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Tribological behaviour of Aluminium Hybrid Metal Matrix Composite

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Abstract

Aluminum based metal matrix composites (MMCs) are appropriate materials for structural applications in the aircraft and automotive industries because they are ductile, highly conductive, lightweight and have a high strength to weight ratio. Wear and Friction behaviour of Al6061 with various percentage volumes of Multiwall carbon nanotube and Silicon Carbide reinforcement through stir casting method followed by die-casting was investigated. Wear test was made by using Pin on Disc Apparatus on the prepared Specimen. It was found that, under mild wear conditions, the composite displayed lower wear rate and friction coefficient compared to Aluminium. However, for severe wear conditions, the composite displayed higher wear rate and friction coefficient and it was clarified that the friction and wear behaviour of Al–SiC-MWCNT composite 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 aluminium alloy. Also the hardness of the composite was increased by increasing the percent volume of reinforcement.

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Keywords: Metal matrix composites; Multiwall carbon nanotue; Silicon carbide; Pin on disc apparatus; Stir casting.

1. Main text

Materials with unusual combination of properties like low densities, strong, stiff and impact resistant and not easily corroded are needed for aerospace, underwater and transportation applications and that cannot be met by the metals, conventional metallic alloys, ceramics and polymeric materials.

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Strong materials are relatively dense, also increasing the strength or stiffness generally results in a decrease in impact strength. Therefore, a composite material which consists of a mixture or a combination of two or more distinctly differing materials can be used whose properties are superior in a specific application to those of the original substances.

Metal matrix composites (MMCs) possess significantly improved properties including high specific strength, specific modulus, damping capacity and good wear resistance compared to the unreinforced alloys. Aluminum alloys [1,2] are used in many engineering applications due to their light weight and high strength characteristics. However, low hardness and consequently low wear resistance limit their use in some applications. Aluminum metal matrix composites (Al-MMCs) containing particulate reinforcements are considered as the promising solution for imparting better wear resistance to aluminum alloys. The addition of siliconcarbide [3–20] and alumina [5,21–23] to aluminum alloys was reported to improve their wear resistance. Various other types of reinforcements such as aluminium nitride [24], granite [25], nickel aluminide [26,27], garnet [28], glass [29], beryl [30], boron carbide [31,32], titanium dioxide [33], aluminium diboride [34] and cerium dioxide [35] have also been reported as effective reinforcements for improving tribological properties of aluminum based alloys. It was reported that wear resistance increases with the increase of reinforcement content due to high hardness and strength of the reinforcement phase.

Recently, research has been extended to evaluate the effect of nanoparticles on wear resistance of aluminum and its alloys. One of the promising nano reinforcements was carbon nanotubes (CNTs) which has exceptionally high mechanical properties [36,37]. Improvement of wear resistance of aluminum as a result of CNTs addition was reported in few studies [38–40]. Zhou and coworkers [38] fabricated aluminum composites reinforced with CNTs through pressureless infiltration of aluminum into CNTs–Mg–Al preformed in N_2 atmosphere at 800˚C. They found that CNTs were well dispersed and embedded in the Al matrix, the friction coefficient of the composite decreased with increasing the volume fraction of CNTs, and the wear rate of the composite decreased steadily with the increase of CNTs content (from 0 to 20 vol%).

Friction and wear characteristics of CNT composites were evaluated based on the dispersion condition, fabrication method, and CNT content [39]. The authors found that the best dispersion condition was performing the acid treatment, next, mixing aluminum powder and then performing ultrasonication for 20min. Also,they reported that the SPS method was more effective than the hot pressing(HP)method for minimizing the amount of wear and maintaining a stable friction. The spark plasma sintered composite with1wt%CNT(2vol%approx.) had the lowest friction and wear. Choi and coworkers [40] investigated the mechanical properties and wear characteristics of aluminum-based composites.They found that the well dispersed and aluminum atom-infiltrated multiwall carbon nanotubes (MWCNTs) formed a strong interface with the matrix by mechanical interlocking. The strength and wear resistance were significantly enhanced and the coefficient of friction was extremely reduced with the decrease of grainsize and the increase of CNT content. The optimum CNT content for minimum wear loss was reported as 4.5vol% (2wt%approx.). Also, they reported that the coefficient of friction and the wear rate increased with increasing the load and reduced with increasing the sliding speed. From the above studies [38–40], it is clear that the tribological properties of Al–CNT composites are highly sensitive to the CNT content, the method used for dispersing CNTs as well as the fabrication method used to consolidate the composite.

