Fabrication and Wear Testing of Nano and Micro Carbides/Oxides Reinforced Aluminium based Metal Matrix

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***Abstract* — Aluminium metal matrix composites (AMCs) possess tremendous potential for number of applications in addition to their present uses in different engineering fields. In the present study, aluminium composite with 10 % reinforcement of Al_2O_3 and SiC was prepared using a cost effective stir casting technique. Characterization of the as-cast aluminium composite specimens was done using optical microscopy and scattered electron microscopy (SEM) which showed the uniform distribution of the reinforcing particles in the aluminium metal matrix. Hardness tests carried on the specimens showed increase in hardness over the pure aluminum metal. Testing of wear behavior was done on pin on disc apparatus. The fabricated composites showed improvement in wear resistance over the pure aluminum metal. Considering all the factors, it can be concluded that aluminium based composite with 10% SiC(nano) reinforcement possess better mechanical and wear resistance properties than rival specimens i.e. pure aluminium and Al+ Al_2O_3, Al+ Al_2O_3 (nano), Al+SiC, Al+SiC (nano) composite.**

Keywords— Aluminium Composites, SiC, Al_2O_3, Stir Casting, Wear

I. INTRODUCTION

The term “Composites” can be defined as material system in which the reinforcement distributed in the matrix and also which obtain its unique characteristics from the properties of the different constituents, from the architecture and the geometry of the constituents of composites and from the interfaces between the different constituents [1]. Composites are mainly classified on the basis of chemical or physical characteristics of the matrix phase e.g. polymer matrix, ceramic matrix and metal matrix. Aluminium Matrix Composites (AMCs) offer solution to common problems i.e. strength to weight ratio and wear resistance [2]. Wear behavior of Al_2O_3-Graphite reinforced with Al6061 hybrid metal matrix composites was predicted using the feed forward back propagation algorithm. It was observed that incorporation of alumina and graphite improves the wear behavior of aluminium metal matrix composites [3]. Yuan et al [4] studied the mechanical properties of the particles reinforces aluminium metal matrix composites by doing micro indentation experiments. The micro hardness and Young’s modulus of SiC particles reinforced aluminum matrix composites were examined with micro-compression-tester (MCT).

II. EXPERIMENTAL DETAILS

After considering all the available options of polymer matrix composites, ceramic matrix composite, metal matrix composite etc. finally metal matrix composites were selected. Aluminium was selected as a matrix because of its enormous advantages & applications. After selection of base material, the selection of the reinforcing material was done & SiC and Al_2O_3 were selected as the reinforcement material.

A. Filler materials

The filler materials are normally discontinuous, stronger and hardest than the matrix material. The main aim of these filler materials is to enhance the physical, mechanical and tribological properties of the composite. In the present work the most commonly used and readily available ceramics particles (i.e. silicon carbide and aluminium oxide) are used as filler materials to improve the mechanical wear resistance properties of pure aluminium. Aluminium oxide is one of the cost effective and widely used materials in the family of engineering ceramics. Because of excellent combination of properties, it is no surprise that the fine grain technical grade alumina has a wide range of applications. Its high hardness, exceptional dielectric properties and excellent thermal properties makes it the material of choice for a wide range of applications. Silicon carbide is basically composed of tetrahedral of carbon and silicon atoms with the strong bonds in the crystal lattice. It produces very large and very strong material. Also Silicon carbide is never attacked by any acids or alkalis or molten salts upto 800°C. In air, SiC forms a protective silicon oxide coating at 1200°C and is able to be used up at 1600°C. Its high thermal conductivity coupled with low thermal expansion and its high strength gives this material exceptional thermal shock resistant qualities.

