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

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Abstract

In this report, the aluminium metal matrix was reinforced with 1.5 wt. % of alumina nano particles using non-contact cavitation method to prepare the metal matrix nano composite. Microstructural investigation was conducted on the worn out samples. It showed uniform distribution of alumina particles in the matrix. Sliding wear behavior of the as-cast MMNC was studied in dry condition, under different test conditions by varying the load (constant and step loads) and the sliding speed (constant and step speeds) using a Multiple Tribo Tester. It was found that resistance to sliding wear improved considerably with the addition of alumina nano particles. FESEM images 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 rate increases with increase in load and sliding velocity. Wear rate is more when load and speed are increased in steps. Delamination and abrasion are the dominating types of wear observed.

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

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1. INTRODUCTION

Since new processing techniques have been developed, the requirement for composite materials which are light in weight having high strength and stiffness, high performance with enhanced properties compared to traditional metals and alloys, has gone up. Most of these composite materials are metal matrices reinforced with fibre, particulate or whiskers. Metal marix nano composites are the most versatile materials for applications in advanced structural, automotive, aviation, aerospace because of their excellent blend of properties. In recent years, significant attention has been paid for extending the use of these composite materials in marine environment [1, 2]. The properties of MMNCs can be tailored according to their need. They differ from the conventional engineering materials because of their homogeneity [3]. MMNCs with aluminium matrix possess 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 high cost of production, their application in industries is slowed down. Casting Technology plays important role to overcome this problem, although several technical challenges exist. It is a big challenge to achieve a uniform distribution of reinforcement within the matrix because it 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]. It is reported that if nano particles of quantity 2 wt. percent are reinforced, it enhances the hardness and yield strength of the composite by a factor as high as 2 [16]. Several methods are followed for the production of MMNCs which include mechanical alloying, vertex process, and spray deposition etc. But, these processes are expensive. Solidification processing is a relatively cheaper route. Nano particles generally agglomerate during solidification process due to Van der Waals forces. Hence, proper dispersion of the nano particle in metal matrix poses a big challenge. In the present report, a non-contact cavitation method, in which the ultrasonic probe is not in direct contact with the liquid metal, was attempted to disperse nano sized alumina particles in aluminum matrix. In this method, the mold was subjected to ultrasonic vibration [16-20].

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 duration.

2. METHOD OF EXPERIMENT

2.1 Material for MMNC

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 aim is to design the MMNC by combining the metal & ceramic i.e. addition of high strength, high modulus refractory particles to ductile metal matrix to get tailor made tribological 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

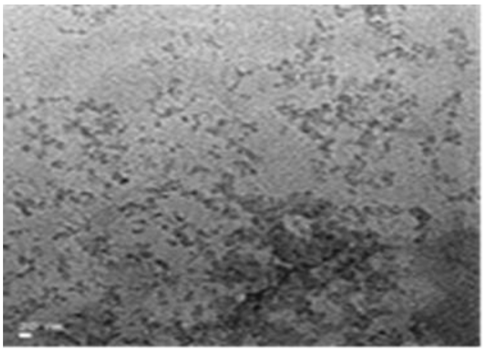

Fig-1 HRTEM micrograph of Al_2O_3 nano powder

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. The set up consists of an ultrasonic generator that generates ultrasonic waves, an ultrasonic chamber and steel mould. In order to prevent thermal cracking, the mould was preheated. The preheated mould was kept in the ultrasonic chamber and the chamber was subjected to vibration at a frequency of 35 KHz. Liquid aluminium and alumina particle (1.5 wt. %) having average size of 10 nm were simultaneously poured into the vibrating mould from the mixing chamber.

