Tribological Properties of Micro and Nano TiO_2 Reinforced Aluminium Metal Matrix Composites

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***Abstract* - Metal Matrix Composites (MMCs) have a prospective for improved wear resistance over the unreinforced alloy and are the most capable in achieving enhanced mechanical properties. In this research, composites of Al 6061- micro TiO_2 (5, 10 and 15 wt.%) and Al 6061- nano TiO_2 (0.5, 1.0 and 1.5 wt.%) were produced by stir casting technique. Hardness and wear tests were performed on the micro and nano composite specimens. The fabricated nano composites showed improvement in hardness and wear resistance over the micro composites. The microstructure of the worn out specimen was examined by scanning electron microscope. Considering all the factors, it can be concluded that aluminium based composite with 1.0% by weight nano TiO_2 reinforcement possess better wear resistance properties as compared to micro TiO_2 reinforced aluminium metal matrix composites.**

Keyword - Aluminium Metal Matrix Composites, wear resistance, stir casting, nano TiO_2.,

I. INTRODUCTION

Metal matrix composites have a prospect for increased wear resistance over the unreinforced alloy and are the foremost promising in achieving increased mechanical properties [1]. Amongst different composites, MMCs are promising new materials for recent engineering applications having high specific strength, stiffness and their high temperature stability and widely used in aerospace and automotive industries. Aluminium is the most popular matrix for the MMC's and the aluminium alloys are quite attractive due to their low density, low cost, its capability to strengthen by precipitation, good corrosion resistance, high electrical and thermal conductivity and improved tribological properties [2,3]. The mechanical property results of micro and nano composites led in to improvement of wear rate, yield strength, ultimate tensile strength, compressive strength and hardness. The fabrication process such as compo casting and the size of the reinforcement particles were the effective factors influencing on the mechanical properties [4,5]. To avoid agglomeration of nano particles during solidification process, a non-contact method, where the ultrasonic probe is not in direct contact with the liquid metal was attempted to disperse nanosized Al_2O_3 particulates in aluminium matrix and the mould was subjected to ultrasonic vibration [6]. SiC and Al_2O_3 are the common reinforcing materials used in aluminum matrix composites [7].

In recent times extensive study on Al-SiC composites has been made as SiC in particular delivers superior wear resistance and mechanical properties. Addition of SiC reinforcement to the base aluminum metal added strength to the composite [8]. The improvements in wear resistance of Al alloy-SiC particles reinforced composite is a strong function of reinforcement content and its size [9]. The occurrence of SiC makes the composites hard to be machined due to its brittle property. Adding up of metal oxides like TiO_2 shifts the brittleness of SiC and widens its engineering applications. Use of TiO_2 as reinforcement in aluminium alloy has established modest attention even though it posses high hardness and modulus in the midst of superior corrosion resistance [10]. Momentous enrichment in wear resistance and hardness characteristics were achieved with Al6061 alloy with TiO_2 reinforcement. Hardness, density and wear rate was improved with TiC and TiO_2 reinforcements with Al alloy [11]. The function of TiO_2 particles on the powder surface morphology and grain refinement, the effect of particle size-to-reinforcement ratio in terms of green compressive strength, and densification as percentage theoretical density of Al- TiO_2 composites were studied. Structure and sinter ability of micro and nano TiO_2 with Al-6061 was synthesized [12]. The composite with good dispersion of reinforcement particulates has shown higher hardness and wear resistance [13].

In recent years countless processing techniques like stir casting, squeeze casting, spray decomposition and powder metallurgy have been developed to process particulate reinforced MMCs. In a stir casting process, the reinforcing phases are dispersed into molten matrix through mechanical stirrer. Mechanical stirring in the furnace is a key factor of this process. The consequential molten alloy, with ceramic particles, can then be used for die casting, permanent mold casting, or sand casting. Stir casting is appropriate for manufacturing composites with up to 30% volume fractions of reinforcement [14, 15]. The aim of the work presented here is to investigate the possibility of combining the micro TiO_2 (5, 10 and 15 wt.%) of 400 mesh and nano TiO_2 (0.5, 1.0 and 1.5 wt.%) reinforcement particles of 50nm size with aluminum alloy Al 6061 to form lightweight, high performance MMC materials. Particular attention is given to characterize the wear properties of these materials.