B. Composite Fabrication

The fabrication of the metal matrix composites are generally based on two technological methods such as solid state processing and liquid state processing method. In solid state processing method, the reinforcements are embedded in the matrix through diffusion phenomenon and are produced at high temperature and pressure. In this process some special care should be taken to avoid the growth of the undesirable phases or compounds species on interfaces. Some commonly used techniques under this method are diffusion bonding, powder metallurgy etc. In liquid state processing, the matrix is in liquid form and the reinforcement either in form of fibers or particles embedded in it. The uniformity in distribution of reinforcement can be made by means of applying some mechanical actions. This is one of the most used and inexpensive method for fabrication of metal matrix composites. Hot forming, liquid infiltration, squeeze casting and stir casting are most common techniques under this method.

C. Stir casting method of fabrication of MMCs

The objective of work is to form the reinforcing particles within the Al melt by addition of oxides and carbides into base metal in the liquid state. In this method, when the matrix material is melted, it is stirred vigorously to form a vortex at the surface of the melt, and the reinforcement material is then introduced at the side of the vortex. The particles transfer into matrix melt due to the pressure difference between the inner and outer surface of the melt.

III. APPARATUS ACQUIRING & FABRICATION OF SET-UP

Now after finalization of the composite to be prepared & the method or process to be used for its fabrication along with the materials to be used, the next step was to acquire the apparatus required. First step of process was to acquire the most important component of the apparatus or set up. For the fabrication of set up, the following components were taken and these were checked for the configuration which was required in them to fulfill the purpose:

A. Furnace

Furnace used was having a heating range of 0º-1200ºC which was electrically operated. The door of the furnace was on the upper side of the furnace as shown in figure below. It is rectangular in shape with dimensions 2.5x2.5x2.5 feet. The temperature is shown on digital meter of control panel with heat input setting Screw to maintain the heat input and stabilize the temperature within required range.

B. Crucible

To melt the material in a furnace it has to be placed in some utensil. The utensil which is used for that purpose is known as crucible. The crucible which was used to melt the aluminium was made up of graphite which is mostly used for this purpose in industries also. The size of crucible is basically pre-fixed and these are available in the market having size numbers i.e. 1,2,3,4...etc. The size number 5 crucible of graphite was used because it could carry up to 2 Kg of aluminium.

C. Stirrer

Purpose of stirrer is to mix the reinforcing materials properly and disperse them in the base material thoroughly. Design of stirrer is also of great importance because if the design of stirrer is not proper then it will not provide whirling properly and the mixing will not take place accordingly.

D. Mould

Mould is the component used in casting in which the molten material is poured and allowed to solidify. The mould is designed to prepare components of required shape and dimensions. The material and shape of mould varies considerably according to the material to be casted and temperature range. The mould used for casting composites was made up of mild steel. The mould was made by two 1 inch thick plates of dimensions 25 cm x 17 cm. It consisted of 6 cylindrical grooves of 2 cm diameter each with a depth of 8 cm. These grooves were joined at the bottom with a groove of 2 cm diameter and a gap of 1 cm was provided between each vertical groove.

On one side of the mould it is provided with handles to open and close it tightly with the help of locking arrangement. On the other side it is provided with a mechanism to connect the two sheets properly and to open and close them easily. All the faces of this mould were firstly surfaced completely flat and to make them able to stand on ground properly.