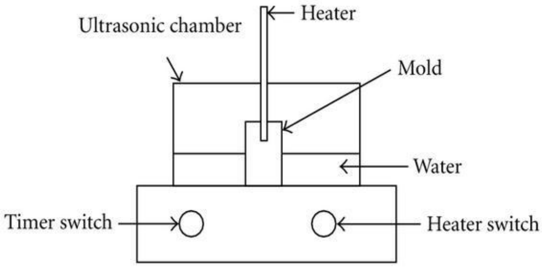

Fig-2: Experimental set up

When the simultaneous pouring was over, the heating element was immediately brought down above the liquid metal for delaying the solidification. The vibration was carried out for a period of five minutes to break the agglomeration and to ensure complete mixing.

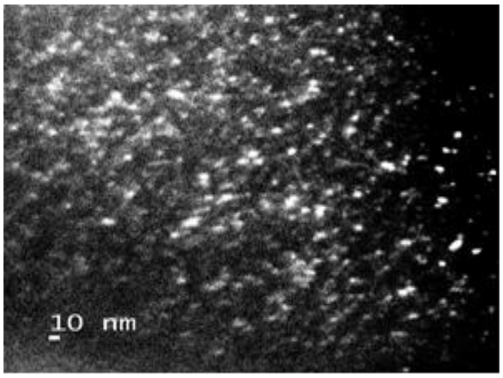

Fig-3: HRTEM micrographs of Al-Al2O3 nano composite showing uniform distribution of nano particles

2.3 Wear Tests

The sliding wear experiments were carried out on a Multiple Tribo Tester (TR-5), Ducom make, in dry condition. In this set up, the wheel rotates and the specimen, cut to the size of 6.35 x 6.35 x 9 mm, is pressed against the wheel. The specimen is held by the fixture. Loads from up to 1000 N and sliding speeds up to 2000 rpm can be applied to press the specimen against the periphery of the 20 mm thick and 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.

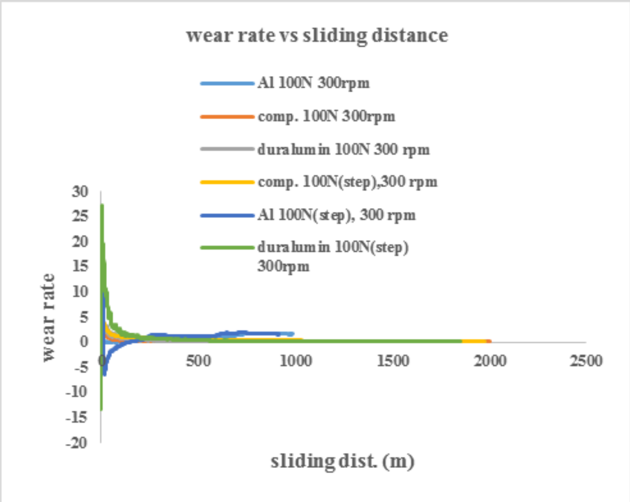

Fig-4: Wear rate verses sliding distance keeping speed constant at 300 rpm at two different load conditions of 100 N (constant) and 100 N (step load) for MMNC, alloy and pure Aluminium.

The above figure shows wear rate verses sliding distance keeping speed constant at 300 rpm at two different load conditions of 100 N (constant) and 100 N (step load) for MMNC, alloy and pure Aluminium. In case of pure aluminium, under the effect of constant load of 100N, wear rate first rises to 25 µm/sec and then falls to zero level. It then rises to approximately 2 µm/sec, but continues up to only 1000 meters of sliding distance whereas under the effect of step load condition i.e. load increased in steps, wear rate first rises to 15 µm/sec, then falls and shows negative due to the sticking of the metal to the wheel. It then rises to approximately 2 µm/sec and continues up to only 900 meters of sliding distance. For MMNC, under constant load of 100 N, wear rate first rises to 9.5 µm/sec, then falls to approximately 0.5 µm/sec and completes the whole sliding distance of 2000 meters whereas under the effect of step load, wear rate first rises to 10 µm/sec, then falls to approximately 1 µm/sec and continues to cover the total sliding distance of 2000 meters. In case of duralumin, under constant load of 100 N, wear rate first rises to 8 µm/sec, then falls and shows negative due sticking of metal to the wheel. It then rises to 4 µm/sec and falls again to approximately zero level, but covers the whole sliding distance. Under step load condition, the wear rate first shows negative due to the sticking of the metal to the wheel and then rises to 28 µm/sec. it then falls to zero value and covers 1850 meters of sliding distance. Wear rate is more when load is increased in steps. Resistance to wear is more in case of MMNC.