II. EXPERIMENTAL PROCEDURE

The stir casting method was used to prepare micro and nano composites. The Al6061 alloy pieces were heated in a graphite crucible. The reinforcement particulates of micro and nano TiO_2 and magnesium (1%wt) are preheated incoherently for 30 minutes. Magnesium is added to promote wettability. Aluminium degassing tablets are added in the powdered form to remove the suds formed during the process. The heated slurry was stirred at 320 rpm for 15 minutes using a two blade stainless steel impeller to ensure uniform incorporation of the reinforcement particles into the Aluminium matrix. The two blade stainless steel impeller was coated with alumina powder to avoid iron contamination of the molten Al metal. The impeller was placed just 20 mm above from the bottom of the graphite crucible, and the blades of the impeller (tilted at an angle of 55°), when rotated, covered a relatively large area of the crucible base and this design barred the TiO_2 from settling down when the melted slurry was stirred for 5 minutes. Furthermore, stirring at an optimized speed of 320 rpm created a vortex in the melt, and this effectively enhanced the distribution of the particles. This stirring process was used to ensure the homogeneity of the melted slurry. The melt, with the micro TiO_2 incorporated Al6061 MMC and nano TiO_2 particles incorporated Al6061 MMC, are poured in to a mould of length 100mm and diameter 10mm as a rod. The stir casting setup is shown in fig.1[14].

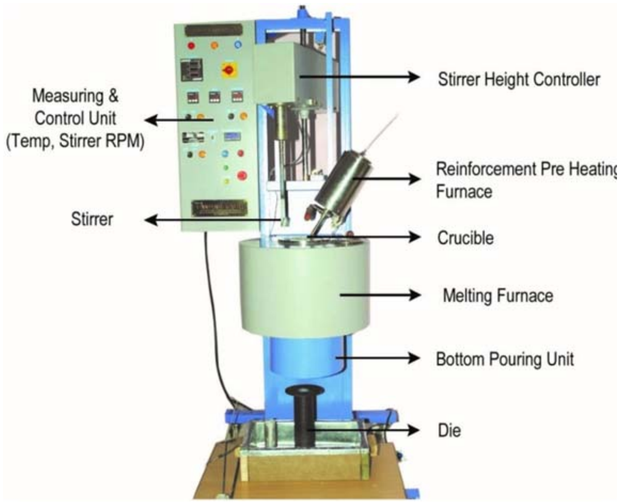

Fig.1. Photograph of Stir casting setup (source : SCT, nkl)

III. RESULTS AND DISCUSSION

The Pin on Disc tester is used for a quick and easy method of kinetic friction and sliding wear measurement. The pin on disc tester measures the friction and sliding wear properties of dry or lubricated surfaces of a variety of bulk materials and coatings [16, 17]. The pin surface can be worn and friction tested. The normal load, rotational speed, and the wear track diameter are all set by the user prior to the pin on disc test. Dry sliding wear tests were conducted using a pin-on-disc tester as per the ASTM G-99 standard. Pin specimens of diameter 8mm and length 30 mm were machined from the casted rods. A pin holder loaded the stationary pins vertically onto a rotating En-31 steel disc. A normal load of 1 kg was applied using dead weights at 600, 450 and 360 rpm for the corresponding wear tracks of 30, 40 and 50mm diameter over the steel disc. For each sliding condition, 26 minutes of run were carried out. At the end of it, the pins were carefully cleaned and weighed using a sensitive electronic balance with an accuracy of ±0.001 mg to determine the weight loss. The following table 1 shows the mass loss and wear rate for the applied load of 1 kg for Al6061- micro TiO_2 and Al6061-nano TiO_2 Composites and interprets that increasing the weight percentage of reinforcement particles, reduces the wear rate up to 10wt% micro TiO_2 and 1.0 weight % of nano TiO_2. The variation of wear rate of Al6061- micro TiO_2 and Al6061- nano TiO_2 composites for a sliding distance of 1500 meters are depicted in fig.2 and the co-efficient of friction (COF) are shown in figure 3 and figure 4.