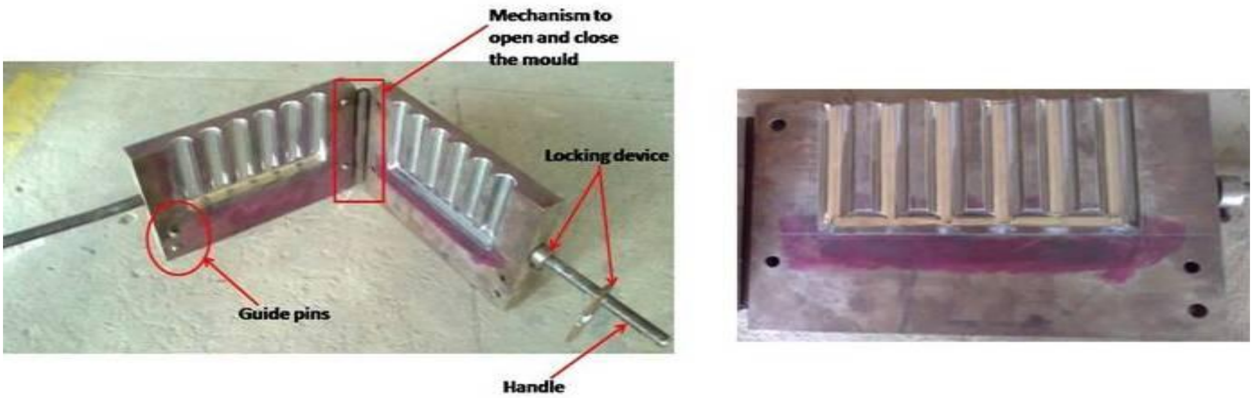


Figure 1: Open view of mould

Guiding pins are provided to make sure the proper alignment of mould and grooves in front of each other. It also provides proper and tight bonding as shown in figure 1. The vertical grooves were made by drilling holes in plates holding together tightly. The horizontal groove was done by special machining apparatus. These grooves were then finished with the help of portable grinder. After getting the rough finishing the surface was needed to be smooth enough to make the removal of casted material from the mould after solidification. This was achieved by the help of diamond paste coating inside the grooves. This coating provides smoothness as well as it withstands high temperatures and provides protection to the inner surface of groove from erosion or distortion.

E. Raw material

In this experiment or process the raw material used was aluminium in pure form as a base material and SiC/Al_2O_3 as a reinforce material which is to be mixed in this base material to form a composite. Aluminium which was used was in the form of billets, were further cut down in small pieces with the help of power hacksaw. The pieces of small sizes according to the size of crucible were prepared, because the height of crucible was fixed and the diameter was also according to dimensions of furnace. The large pieces were not suitable to fit the crucible as well as furnace. Another raw material, Al_2O_3, SiC, Al_2O_3 (nano) and SiC (Nano) was available in the powder form. The powder which was used for this purpose was of mesh size of 400 mesh.

F. Tools

Following tools were used to perform the complete process of moulding from the beginning: Tongs, Gloves, Hook, Unloading tool, Pouring tool

G. Specimen Preparation

After the completion of set-up fabrication, the next step was to prepare specimens. For that purpose the first step which needed to initiate was to prepare mixing of samples of SiC/Al_2O_3.

Step1. Volume calculation of mould

Step2. Volume then multiplied by density of Al to calculate the weight of metal required.

Step3. Samples of SiC/Al_2O_3 were then prepared according to weight %age and reinforcement was decided to be taken 10%.

Step4. Al metal was cut into small strips

Step5. According to the weight of metal (Al) required, Samples of Al were prepared

Step6. Simultaneously furnace was switched on for preheating to remove the moisture

Step7. Metal (Al) was now placed in the crucible present in furnace

Step8. Furnace was allowed to heat up to 750^o C for melting of metal (Al)

Step9. In between when the temperature of furnace reached 600^{0}C, mould was placed in another furnace generally used in labs i.e. Muffle Furnace for preheating

Step10. Along with the mould, 10 % by weight SiC/Al_20_3 was also placed in the muffle furnace for preheating

Step11. Now stirrer blade and shaft was also preheated so that molten metal does not stick to it

Step12. After continuously heating Al for 1 hour at 750^o C, SiC/Al_20_3 was poured in to the crucible for mixing with Al

Step13. For proper mixing of SiC/Al_20_3 with Al, Stirring was done for about 20 minutes

Step14. Mould was taken out of the muffle furnace

Step15. Crucible was taken out of the furnace & the mixture or composite so prepared was poured into the mould

Step16. Mould was now allowed to cool down for about 15-20 minutes and then the specimens were taken out of the mould for further cooling

Step17. Then the specimens were cut down into desired pieces along with their turning for their further testing

Step18. With the same procedure mentioned above except stirring, samples of pure Al were also prepared for their comparison with the composite