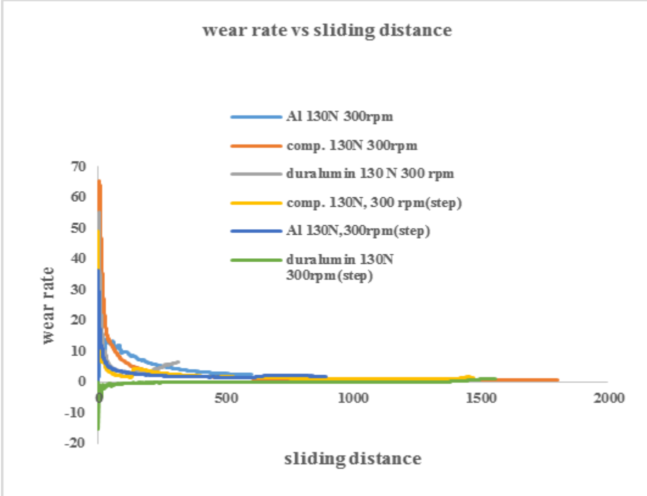

Fig-5: Wear rate verses sliding distance keeping load constant at 130 N at two different speeds of 300 rpm (constant) and 300 rpm (step speed) for MMNC, alloy and pure Aluminium.

The above figure shows wear rate verses sliding distance keeping load constant at 130 N at two different speeds of 300 rpm (constant) and 300 rpm (step speed) for MMNC, alloy and pure aluminium. For pure aluminium, under constant speed of 300 rpm, wear rate increases to 14 µm/sec initially and then falls to 2 µm/sec and covers only 600 meters. But when speed is increased in steps, wear rate rises to 37 µm/sec initially, then it falls to 2 µm/sec and covers only 900 meters. For MMNC, under constant speed, wear rate rises to 65 µm/sec initially, then falls to almost zero value and covers 1800 meters of sliding distance. Similarly, under the step speed i.e. speed increased in steps, wear rate of MMNC initially rises to 50 µm/sec, then falls to 1 µm/sec and covers 1500 meters of sliding distance. For duralumin, under constant speed, wear rate rises to 55 µm/sec initially, then falls to 5 µm/sec and covers only 300 meters. Similarly, under the step speed, wear rate shows negative as the metal sticks to the wheel. Again it shows that wear rate is more when speed is increased in steps.

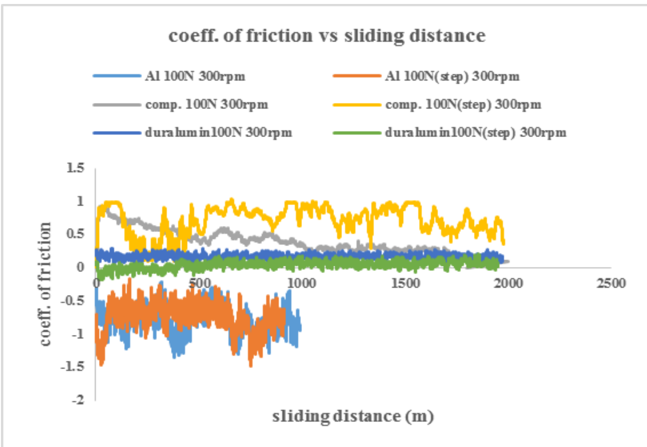

Fig-6: Coefficient of friction verses sliding distance keeping speed constant at 300 rpm at two different load conditions of 100 N (constant) and 100 N (step load) for MMNC, alloy and pure Aluminium.

