Wear Behaviour of CNT and Boron Fibers Reinforced Al 6061 Metal Matrix Composites

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Abstract - Abstract— **Aluminum based metal matrix composites are used in various structural applications such as aerospace, automobile, and other sports equipment due to their physical properties such as ductility, light weight, more stiffness etc., as compared to base alloy. In this present work, Al 6061 was used as metal matrix with varying weight percentages of Multiwalled Carbon nanotubes (MWCNT) and Boron fibers as reinforcements. Stir casting method was used to fabricate the metal matrix composites. The fabricated composites were machined to prepare wear specimens according to ASTM Standards. The wear properties were investigate using pin on disc apparatus. Testing was conducted by varying load and keeping speed constant. From the obtained results and graph plotted, it is found that as the percentage of reinforcement increases there was a decrease in wear rate of the composite. The specimen of 1.5 to 2 weight percentage of MWCNT and 3 to 5 weight percentage of Boron fiber yielded better results compared to the base material. The worn-out surface was analyzed using Scanning Electron Microscope (SEM).**

***Index Terms* - Al 6061, Boron fibres, MWCNT, SEM, Wear.**

I.INTRODUCTION

Aluminum 6061 is a precipitation hardening aluminum alloy, has good mechanical properties, and exhibits good weldability. It is used in aircraft and aerospace components, bicycle frames, drive shafts and brake components. Carbon nanotubes (CNT) have attracted more attention as an ideal reinforcing material in fabricating composites for their good electrical and thermal properties, extraordinary strength as well as their high elastic modulus values. Srinivas R [1] developed a MWCNT reinforced Aluminum metal matrix composite specimen by stir casting method, tailoring the weight percentages of MWCNT's (0.5%, 1%, 1.5%, 2%) with Nickel deposition over the surface and concluded that, with increase in CNT content the wear rate decreases till 1% of CNT, then it starts increasing again. Amuthakkannan[2] studied the effect of basalt fiber reinforcement on dry sliding wear of Al 6061 alloy composites using pin on wear tester. Ashwin C Gowda [3] studied the wear characteristics of Al/B4C/CNT hybrid composites under different load conditions. Here wear characteristics of composites developed through different blends of the reinforcements. Atla Sridhar studied the effect of graphite on the tribological behaviour of hybrid composites with Al 7075. Jeyasimman [5] investigated dry sliding wear behaviour of AA6061nanocrystalline and AA 6061 – 2 weight percentages of MWCNT. The worn surface morphologies were analyzed by SEM. Deepak [6] used Al 6061 alloy as a matrix and SiC, E glass and flyash as reinforcement, that resulted in increase of compressive strength and decrease in wear rate. Manjunath [7] synthesized Aluminum Graphene nano composites successfully through powder metallurgy. Karthikeyan [8] characterized and compared the wear properties of Aluminum 6061 based SiC composites using SEM and found that micro and transverse cracks with meek and stern wear taken place in the specimen.

II. MATERIALS AND METHODS

A. Aluminum 6061

Al 6061in the form of ingots is used in this study. It is best suited for mass production of light weight metal castings. It has a melting temperature of 6600C. The elastic modulus of Al 6061 ranges from 70 to 80 Gpa and has density of 2.7gm/cm3. It has better properties such as ductility, machinability, etc compared to other alloys. It forms a clear interface when mixed with other materials.

B. Multiwall Carbon Nanotubes (MWCNT)

Multiwall Carbon Nanotubes (MWCNT) are used as reinforcement which are one dimensional pipe wall, with carbon content greater than 98% with outer diameter of 20nm and inner diameter of 16nm. It has length of 20µm. The bulk density is 0.10gm/cm3.

C. Boron Fibers

There are limited number of studies on properties of Boron fibers reinforced metal matrix composites. Boron fibers are not only strong in tension but also facilitate strong compression in composites. Boron fibers manifests a combination of high strength and elastic modulus. Boron fibers in the form of Chopped strands having diameter 12.5µm and density of 2.4g/cm3 is used in this study.

D. Method for preparation of Composites

Metal Matrix composites was prepared by stir casting method. In this method, Al 6061 in the form of ingots were placed in the crucible and kept in furnace. The ingots were melted at a temperature of more than 700oC. Predetermined weight percentage of MWCNT (0.5, 1, 1.5, 2) and weight percentage of Boron fibers (1, 3, 5, 7) were added to the melt aluminum and stirred to get the composites. After mixing of reinforcement and base metal, the crucible is taken out from the furnace and the molten metal is poured into die and allowed to solidify. After solidification, the casted composite is removed from the die and machined to prepare the specimen as per ASTM standards for various testing.