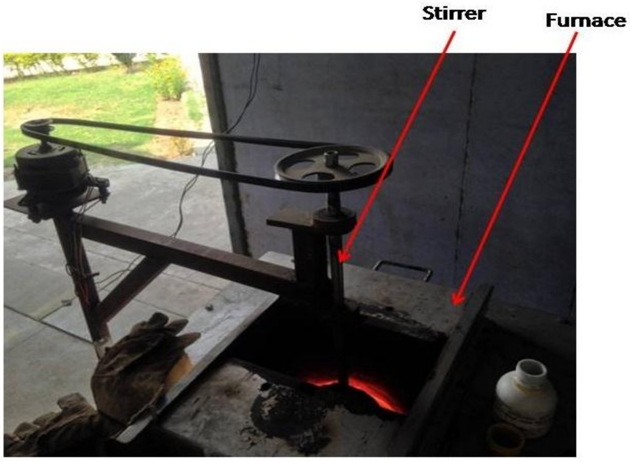


Figure 2: Stirring process in crucible

IV. TESTING OF SPECIMEN PREPARED

After preparation of specimen/samples, numbers of tests were done to analyze their properties. These tests include optical microscopy, hardness, wear testing, and SEM analysis.

A. Optical Microscopy

The casting procedure was examined under the optical microscope to determine the cast structure. Specimens of size Φ5mm*20mm were prepared and then the polishing operation was done. The specimens were then rubbed by using emery paper of grade 100,320,500, and 1000 in increasing order. When mirror like surface was attained, the specimens were washed using Acetone.

