period and is more when load is applied in step. In case of pure aluminium, force of friction is negative i.e. friction resistance is almost zero under both the load conditions. For duralumin, the force of friction is almost constant over the entire time period under constant load condition where as it is negative when load is increased in steps because it sticks to the wheel. Friction resistance is more in case of MMNC.

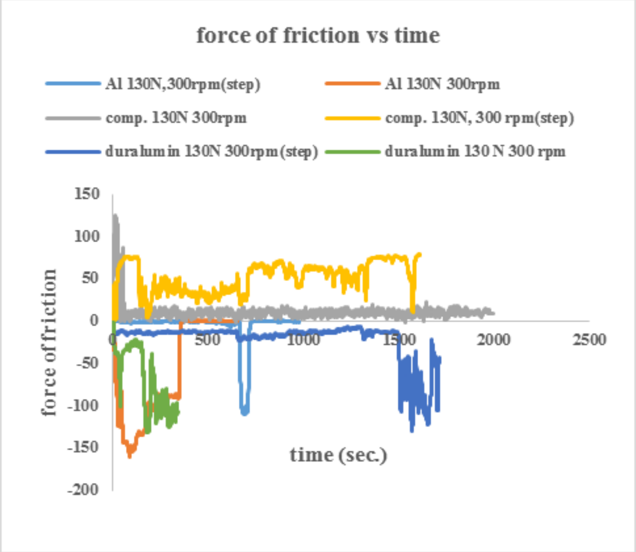

Fig-9: Force of friction verses time keeping load constant (130 N) at two different speed conditions of 300 rpm (constant) and 300 rpm (step) for pure Al, duralumin and MMNC.

Figure-9 shows the graph between force of friction verses time (seconds) keeping load constant at 130 N under two different speed conditions i.e. 300 rpm (constant) and 300 rpm (step). For MMNC, the friction force is maximum initially and then remains almost constant under constant speed condition of 300 rpm over the entire time period, while under the step speed condition of 300 rpm, it is also maximum at many points of the curve, but fluctuating significantly as speed is applied stepwise over a time period of 1700 seconds. In case of pure aluminium, force of friction is negative in both the cases. As the material is sticking to the wheel, the characteristic curves of aluminium in both the cases show negative. For alloy, as the material is sticking to the wheel, the characteristic curves in both the cases show negative.