The figure no. 6 shows coeff. of friction verses sliding distance keeping speed constant at 300 rpm at two different load conditions of 100 N (constant) and 100 N (step load) for MMNC, alloy and pure aluminium. Under both the cases of constant load and step load, the coeff. of friction shows negative curves which implies that friction resistance is zero in case of pure aluminium. Duralumin, under constant load, shows some frictional resistance whereas, under step load condition, value of coeff. of friction falls further with negative initially. In case of MMNC, under constant load condition, the value of friction coefficient becomes high initially and then falls uniformly over the entire sliding distance. But, under step load condition, the friction coefficient curve touches highest value at many points with fluctuations over the entire sliding distance. Frictional resistance, in case of MMNC, is higher than others.

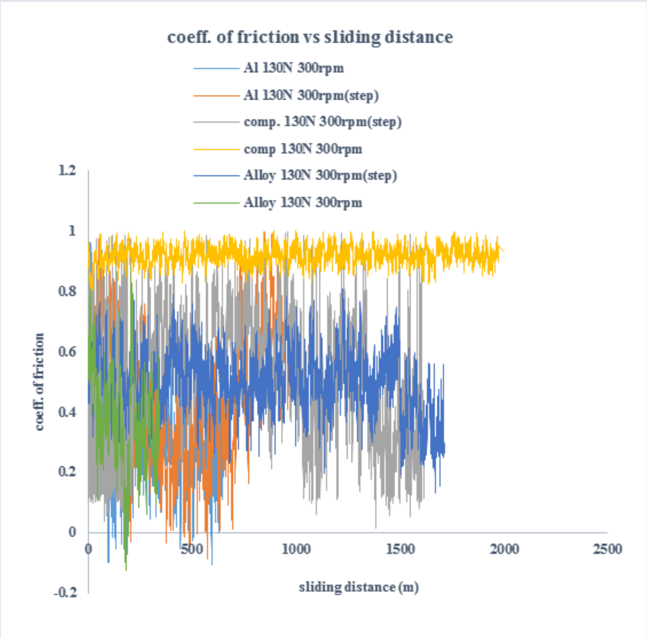

Fig-7: Coefficient of friction verses sliding distance keeping load constant at 130 N at two different speed conditions of 300 rpm (constant) and 300 rpm (step load) for MMNC, alloy and pure Aluminium.

For MMNCs, the coeff. of friction is maximum and almost constant under 300 rpm (constant) over the entire sliding distance of 2000 rpm, while under the speed of 300 rpm (step), it is also maximum at many points on the curve, but fluctuating significantly as speed is increased stepwise over a sliding distance of 1700 meters. In case of pure aluminium, fluctuation in coeff. of friction is observed in both the cases. However the fluctuation is significant in case of 300 rpm (step). As the material is sticking to the wheel, the characteristic curves of aluminium in both the cases show negative at some places. For alloy, under 300 rpm (constant speed), the curve is negative at some points due to the sticking of metal to the wheel whereas, under 300 rpm (step), it covers 1750 meters with fluctuations.