Figure 3: Ball bearing machine

These prepared samples were examined under Inverted Metallurgical Microscope

Results of Optical Microscopy

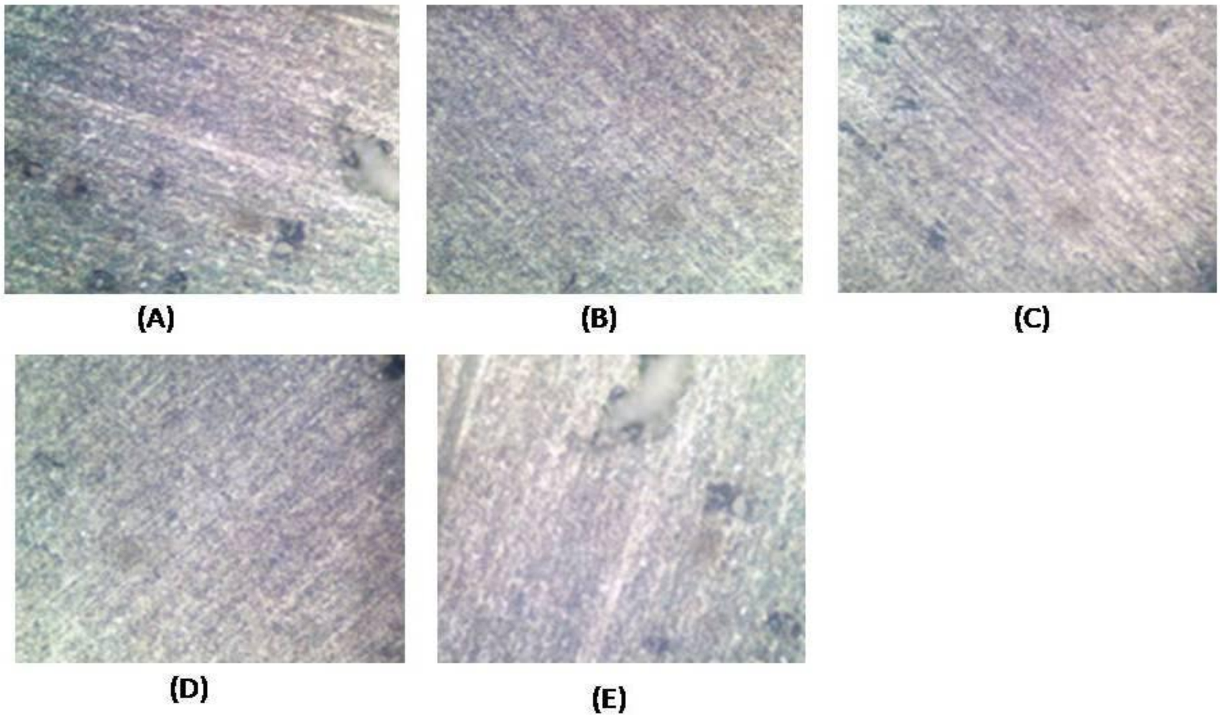


Figure 4: Optical micrographs of (a)Al+SiC(Micro) Composite (b)Al+SiC (Nano) Composite (c)Al+Al_2O_3(Nano) Composite, (d) Pure Al, (e) Al+Al_2O_3(Micro) Composite.

The Figure 4 shows the optical micrographs composites there is non-uniform distribution of filler materials in the aluminium matrix in case of Al+SiC (Micro) Composite and Al+Al_2O_3 (Micro) Composite. But in case of aluminium composites with reinforcement of nano particles of SiC and Al+Al_2O_3, there is uniform distribution of reinforcements and there is proper mixing. So this can be concluded that nano composites give better results than the micro composites.

Specimens of size Φ5mm*20mm were prepared and polished. The specimens were rubbed using the emery paper of grade 100, 320, 500, and 1000 in increasing order. And when the mirror like surface was attained, hardness test was performed on the specimens using Rockwell hardness testing method.

B. Hardness Testing

Table 2: Hardness Values of Specimen at 100 Kg Load

Sr. No.	Pure Al	Al+Al_2O_3 (Nano)	Al+Al_2O_3 (Micro)	Al+ SiC (Micro)	Al + SiC (Nano)
1	31	28	33	35	55
2.	42	39.5	32.5	56	65
3.	33	43	40.3	42	78
4.	37	42.2	37.5	84	56
5.	35	55	42.2	65	84
Mean	35.6	41.54	37.1	56.4	67.6

The table 2 above shows that addition of reinforcements has resulted in the increase of hardness in aluminium however degree of increase is varying. The maximum increase in hardness is noticed in case of SiC (Nano) while with SiC, Al_2O_3 and Al_2O_3 (Nano) addition has also increased hardness but not that much as is seen in SiC (Nano) which is may be due to the porosity in the composite. This porosity or agglomeration may have occurred either due to the entrapment of gases while casting or improper wetting of the as received SiC .

C. Wear Behavior

The wear tests were done for two normal loads of 3Kg at constant speed 500 RPM. The cumulative wear rate with load has been plotted in subsequent graphs. Than Dry sliding wear tests for Pure Aluminium, Al+ SiC, Al+ Al_2O_3, Al+ SiC (Nano), Al+ Al_2O_3 (Nano) composites were conducted using a pin- on –disc machine [Model: Wear and Friction Monitor Tester TR-20]. The tests were conducted in air having relative humidity in range from 40 to 75 % with room temperature of 30-32°C. Wear tests were carried out on the pin specimens that had very flat surfaces in the contact regions. The pin was placed stationery against the counter face of the rotating disc made of En-32 steel at 80 mm and 100 mm track diameter. En-32 steel is a plain carbon steel; case hardened 62 to 65 HRC as imparted with the pin-on-disc machine.