Kuzumaki et. al., said CNTs were synthesized using arc discharge. The purity of CNT used was reported to be about 60% by volume which, compared to CNT produced nowadays, is considered low. They mixed 5 and 10% volume of CNT with pure Al and stirred the mix in ethanol for half an hour in order to disperse CNT. The mix was then dried and packed in an Al case. The case was preheated and compressed in a steel die, then hot extrusion was performed at 773 K. Several characterization techniques were performed, but the significant results came from the tensile strength and elongation percentage tests versus annealing time[41]. Hansang Kwon et.al., discussed Functionally graded carbon nanotubes(CNT) and nano Silicon carbide (nSiC) reinforced aluminum (Al) matrix composite materials were fully densified by a simple ball milling and hot-pressing processes. The nSiC was used as a physical mixing agent to increase dispersity of the CNT in the Al particles. It was observed that the CNT was better dispersed in the Al particles with a nSiC mixing agent compared to without it used[42]. Subrata Kumar Ghosh & Partha Saha discovered that crack density and wear performance of SiC particulate (SiCp) reinforced Al-based metal matrix composite (Al-MMC) fabricated by direct metal laser sintering (DMLS) process have been studied. Mainly, size and volume fraction of SiCp have been varied to analyze the crack and wear behavior of the composite.

The study has suggested that crack density increases significantly after 15 volume percentage (vol.%) of SiCp. The paper has also suggested that when size (mesh) of reinforcement increases, wear resistance of the composite drops. Three hundred mesh of SiCp offers better wear resistance; above 300 mesh the specific wear rate increases significantly. Similarly, there has been no improvement of wear resistance after 20 vol.% of reinforcement [20].

Deuis R.L et al., investigated Aluminium-silicon alloys and aluminium based metalmatrix composites have found application in the manufacture of various automotive engine components such as cylinder blocks, pistons and piston insert rings where adhesive wear (or dry sliding wear) is a predominant process. For adhesive wear, the influence of applied load, sliding speed, wearing surface hardness, reinforcement fracture toughness and morphology are critical parameters in relation to the wear regime encountered by the material.In this review contemporary wear theories, issues related to counterface wear, and wear mechanisms are discussed [43].

Hybrid composites are those composites which have a combination of two or more reinforcements. The behavior of hybrid composites is a weighed sum of the individual components in which there is a more favorable balance between the inherent advantages and disadvantages [44,45]. The objective of this work is to investigate the wear and friction behavior of Al6061 alloy reinforced with MWCNT and SiC to form a lightweight, high performance hybrid metal matrix nano composite materials.

2. Experimental

2.1. Materials

Al 6061 with density 2.7 g/cm3, tensile strength 310 MPa (T6 condition) and modulus of elasticity 70 GPa was used as a matrix material. 6061 is a precipitation hardening aluminum alloy, containing magnesium and silicon as its major alloying elements. It has significant applications in aircraft, marine and automobile industries. The mixture of nano SiC and MWCNT particles were used as the reinforcement material. Two different volume percent of MWCNTs (0.5 % and 1.0 %) and fixed volume percent of SiC (15 %) were used in the experiments. Properties of matrix and reinforcements (as received) are shown in Table 1,2 and 3. The SEM image SiC is shown in Fig.1.