4. MICROSCOPIC EVALUATION

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

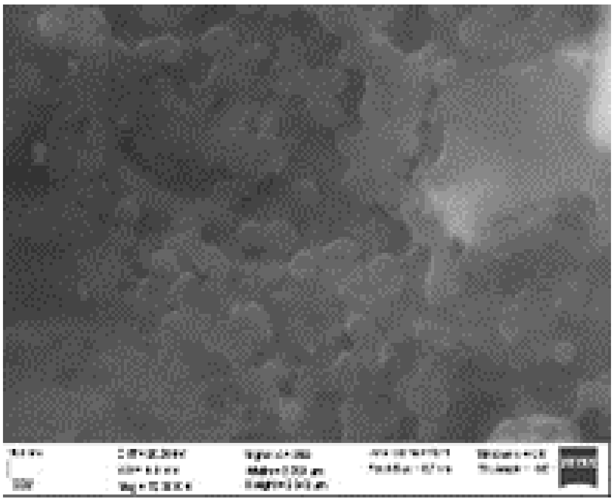

Fig-8 Microstructure of pure Al at 100N and 300 rpm

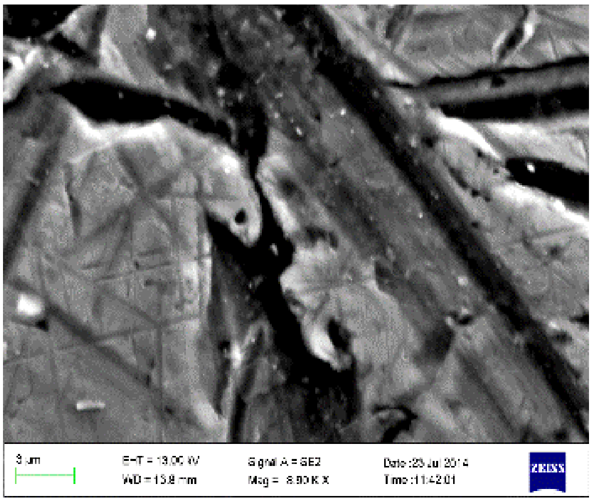

Fig-9 Microstructure of alloy at 100N and 300 rpm

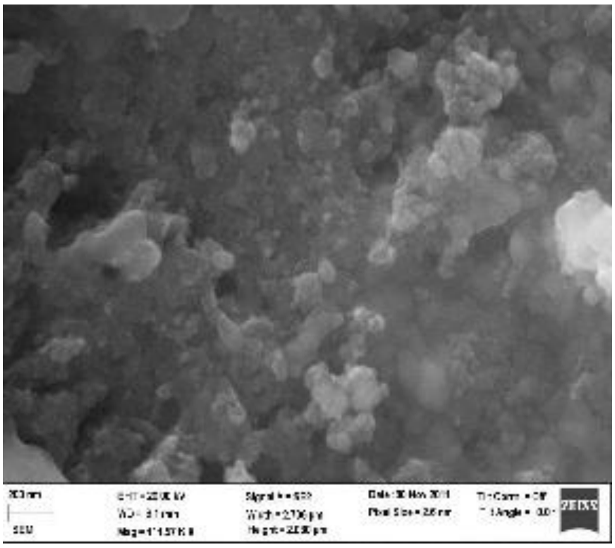

Fig-10 Microstructure of MMNC at 100N and 300 rpm