4. MICROSCOPIC EVALUATION

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

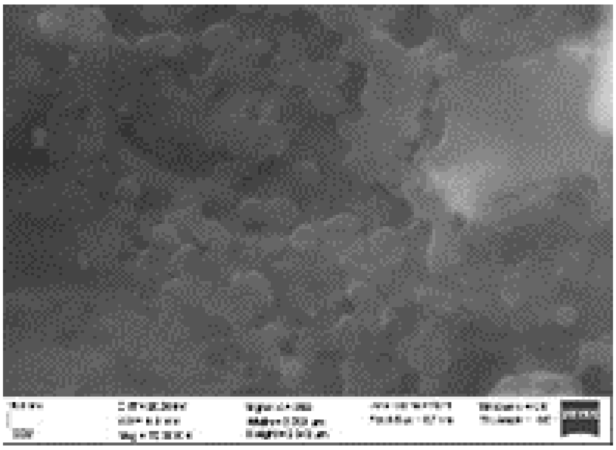

Fig-10 Microstructure of pure Al at 100N and 300 rpm

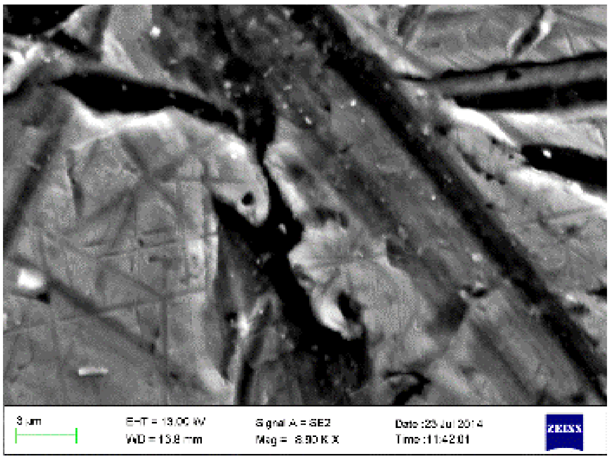

Fig-11 Microstructure of alloy at 100N and 300 rpm

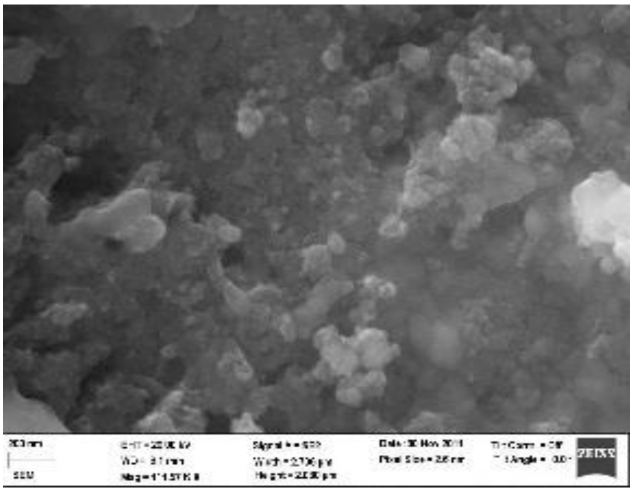

Fig-12 Microstructure of MMNC at 100N and 300 rpm

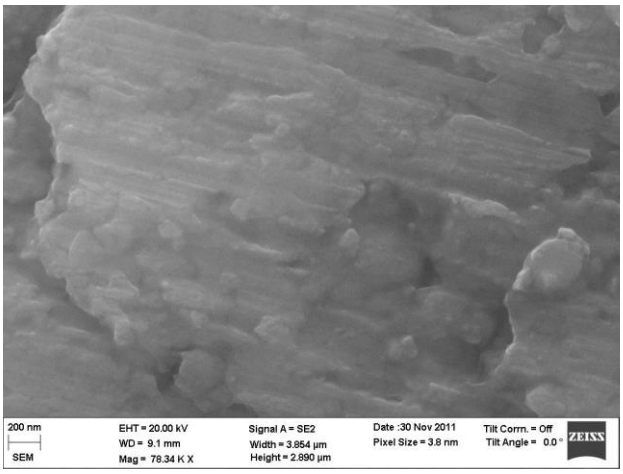

Fig-13 Microstructure of Al at 100 N (step) & 300 rpm