Table 1.a. Properties of Al 6061

Component	Si	Mn	Cr	Mg	Sn	Fe	Ti	Cu	Al
Amount(wt.%)	0.477	0.048	0.191	0.864	0.063	0.463	0.008	0.307	Balance

Table 2. Properties of MWCNT

Aspect ratio	~1000
Specific surface area	SSA 350 m^2/g
Purity – wt%	>97%
Average Outer Diameter	20 nm
Average Inner Diameter	5nm
Number of walls	5-15
Length	50 Micrometer

Table 3. Properties of SiC

Appearance	Super black fine powder
Density	3.22g/cm^3
Melting point	2,730 °C

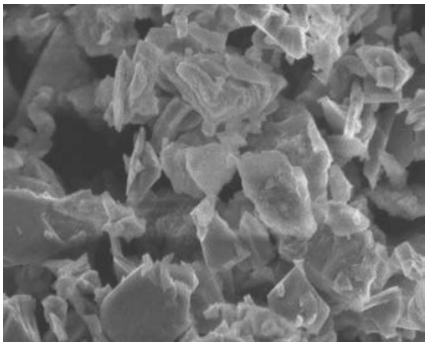

Fig.1. SEM image of SiC

2.2. Experimental procedure

The composites were fabricated by stir casting method to ensure uniform distribution of the reinforcements. The Al 6061 alloy, which was in the form of ingot, was cut into small pieces to accommodate in the graphite crucible. The nanoSiC for the study was procured from Mahalakshmi Scientific, chemicals company, Chennai and MWCNT was procured from Redex Technologies Pvt. Ltd., Ghazhiabad, U.P. Aluminum alloy was first melted in an electric furnace. MWCNT and SiC, preheated to a temperature of about 620 °C, were added to the molten metal at 750 °C and stirred continuously. The stirring was carried out at 450 rpm for 5 minutes using a twin blade mild steel impeller to ensure uniform incorporation of the SiC and MWCNT particles into the Al6061 matrix.

The twin blade mild steel impeller was coated with alumina powder to avoid iron contamination of the molten Al metal. The impeller was placed just 20 mm above the base of the graphite crucible, and the blades of the impeller (tilted at an angle of 45°), when rotated, covered a relatively large area of the crucible base. This design prevented the SiC and MWCNT nano particles from settling when the melted slurry was stirred for 5 minutes. Furthermore, stirring at an optimized speed of 450 rpm created a vortex in the melt, and this effectively enhanced the distribution of the particles. The stir casting setup is presented in Fig.2.

Fig.2 Experimental set up used for stir casting

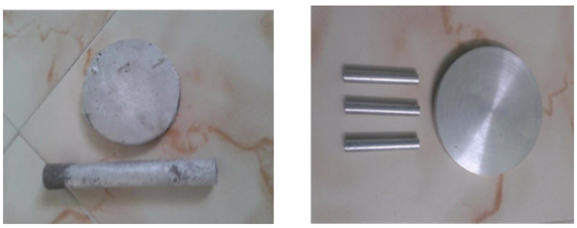

Fig.3 Fabricated samples before and after machining

The melt with the incorporated SiC and MWCNT particles, were poured into a mould with the dimensions of length 200mm and diameter 20mm as a rod and a 10mm thick and 95mm diameter circular plate. The Fig.3shows the Al-SiC-MWCNT nanocomposite samples before and after machining.

Rockwell hardness testing was performed for measuring the hardness for Al-SiC-MWCNT metal matrix nanocomposites. A pin-on-disc wear testing machine was used to evaluate the sliding wear behaviour of the composites. The wear tests were carried out under dry sliding conditions in air at 30±3˚C with the relative humidity of 59-69% as per ASTM G99-95. Pin specimens of 8mm diameter and 50 mm height were cut from the machined samples, and then polished. A normal load of 0.5, 1 and 1.5 kg was applied using dead weights, at 636 rpm for 5 minutes and the pins were carefully cleaned with alcohol and weighed using a sensitive electronic balance. All tests were conducted at room temperature. The initial weight of the specimen were also measured using an electronic precision balance. During the test, the pin was pressed against the counterpart rotating against a AISI-O1 Cast Iron disc (hardness 63 HRC) by applying the load. The Fig.4 shows the Pin-on-disc apparatus and Fig 5 shows the photograph of the prepared pin and cast iron disc. Were studies were conducted on the AL-SiC-MWCNT nanocomposite samples in order to determine the co-efficient of friction.