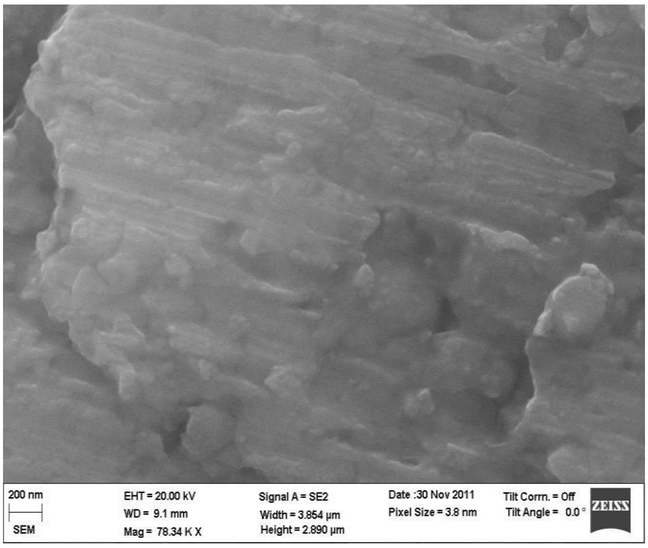

Fig-11 Microstructure of Al at 100 N (step) & 300 rpm

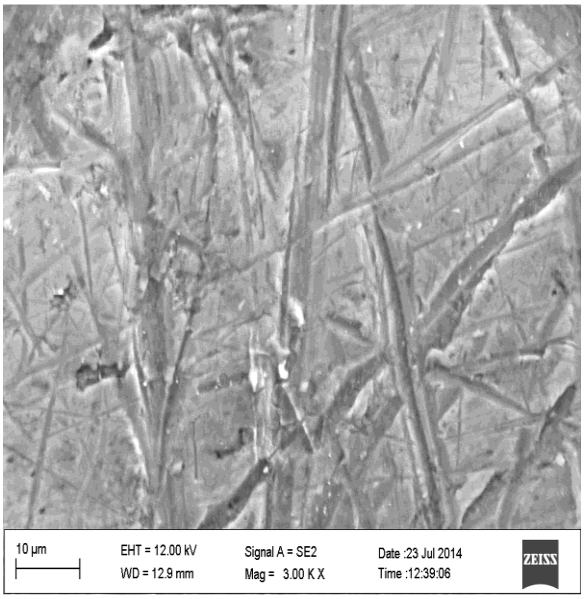

Fig-12 Microstructure of alloy at 100 N (step) & 300 rpm

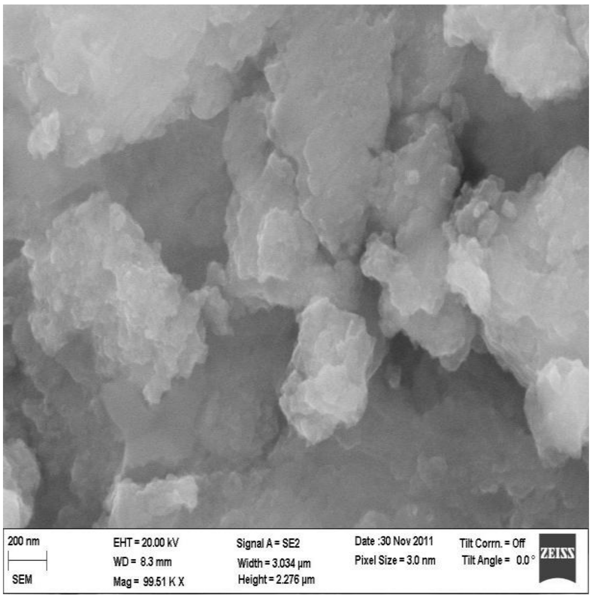

Fig-13 Microstructure of MMNC at 100 N (step) & 300 rpm

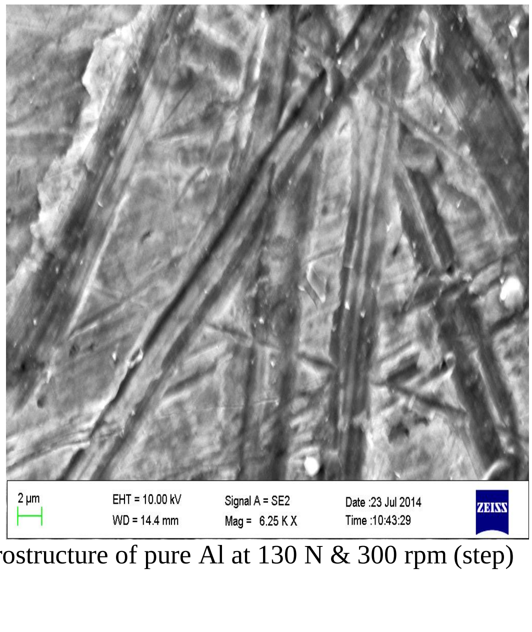

Fig-14 Microstructure of pure Al at 130 N & 300 rpm (step)