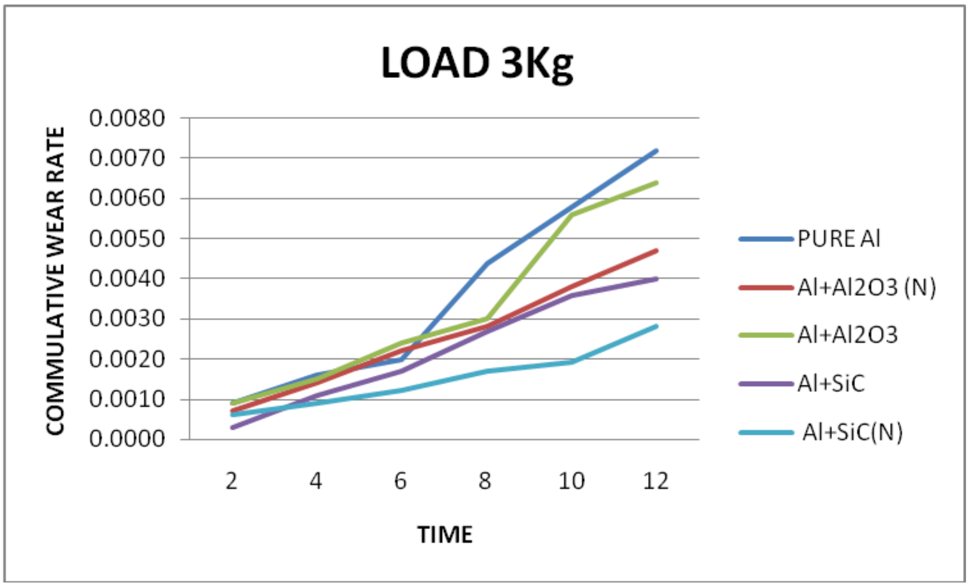
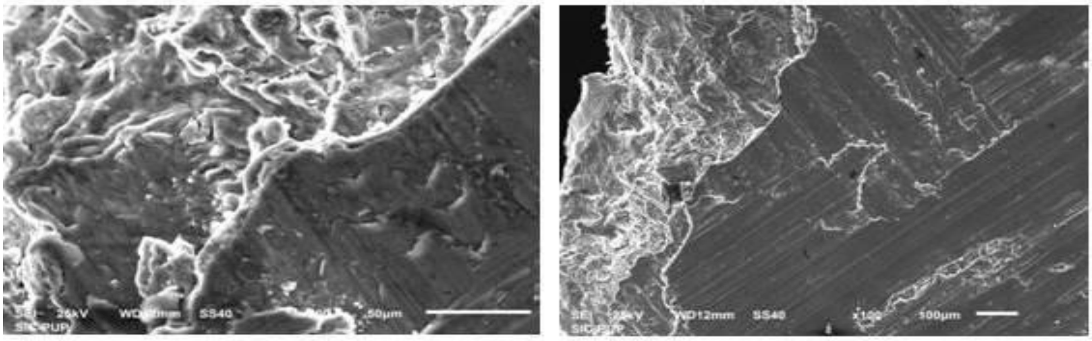


Figure 5 : Cumulative wear rate for the Pure Al, Al+ SiC, Al+ Al_2O_3, Al+ SiC (Nano), Al+Al_2O_3(Nano) subjected to wear at Load of 100 Kgf and at 500 RPM.

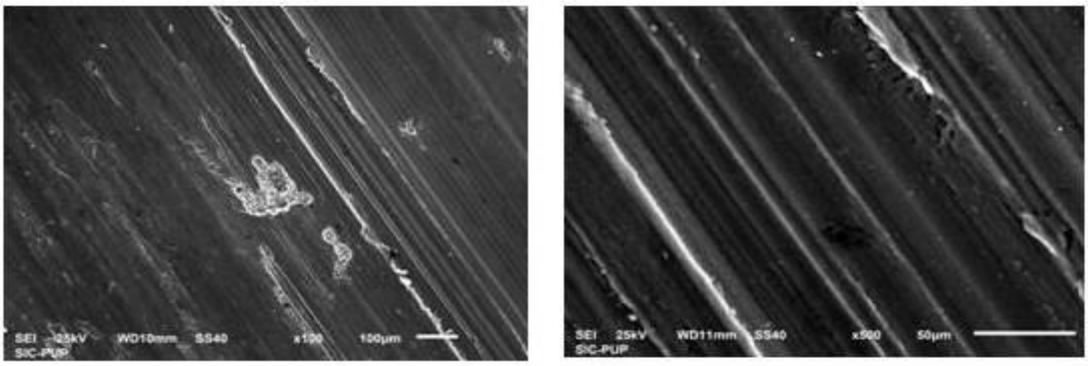
D. SEM analysis of the worn surface of the Specimen