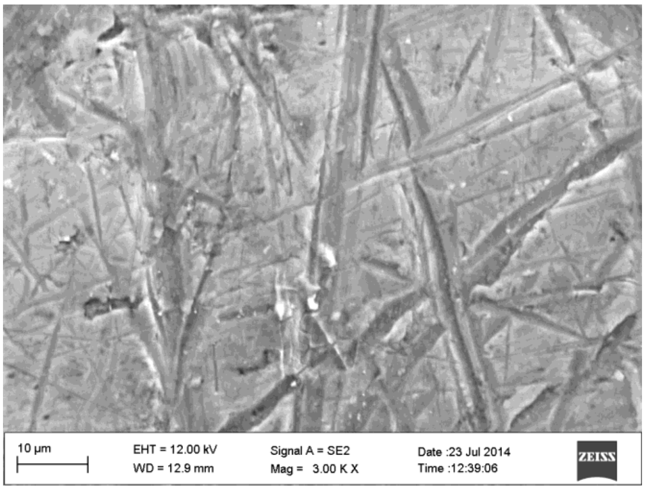

Fig-14 Microstructure of alloy at 100 N (step) & 300 rpm

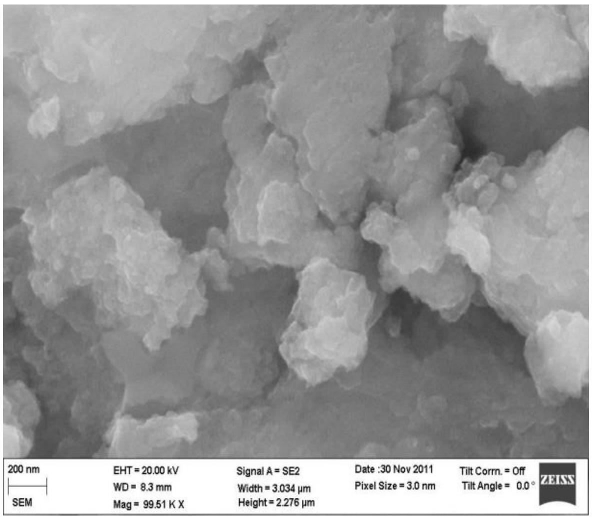

Fig-15 Microstructure of MMNC at 100 N (step) & 300 rpm

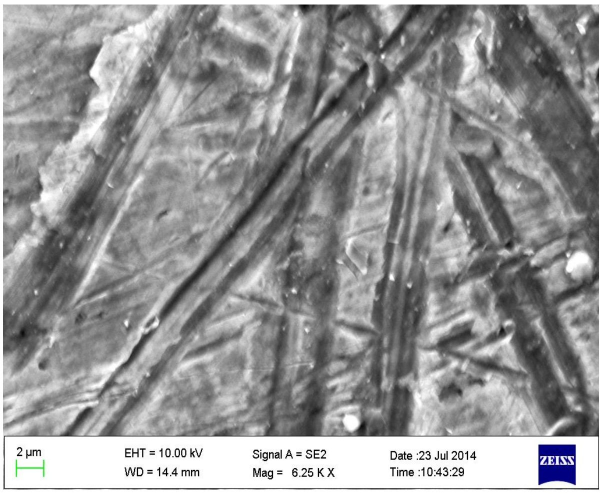

Fig-16 Microstructure of pure Al at 130 N & 300 rpm (step)

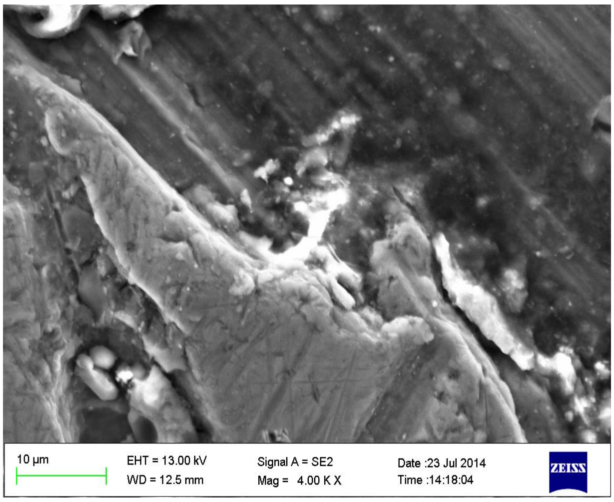

Fig-17 Microstructure of Alloy at 130 N & 300 rpm (step)

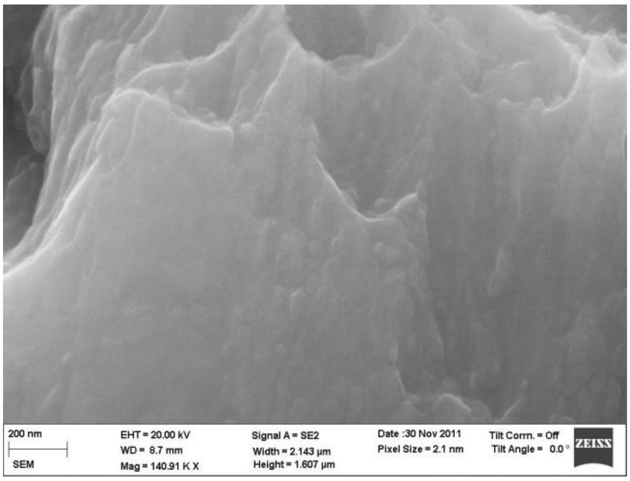

Fig-18 Microstructure of MMNC at 130 N & 300 rpm (step)