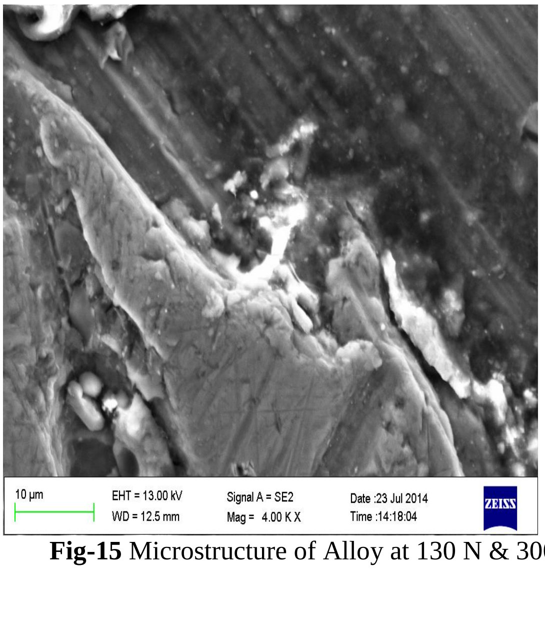

Fig-15 Microstructure of Alloy at 130 N & 300 rpm (step)

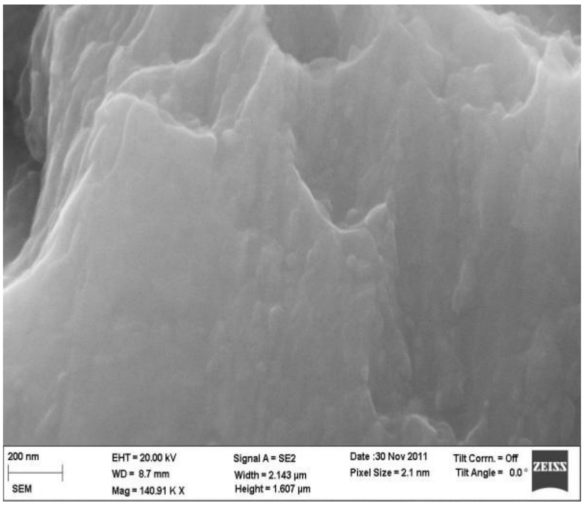

Fig-16 Microstructure of MMNC at 130 N & 300 rpm (step)