Surface morphology of the composites was studied with the help of Scanning Electron Microscope from an angle of 10° to 110° with an aim to understand the type of wear the composites were subjected to along with the damage caused to these specimen due to wear. Some of the specimens subjected to sliding wear were analyzed for the characterization of the wear surfaces. The worn surfaces of the specimen were examined under the scanning electron microscope using JEOL Scanning Electron Microscope (Model: JSM-6510). The specimens were scanned under the microscope and the critical areas of interest on the specimens were analyzed in order to identify the cracks, micro cracks and morphology. SEM micrographs of the pure Al, Al+Al_2O_3, Al+ SiC, Al+ SiC (Nano), Al+Al_2O_3 (Nano). It is evident that all the specimens have suffered major damage of its surface in the shape of craters or micropits.



(A) (B)

Figure 6: SEM : Micrographs of Al+Al_2O_3 (Micro) composites



(A) (B)

Figure 7: SEM: Micrographs of Al+SiC (Micro) composites

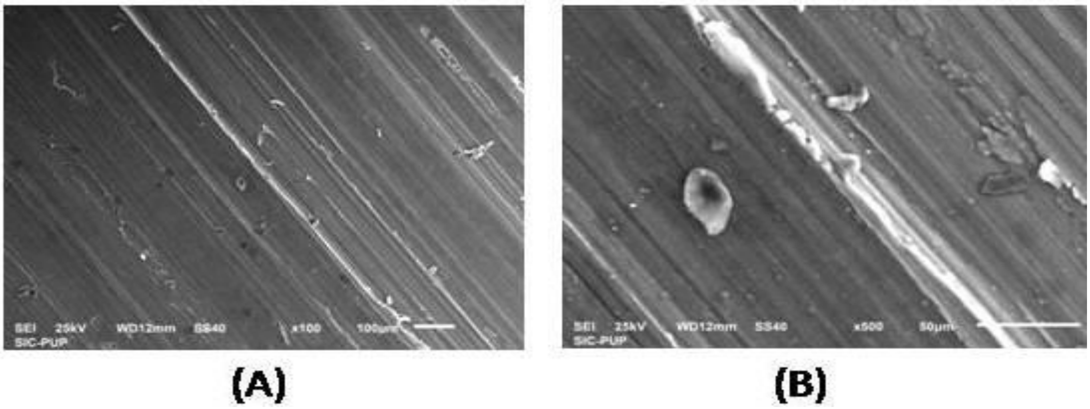


Figure 8: SEM: Micrographs of SiC (Nano) composites

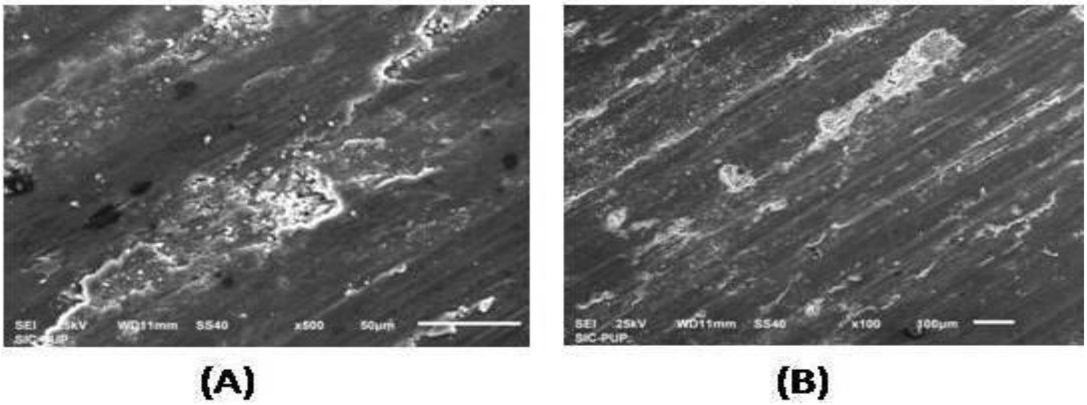


Figure 9: SEM: Micrographs of Al+Al_2O_3 (Nano) composites

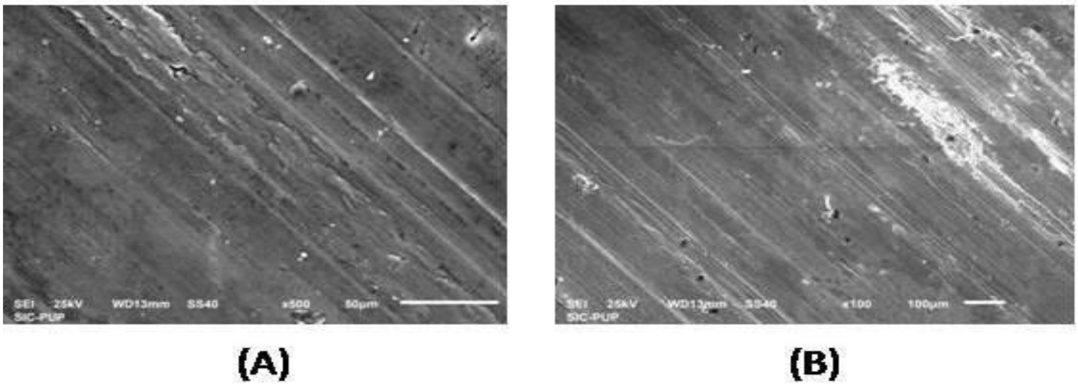


Figure 10: SEM: Micrographs of Pure aluminium

CONCLUSIONS

1. There Is A Significant Increase In The Values Of Hardness Of Aluminium With The Addition Of All The Reinforcements. The Trend Shown By The Specimens In Case Of Hardness Is:-