III. EXPERIMENTAL PROCEDURE

Wear test were carried out by a pin-on-disc wear test apparatus (Model DUCOM) according to ASTM G99 the specimen(pins) having diameter of 6mm was used and is as shown in Fig.1. The end of the pins surface was maintained without any burr and sharp corners since this surface may damage the disc surface while testing. The surface of the pins was checked for the perpendicularity and the flatness to seat with counter surface. The prepared Sample were set in slot which was provided in the arm above the rotating disc. The weight of the pins was measured before and after wear test by using a sensitive electronic balance. The track radius was taken as 40mm. The experiment was conducted under normal applied load varied of 2kg, 4kg, and 6kg at constant speed of 200rpm. A total of 17 specimens were tested.

Fig.1 Wear Test Specimen.

IV. RESULTS AND DISCUSSIONS

The wear results of specimens obtained by varying composition of CNT (0.5%, 1%, 1.5%, 2%) and Boron fiber (1%, 3%, 5%, 7%) of Total weight of aluminum for three different loads (2kg, 4kg, 6kg) at constant speed of 200rpm are listed below as in Table I, II and III. The wear rate was calculated by difference in initial and final mass of the specimen. Specimen A0.5C1B means Aluminum + 0.5% CNT + 1% Boron Fiber.

Table I: For 2Kg Load

Specimen	Initial Mass (M_I) (gm)	Final Mass (M_F) (gm)	$M_I - M_F$ (gm)	Wear Rate10^{-6} (mm^2/kg)
A 0C 0B	2.154	2.150	0.004	2.453
A 0.5C 1B	2.283	2.278	0.005	3.068
A 0.5C 3B	2.391	2.387	0.004	2.453
A 0.5C 5B	2.358	2.354	0.004	2.453
A0.5C 7B	2.336	2.333	0.003	1.823
A 1C 1B	2.449	2.445	0.004	2.453
A 1C 3B	3.372	3.368	0.004	2.453
A 1C 5B	2.352	2.347	0.005	3.068
A 1C 7B	2.378	2.374	0.004	2.453
A 1.5C 1B	2.345	2.342	0.003	1.823
A 1.5C 3B	2.319	2.315	0.004	2.453
A 1.5C 5B	2.366	2.364	0.002	1.226
A 1.5C 7B	2.372	2.369	0.003	1.823
A 2C 1B	2.265	2.262	0.003	1.823
A 2C 3B	2.099	2.097	0.002	1.226
A 2C 5B	2.393	2.391	0.002	1.226
A 2C 7B	2.528	2.525	0.003	1.823

TableII: For 4kg Load

Specimen	Initial Mass (M_I) (gm)	Final Mass (M_F) (gm)	M_I – M_F (gm)	Wear Rate10^{-6} (mm^2/kg)
A 0C 0B	2.150	2.142	0.008	2.456
A 0.5C 1B	2.278	2.272	0.006	1.842
A 0.5C 3B	2.387	2.378	0.009	2.763
A 0.5C 5B	2.354	2.350	0.004	1.226
A0.5C 7B	2.333	2.327	0.006	1.842
A 1C 1B	2.445	2.439	0.006	1.842
A 1C 3B	3.368	3.364	0.004	1.226
A 1C 5B	2.347	2.338	0.009	2.763
A 1C 7B	2.374	2.371	0.003	0.911
A 1.5C 1B	2.342	2.340	0.002	0.613
A 1.5C 3B	2.315	2.313	0.002	0.613
A 1.5C 5B	2.364	2.360	0.004	1.226
A 1.5C 7B	2.369	2.366	0.003	0.911
A 2C 1B	2.262	2.259	0.003	0.911
A 2C 3B	2.097	2.091	0.006	1.842
A 2C 5B	2.391	2.389	0.002	0.613
A 2C 7B	2.525	2.522	0.003	0.911

Table III: For 6Kg Load

Specimen	Initial Mass (M_I) (gm)	Final Mass (M_F) (gm)	M_I – M_F (gm)	Wear Rate 10^{-6} (mm^2/kg)
A 0C 0B	2.142	2.133	0.009	1.840
A 0.5C 1B	2.272	2.259	0.013	2.66
A 0.5C 3B	2.378	2.369	0.009	1.840
A 0.5C 5B	2.350	2.333	0.017	4.691
A0.5C 7B	2.327	2.316	0.011	2.251
A 1C 1B	2.439	2.423	0.016	3.273
A 1C 3B	3.364	3.353	0.011	2.251
A 1C 5B	2.338	2.326	0.012	2.546
A 1C 7B	2.371	2.364	0.007	1.432
A 1.5C 1B	2.340	2.329	0.011	2.251
A 1.5C 3B	2.313	2.301	0.012	2.546
A 1.5C 5B	2.360	2.351	0.009	1.840
A 1.5C 7B	2.366	2.359	0.007	1.432
A 2C 1B	2.259	2.253	0.006	1.22
A 2C 3B	2.091	2.080	0.011	2.251
A 2C 5B	2.389	2.385	0.004	0.817
A 2C 7B	2.522	2.516	0.006	1.22

From the results obtained, graphs were plotted for number of specimen against wear rate for three different loads as 2kg, 4kg, 6kg.