Table 1 – Mass loss of composite pins

MMCs	% wt of reinforcements with Al6061	Mass loss (gm)	Wear rate (mm3/m)
Micro TiO_2	5	0.00851	3.273 x 10^{-3}
	10	0.00670	2.580 x 10^{-3}
	15	0.00673	2.590 x 10^{-3}
Nano TiO_2	0.5	0.004	1.540 x 10^{-3}
	1	0.003	1.150 x 10^{-3}
	1.5	0.0035	1.350 x 10^{-3}

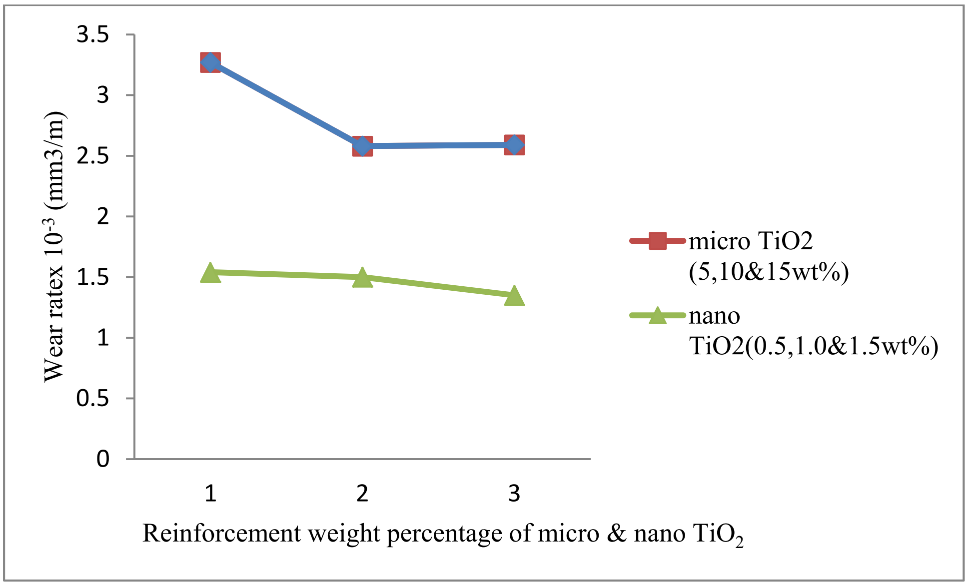

Fig 2. Wear rate of micro TiO2 reinforced composite

It is observed from the fig.2, fig.3 and fig.4 that the amounts of reinforcement in Al6061 alloy have influence on the wear behavior of Al6061-micro TiO_2 and Al6061- nano TiO_2 composite materials. The figures clearly indicate that the wear rate and co-efficient of friction are reduced by increasing the weight percentage of micro TiO_2 up to 10wt% & nano TiO_2 up to 1.0wt% and drastically increased by increasing the micro and nano TiO_2 reinforcement particles. This is due to the fact that adding more amounts of reinforcement particulates to the matrix material makes it as brittle and hence its wear rate is increased.

