EVALUATION OF WEAR BEHAVIOUR OF ALUMINIUM HYBRID NANO METAL MATRIX COMPOSITES FABRICATED BY POWDER METALLURGY TECHNIQUE

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Abstract Aluminium hybrid composites are the new groupof metal matrix composites (MMCs) due to their attractive properties like high ductility, high conductivity, light weight and high strength to weight ratio and ever-increasing demand of these super material in the field of aircrafts, automobile, marineapplications. Carbon Nanotube (CNTs) are also known for their high strength, stiffness and their low density. Graphene also has attracted considerable attention in the last several years because of its excellent properties such as high mechanical strength, modulus, high electrical, high thermal conductivity and optical transmittance, which when combined together makes CNTs and graphene both were an ideal reinforcement to metal matrix composites. In the present research work, the dry sliding wear behavior of aluminum matrix nanocomposites containing various amounts of graphene (0.5 and 1wt.%) particles and fixed percentage of carbon nanotubes (2 wt.%) coated/un-coatedwas investigated. The specimens were prepared by mechanical milling of Aluminium 6061 (AA6061) and Multi walled Carbon Nano Tubes (MWCNTs) and graphene nanocomposite powders, followed by pressing. Wear tests were carried out at room temperature using pin-on-disc machine under variable normal loads. Wear mechanisms are discussed based on scanning electron microscopy image observations of wear tracks and wear debris morphology.

Keywords: Carbon nanotubes, Aluminium 6061, Nanocomposites, Wear, Graphene.

1.INTRODUCTION

In last two decades, a broader attempt and interest has been given towards the improvement of Aluminium Metal Matrix Composites (AMMCs). This is mainly because of theunique combination of its low density, highstrength, good mechanical properties, goodcorrosion resistance, low electrical resistance, andgood machinability properties [1–2].AMMCs are one of the advanced engineering materials that has been developed for load critical practices in aeronautics and in recent times in an automotive manufacturing industries on account of their outstanding properties of high specific strength, lightweight, better corrosion and wear resistance[3]. Wear behavior may be detected in many automotive subassemblies like brake, gears, valves, cams, bearings, clutches and other applications involving sliding or rolling contact. In addition aluminum alloy based composites become breakable with addition of reinforcement particles such as CNTs and Graphene[4-5]. The relativelypoor wear resistance of aluminum alloys, limited their use in certain tribologicalapplications. In recent years, both fiber andparticulate reinforced aluminum alloy compositesfabricated have shown significant improvement intribological properties, including sliding wear,abrasive wear, friction and seizure resistance [6].In thepresent study, an in-depth investigation was carriedout on the dry sliding wear behaviour of Al6061 alloy, reinforced with nanomaterials. A.M.Al-Qutubet.al. [7] investigated the wear properties of Al6061alloy reinforced with 1 wt% of carbon nanotubes prepared by ball milling and spark plasma sintering. The results shows that, under mild wear conditions, the samples reveals lower wear rate and coefficient of friction compared to Al6061 alloy. The composites displayed severe wear conditions at higher wear load, it was clarified that the friction and wear behavior of Al–CNT composites is largely influenced by the applied load and there exists a critical load beyond which CNTs could have a negative impact on the wear resistance of aluminum alloy.

2.EXPERIMENTAL SETUP AND PROCEDURE

2.1 Materials and Methods

Al6061 was procured from DMRL, Hyderabad, 300 mesh of particle size and density of 2.7 g/cc. The chemical composition of Al6061 is shown in Table 1. MWCNTs cheap tubes USA, and graphene having thickness 8-10nm, density 2.2g/cc (United nanotech innovations Pvt.Ltd.) were used in the present study. The Table 2 shows the typical properties of MWCNTs as received.