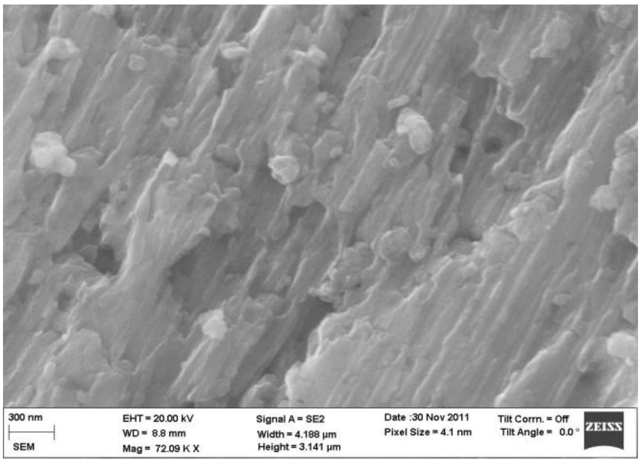

Fig-19 Microstructure of pure Al at 130 N & 300 rpm

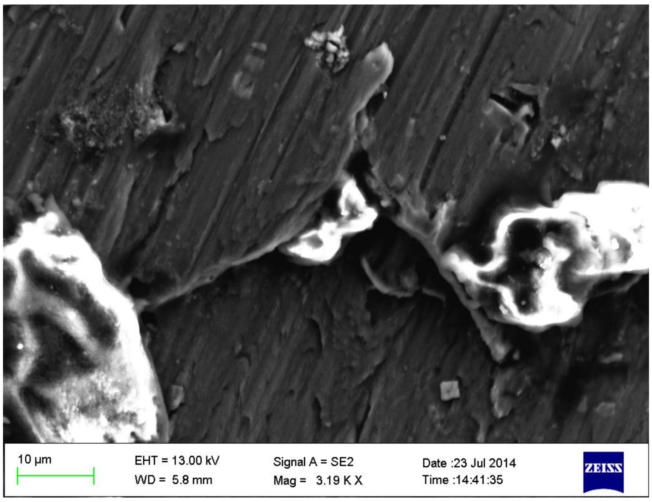

Fig-20 Microstructure of Alloy at 130 N & 300 rpm

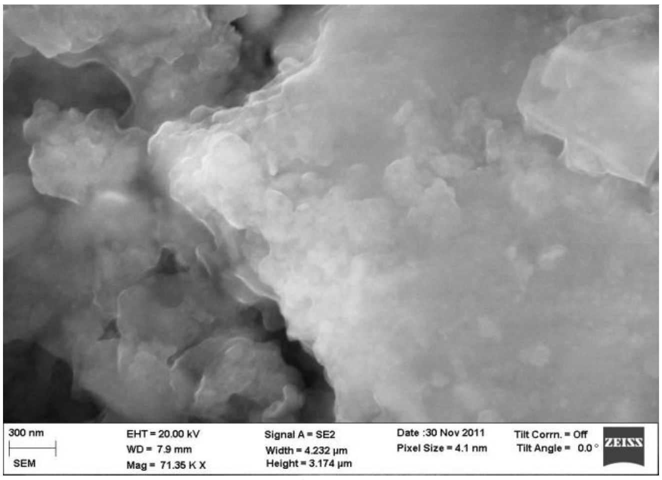

Fig-21 Microstructure of MMNC at 130 N & 300 rpm

Figures 10, 11 and 12 present the FESEM micrograph of worn out samples of pure aluminium, duralumin and MMNC respectively under constant load of 100 N and constant speed of 300 rpm. Figure 10 shows a wavy surface which is formed because of the heat generation and localized welding in pure aluminium. Since the surface is sticky, the wear of aluminium becomes more. In figure 11, deep cuts are observed due to non-uniform wear. In figure 12, a uniform worn out surface is observed throughout. This occurs because of less wear and the peening effort of nano particles embedded in the matrix.

In figure 13, only wavy surfaces are observed instead of nodular ones. Grooves are also observed at some points. This occurs because of the application of step load. When higher load is applied, nodular surfaces are eliminated in every step. When the higher load is applied at the last step, at some points, grooves are observed due to localized heating. Figure 14 presents the microstructure of the alloy where, deep cuts and grooves are also observed due to step load. The worn out surface is not uniform due to non-uniform wear. Figure 15 presents the microstructure of MMNC where, in addition to its smooth worn out surface, some grooves are visible in few places due to the application of step load. Grooves are formed instantly at some points at the time of application of step load and it continues to be a groove in the successive application of step load.

Figures 16, 17 and 18 present the FESEM pics of pure aluminium, alloy and composite respectively at 130 N load and speed of 300 rpm applied in step. At higher load, the wear is more in all the cases. In case of pure aluminium, the wear rate is so severe for which scratches as observed in fig. 16. In figure 17, deep scratches and ploughing action are observed due to severe wear in case of alloy. In figure 18, no scratch is observed as wear is very less compared to pure Al and alloy.

Figures 19, 20 and 21 present the microstructure of worn out surfaces of pure aluminium, alloy and MMNC respectively under constant speed of 300 rpm and constant load of 130 N. Severe wear is observed in case of pure aluminium compared to composite. Duralumin also experiences severe wear compared to MMNC. In both the cases of aluminium and alloy, ploughing action is observed. But in case of MMNC, no ploughing action takes place thus keeping wear uniform. This is because of the strengthening mechanism of the nano particles embedded in the matrix. As the particles are very small and are embedded in the matrix, no projections are coming out of the surface which prevents ploughing action.

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 decreases as the rolling distance increases.
(c) Wear increases with the increase in load.
(d) Wear increases with the increase in speed.
(e) Wear is more when load and speed are applied/increased in steps.
(f) Force of friction increases with rise in load and speed in case of MMNC.
(g) Resistance to wear and friction is more in case of MMNC compared to aluminium and alloy.

The results shown by MMNC are encouraging in comparison to pure aluminium and duralumin as far as wear, material loss and friction force 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 be conducted 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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