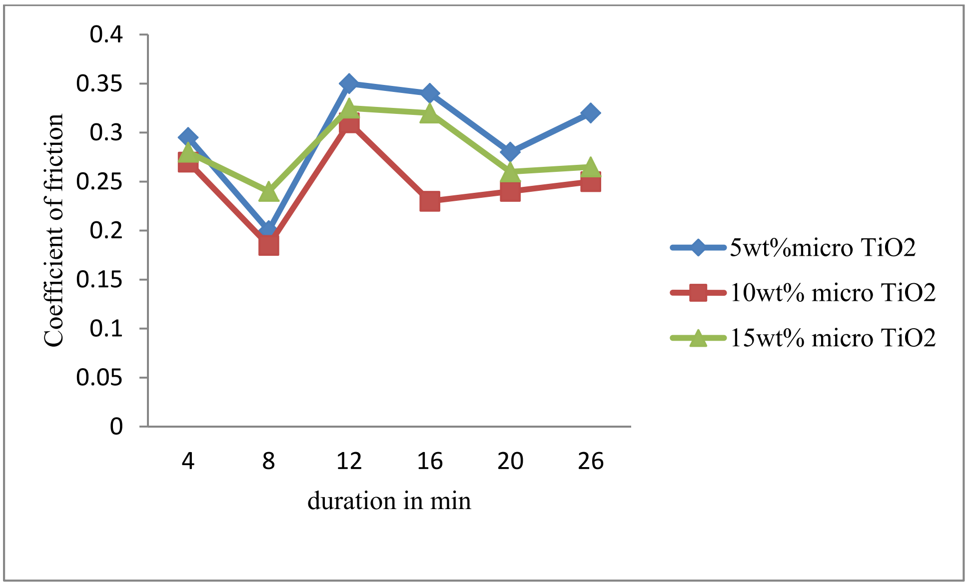

Fig. 3. Coefficient of friction of micro TiO_2 reinforced composite

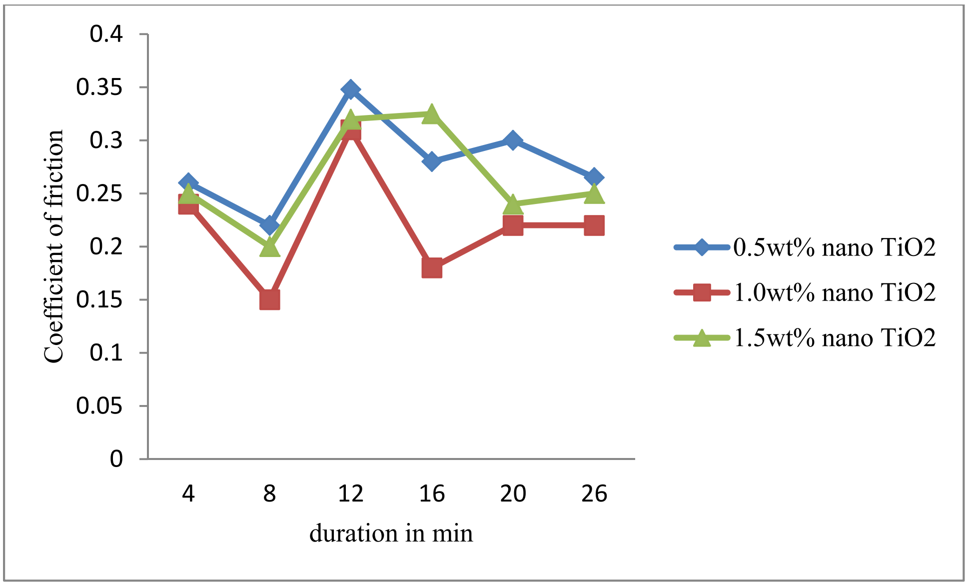

Fig. 4. Coefficient of friction of nano TiO_2 reinforced composite

IV. Hardness Testing

The hardness values are taken at four different places and average hardness values of the Al6061-micro TiO_2 and Al6061- nano TiO_2 composites are calculated. The Vicker's hardness (HV) values are plotted in graph for various weight percentages of Al6061-micro TiO_2 and Al6061- nano TiO2 reinforcement composites and are indicated in Fig.5. and it indicates that the addition of micro and nano TiO_2 increases the hardness of the composite material. The improved hardness by increasing the weight percentage of micro and nano TiO_2 particles mainly results from the presence of extremely harder micro and nano TiO_2 particles in Al6061 matrix material.