Table 1 Al6061 alloy by weight percentage of chemical composition

Element	Si	Cu	Fe	Mn	Mg	Zn	Pb	Ti	Al
Wt(%)	0.62	0.23	0.22	0.03	0.84	0.22	0.10	0.01	BAL

Table 2 Properties of MWCNTs

Properties	Diameter	Length	Density
values	20-30 nm	10-30µm	2.1g/cc

2.2 Electroless Copper Coating to MWCNTs

The MWCNTs was initially purified to remove impurities present [8]. After purification, MWCNTs were subjected to copper coating by electroless deposition method. In order to achieve the uniform copper coating thickness on MWCNTspre-requisite steps to be fallowed are oxidization, sensitization, activation and decoration of copper. Purified MWCNTs were oxidized with H_2SO_4 (98%) and HNO_3 (70%) at 140^0 C for 6h and sample was washed with millipore water and dried at 100^0C . The oxidised MWCNTs were subjected to sensitization and fallowed by activation using $Sncl_2$/Hcl, later the tubes were activated by $pdCl_2$/Hcl solution by magnetic steering for 30 min. The activated MWCNTs were subjected to electroless copper coating for 45min in an electroless copper bath at a pH value 11.4±0.4 for uniform deposition of copper. The copper bath composition of the chemicals used for study as shown in Table 3 [9].

Table 3 Chemical composition of copper bath [9-10]

Sl.No.	Chemical composition	Quantity(g/l)
1	Copper sulfate-5H_2O	35
2	EDTA Disodium salt	45
3	HCHO(add after 10 min)	20
4	Na_2SO_4 -10 H_2O	40
5	HCOONa	20
6	Polyethyleneglycol	6.6
7	PH (adjust with NaOH)	11.5-12.0
8	Temperature(°C)	70

2.3 Preparation of Nanocomposites

In this study, Al6061 powder-2wt.% MWCNTs (coated and un-coated) and 0.5 wt.%, 1.0 wt.% varying of graphene were mixed by ball milling to disperse MWCNTs/Graphene in Al6061.The milling time of 1.5 hr is maintained with 300rpm speed to all the samples, ethanol as process control agents in small amounts was added with ball to powder ratio of 10:1 [10]. Powder metallurgy technique was used to prepare the nanocomposites, where the samples were compacted in harden steel die-punch. Before compacting, the powder samples were pre heated and compacted with compaction pressure of about 550MPa for all the compacted samples of 20mm diameter and 10mm length were produced with different contents of reinforcement. The green compacted samples are subjected to sintering at 580^0C with a dwell time of 60min for all the samples in conventional furnace with nitrogen atmosphere.

2.4 Dry Sliding wear test

Dry sliding wear test for all sampleswere examined using a pin-on-disk setup as shown in Figure 1, and samples were prepared for accordingtothe ASTM G99-05[11].Weight loss method was used to determine the wear rateof specimens. The specimens were weighted beforeand after the wear test by sensitive balance typeinstrument with an accuracyof 0.0001 gm. The weight loss (ΔW) was divided bythe sliding distance and the wear rate was obtained by, Wear rate (W.R) = $\Delta W/ \pi D.N.t$ (gm/cm) ----eq(1)where, D is sliding circle diameter (cm), t is slidingtime (min), N is steel disc speed (rpm)[11].The tests were carried out under dry sliding conditions at constant sliding speed and varying applied load ranging from 20N, 30N and 40N. After wear test, the samples were investigated for wear surfaces topography by using scanning electron microscopy(SEM).

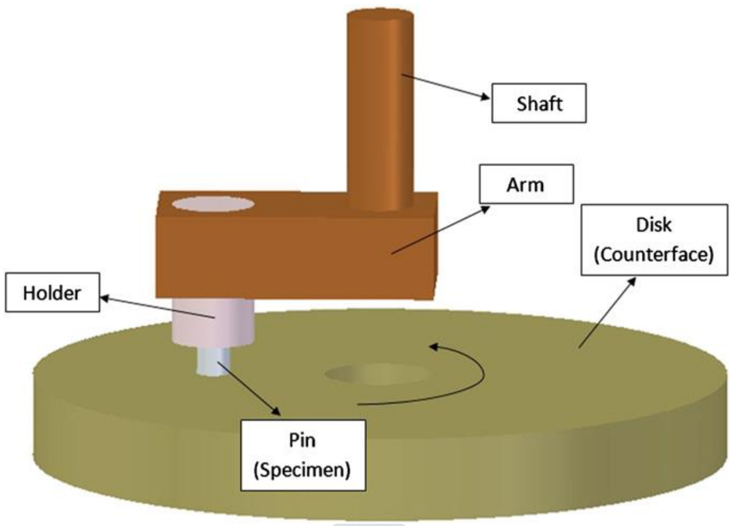

Fig.1 Pin on disk wear test set up[7]