Fig. 4 Pin-on-disc apparatus

Fig.5.a. Al-SiC-MWCNT pin

Fig.5.b.Castiron disc

3. Results and discussion

3.1. Hardness

Rockwell hardness test was conducted for measuring the hardness of the dual reinforced aluminium metal matrix nanocomposite. The 2.5mm steel ball was used as indenter and 500kgf pressure was maintained for a dwell period of 20seconds. The hardness values were measured in three locations over the sample and the average values were calculated as 55, 29 and 36HR for sample 1, 2 and 3 respectively. The results of the hardness are shown in table 4 and the comparison of average hardness values of various percentage of MWCNT are depicted in Fig.6.

Table 4. Rockwell hardness test results

Hardness \ Sample	Al-15%SiC	Al-15%SiC-0.5%CNT	Al-15%SiC-1%CNT
Trail 1	54.7	30.3	33.9
Trail 2	55	21.7	40.6
Trail 3	54.9	35.9	34

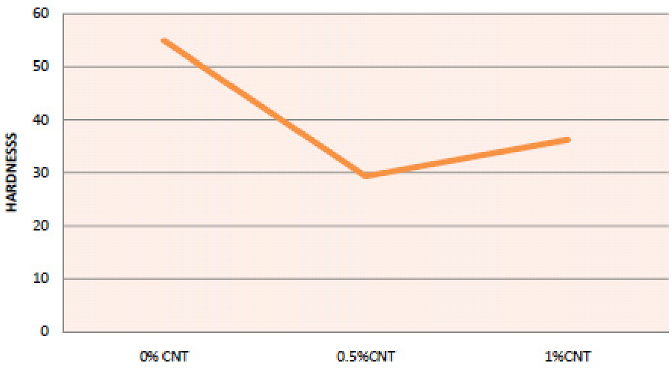

Fig.6. Comparison of hardness values

3.2. Wearloss

During the wear test, the pin was pressed against the counterpart rotating against an AISI-O1 Cast Iron disc (hardness 63 HRC) by applying the load. A friction detecting arm connected to a strain gauge and the pin specimen loaded vertically into the rotating hardened tool steel disc. The frictional traction experienced by the pin during sliding was measured continuously by a PC-based data logging system. After running through a fixed sliding time, the specimen were removed, cleaned with acetone, dried, and weighed to determine the weight loss due to wear. The values of the co-efficient of friction (COF) for the applied load for Al- SiC-MWCNT Nano composites are depicted in Table. 5 and it was observed that there is a decreased COF value over the addition of MWCNT.

Table 5. COF values for 3 samples

Load (Kg) \ COF	Al-15%SiC	Al-15%SiC-0.5%CNT	Al-15%SiC-1%CNT
0.5	0.532	0.404	0.263
1	0.569	0.487	0.382
1.5	0.589	0.535	0.486

4. Conclusion

- The stir casting method is found to be suitable to fabricate the hybrid Aluminium-SiC-MWCNT reinforced metal matrix Nano composites.
- Aluminium reinforced with SiC and MWCNT exhibits better dry abrasive wear resistance.
- For all values of the applied load, specific wear rate decreases with the increase of the % of MWCNT
- Hardness of the composites increase as the hybrid ratio increases.
- This work is a preliminary study. The detailed study is required to evaluate the contribution of SiC and

MWCNT nanoparticles on the wear properties of the hybrid composites.

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