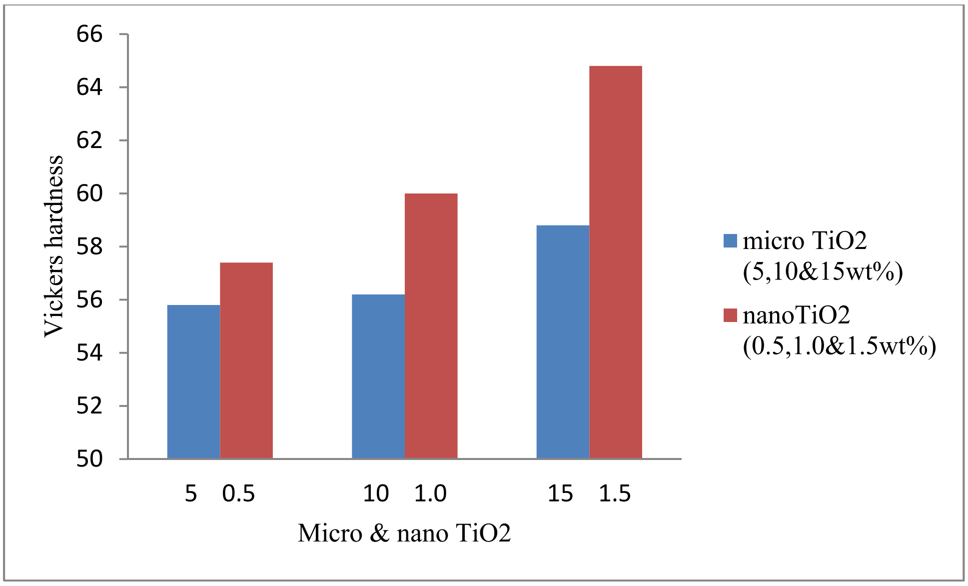

Fig. 5. Vickers hardness values of micro and nano composites

V. SEM ANALYSIS OF THE WORN SURFACE OF THE SPECIMEN

Scanning electron microscopy (SEM) of Al6061 - 10 wt% of micro TiO2 and Al6061 – 1.0 wt% of nano TiO_2 was taken after the wear testing of all the specimens and are depicted in the fig. 6.a. and fig. 6.b. SEM of specimens has taken at a magnification range of 200 and 100µm. It is evident from that all specimens have suffered significant damage of its surface in the form of craters, grooves, debris. Most of the grooves are parallel to the sliding direction and it is evident from the worn pins [18, 19]. Such features are characteristics of abrasion, in which hard asperities of the En-31 steel disc counter face, or hard reinforced particles in between the contacting surfaces, plough or cut into the pin, causing wear by the removal of small fragments of material.

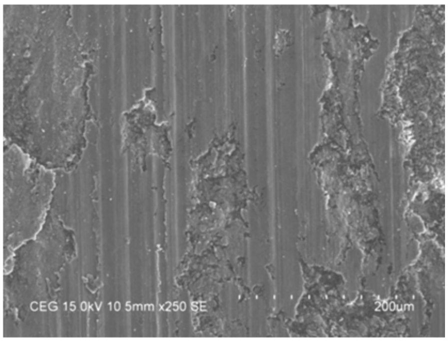

Fig.6.a. Al6061 - 10 wt% of micro TiO_2

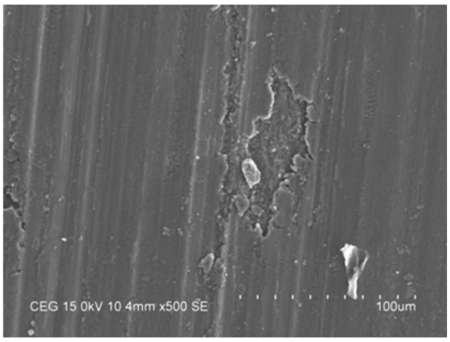

Fig. 6.b. Al6061 – 1.0 wt% of nano TiO_2

VI. CONCLUSION

In the present work, wear test, hardness and microstructural studies were conducted on the cast -micro TiO2 and Al6061- nano TiO2 metal matrix composite (MMC). Based on the present experimental work the following conclusions can be drawn:

1. The stir casting method is found to be suitable for fabricating Al6061-micro TiO_2 and Al6061- nano TiO_2 metal matrix composites.

2. Al6061- nano TiO_2 exhibit less wear rate and co-efficient of friction as compared with Al6061-micro TiO_2 metal matrix composites.

3. Al6061-10% micro TiO_2 as well as Al6061-1.0% - nano TiO_2 composites have low wear rate compared with other reinforcement weight percentages.

4. The hardness values of Al6061 – nano TiO_2 composites are higher than that of Al6061 – micro TiO_2composites.

5. SEM micrographs of the worn surfaces of the specimens have discovered the formation of craters along with the presence of grooves parallel to the sliding direction that is the results of abrasion by laborious asperities of the steel counter face, or laborious bolstered particles in between the contacting surfaces cutting into the pin.

From this investigation it should be suggested that the Al6061 - nano TiO_2 composite is the most suitable choice considering the parameters like wear resistance, co-efficient of friction, hardness and microstructure among the investigated cases.

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