3.RESULTS AND DISCUSSIONS

The variation of wear rate for Al6061 alloy and Al6061+2wt% MWCNTs (un-coated/coated)+0.5 wt% of Graphene, Al6061+2wt% MWCNTs (un-coated/coated)+1wt% of Graphene as a function of applied load is as shown in Figure 2. The tests results revealed that wear rate increased linearly with the applied load. At lower load of 20-30N, the composite displayed better wear resistance. However, at higher loads of40 N, the wear resistance of Al6061 alloy was better than the composite.The wear rate of the composite increased significantly as the load is increased from 30 to 40 N which indicates sharp switch in wear mechanism and hence transition from mild to severe wear regime. Such severe increase was not observed for the coated MWCNTs 2 wt% with 0.5 wt% of graphene, but un-coated MWCNTs with 0.5 wt% of graphene reveals as its wear rate increased considerably. These results show that addition of 2 wt% coated MWCNTs improves wear resistance with 0.5 wt% graphene but 1 wt% of graphene with coated MWCNTs also shows sever wear rate higher loads compared to the Al6061 alloy. At higher loads (extreme conditions), pores present in the composite as well as MWCNTs and graphene agglomerates, serve as a source cause severe sub-surface fragmentation resulting in poor wearresistance of the composite as compared to the monolith alloy.

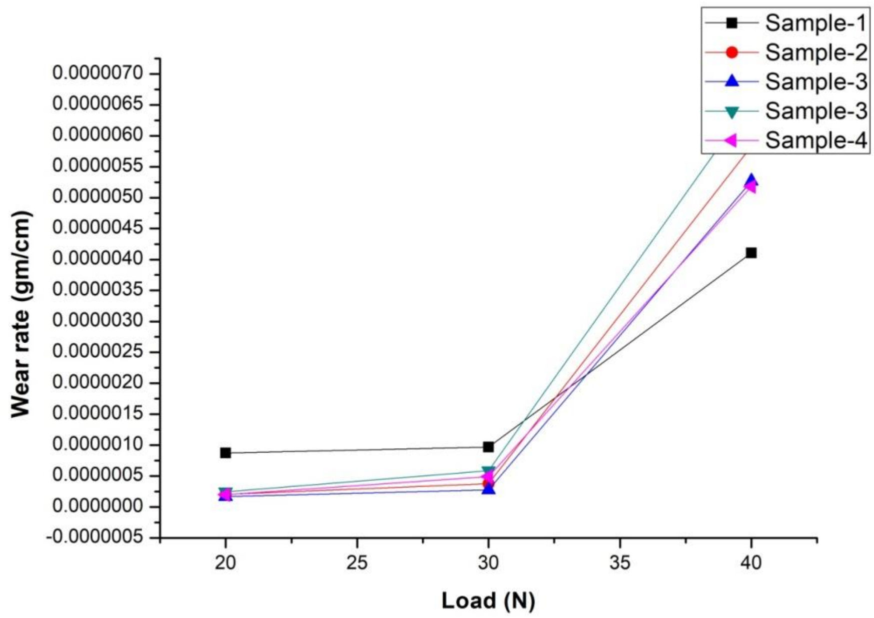

Fig.2 Effect of applied load on wear rate for Al6061 and nanocomposites samples.

Moreover, weak bonding between MWCNTs, Graphene and Al6061 particles in sintered samples could be another possible reason for its excessive subsurface fracturing at higher loads. Wear resistance of a material fabricated by powder metallurgy is very sensitive to the amount of pores present in it. As porosity increases, the wear rate increases because pores serve as a source of crack nucleation and propagation resulting in excessive sub-surface fracturing. The better wear resistance of the composite compared to the monolithic alloy at lower loads is in agreement with other studies that reported that aluminum MMCs display better wear resistance at low loads only and there exists a transition load after which the reinforcement has negative effect on the wear resistance of the matrix.

CONCLUSION

- Aluminium nanocomposites have been successfully fabricated by powder metallurgy technique with uniform distribution of reinforcements in coated MWCNTs and fairly in un coated with 1wt% of graphene.

- The aluminium alloy metal matrix nanocomposites with reinforcement of MWCNTs and graphene improves the wear rate in moderate loads.

- Wear rate of the developed Aluminium metal matrix nanocomposites has increased with the increasing of load with the addition of both MWCNTs and graphene.

- The Al6061 reinforced with 2 wt.% MWCNTs and 0.5 wt.% graphene hybrid composites shows better wear rate at lower load than other nanocomposites and base alloy.

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