   Al+Sic (Nano) > Al+Sic (Micro) > Al+Al_2O_3 (Nano) > Al+Al_2O_3 (Micro) > Pure Al
2. So, The Maximum Hardness Was Shown By Al+Sic (Nano) And Al+Sic (Micro), Composite, But Considering The Cost Parameter, Al+Al_2O_3 (Nano) Composite Can Be Judged As The Best.
3. The Wear Resistance Was Found To Increase Significantly With The Addition Of Reinforcements In Aluminium. Wear Resistance Of Al+Sic (Nano) Was Found To Be Highest, While Pure Al Showed Lowest Wear Resistance. The Wear Resistances Of The Pure Al, Al+Al_2O_3, Al+Sic And Al+Sic (Nano), Al+Al_2O_3 (Nano) Composites At Normal Load Of 100 Kg And 500 RPM Followed The Trend Given Below:-
   Al+Sic (Nano) > Al+Sic (Micro) > Al+Al_2O_3 (Nano) > Al+Al_2O_3 (Micro) > Pure Al
4. Comparison Of Wear Behavior Of Specimens At 500 RPM Revealed That Wear Rate Of All The Specimens I.E. Pure Al, Al+Al_2O_3, Al+Sic And Al+Sic (Nano), Al+Al_2O_3 (Nano) Composites Increased With Increase In Load As Observed From Literature.
5. SEM Micrographs Of Worn Out Surfaces Of The Specimens Have Revealed The Formation Of Craters Along With The Presence Of Grooves In Parallel Direction To The Sliding Direction Which Is The Result Of Abrasion By Hard Asperities Of The Steel Counter Face, Or Reinforced Particles In Between The Contacting Surfaces Cutting Into The Pin.

6. From The Current Investigation It May Be Recommended That The $Al+Al_2O_3$ (Nano) Composite Is The Best Option Considering All The Parameters Like Wear Resistance, Cost Etc. Amongst The Investigated Cases.

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