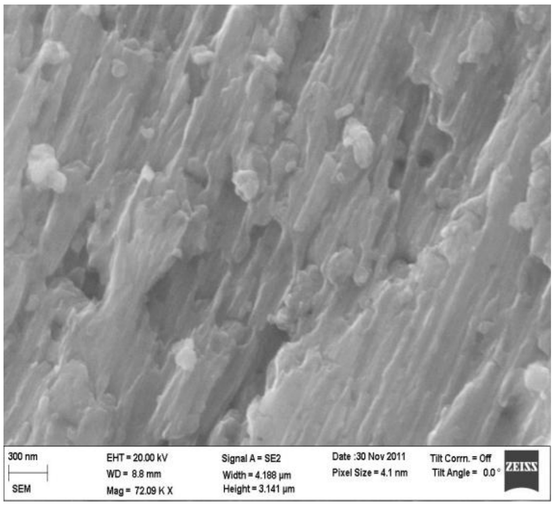

Fig-17 Microstructure of pure Al at 130 N & 300 rpm

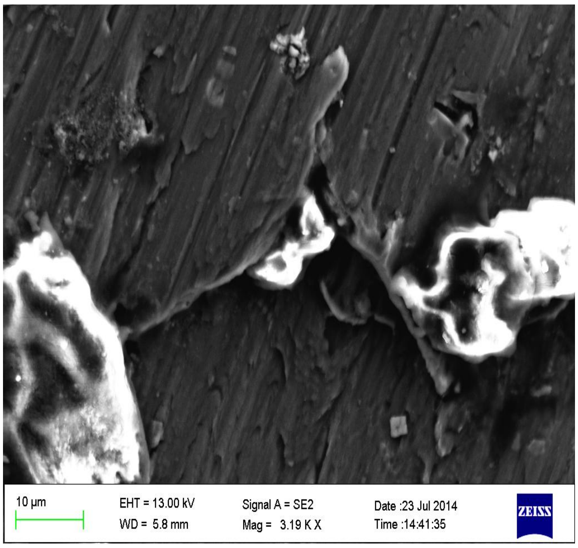

Fig-18 Microstructure of Alloy at 130 N & 300 rpm

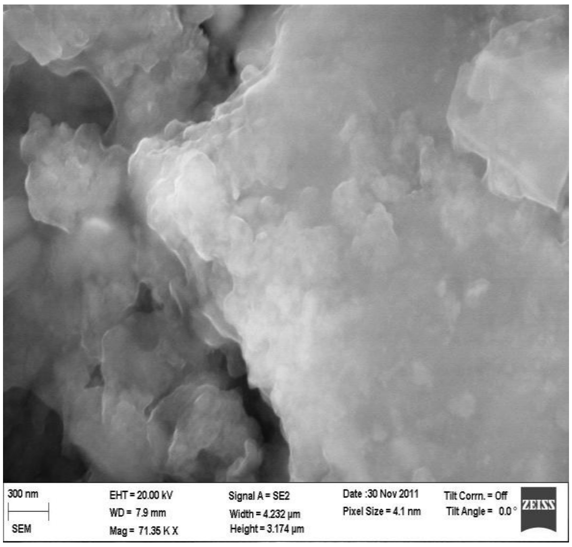

Fig-19 Microstructure of MMNC at 130 N & 300 rpm

Figures at 8, 9 and 10 show the FESEM pics of worn out samples of pure aluminium, duralumin and MMNC respectively under 100 N constantly applied load and constant speed of 300 rpm.

(1) Pure aluminium, at figure 8, gives a wavy surface which is resulted because of the heat generation and localized welding. Because of the sticky surface, the wear of aluminium is more.
(2) Alloy, at figure 9, shows deep cuts due to non-uniform wear.
(3) And MMNC, at figure 10, shows uniform worn out surface throughout which occurs because of less wear and the peening effort of nano particles embedded in the matrix.

Figures at 11, 12 and 13 show the FESEM pics of worn out samples of pure aluminium, duralumin and MMNC respectively under load of 100 N (increased in steps) and constant speed of 300 rpm.

(1) Pure aluminium, at figure 11, gives only wavy surfaces. Grooves are also observed at some points on the worn out surface which occurs due to 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.
(2) Alloy, at figure 12, gives the pic where deep cuts and grooves are also observed due to step load. As observed, the worn out surface is not uniform due to non-uniform wear.
(3) MMNC, at figure 13, presents the microstructure 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 at 14, 15 and 16 show the FESEM pics of worn out samples of pure aluminium, duralumin and MMNC respectively under constant load of 130 N and speed of 300 rpm (increased in steps). At higher load, the wear is more in all the cases because, increase in load increases wear rate..

(1) Pure aluminium, at figure 14, shows scratches due to severe wear rate.
(2) Duralumin, at figure 15, shows deep scratches and ploughing action due to severe wear.
(3) MMNC, at figure 16, shows no scratch since wear is very less compared to pure Al and alloy.

Figures at 17, 18 and 19 show the FESEM pics of worn out samples of pure aluminium, duralumin and MMNC respectively under constant load of 130 N and speed of 300 rpm.

(1) Pure aluminium, at figure 17, shows severe wear compared to composite.
(2) Duralumin, at figure 18, also shows severe wear compared to MMNC. In both the cases of aluminium and alloy, ploughing action is observed.
(3) MMNC, at figure 19, shows no ploughing action 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 and ploughing action is prevented.

5. CONCLUSION

The following conclusions can be drawn from the dry sliding wear behaviour of pure aluminium, alloy and MMNC.

(a) Wear rate decreases with increase in rolling distance.
(b) Wear rate increases with increase in applied load.
(c) Wear rate increases with increase in sliding speed.
(d) Wear rate is more when load and speed are increased in steps.
(e) Friction coefficient increases with rise in applied load and speed in case of MMNC.
(f) Resistance to wear and friction is more in case of MMNC compared to pure aluminium and alloy.

The results shown by MMNC are encouraging in comparison to pure aluminium and duralumin as far as wear rate, material loss and friction coefficient are concerned. Addition of nano alumina powder to aluminium matrix 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 or volume 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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