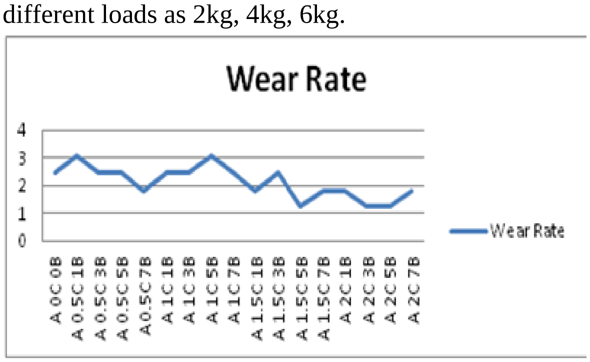


Fig. 2 Wear rate for 2kg Load

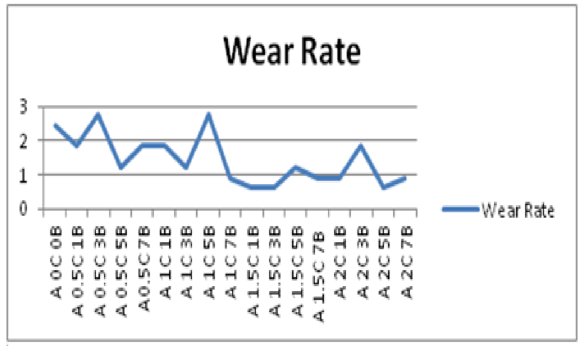


Fig. 3 Wear rate for 4kg Load

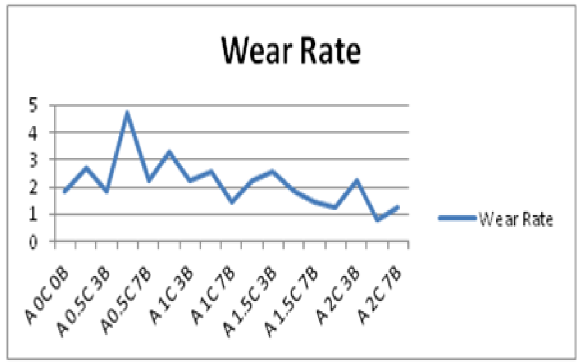


Fig. 4 Wear rate for 6 kg Load

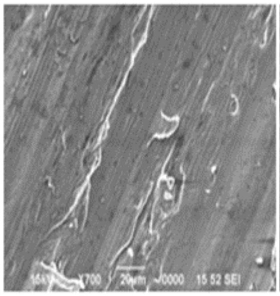
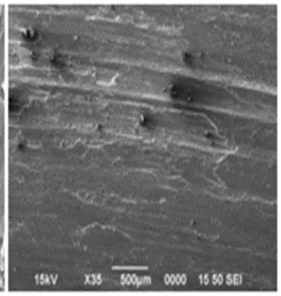
From the plotted graph, it can be found that there was reduction in wear rate as the percentage of CNT and Boron Fiber varied. For 2kg load the wear rate initially increased for 0.5% CNT and 1% Boron fiber and decreased for 1.5% CNT and 5% Boron fiber, the same trend was found for 4kg load also.

There was a peak raise in wear rate for 1% CNT and 1% boron fibers for 6kg load and decreased for 1.5%C5B specimen. The wear rate of the composite reduced with the increase in reinforcement content, which forms a thin film at the contact surface between the composite and the surface. Pure Aluminum alloy has higher wear rate compared to other reinforced composites.

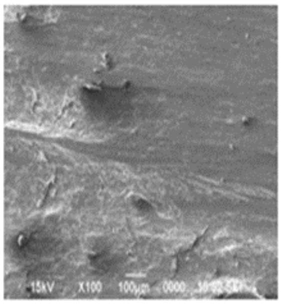
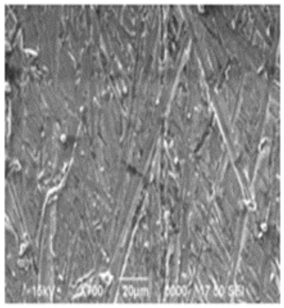
V. WORN SURFACE ANALYSIS

Scanning Electron Microscopy is done on a JEOL make device with a resolution range of 3 to 15 nm and magnification of 8X to 300,000 controlled by a 5 axes computer control.

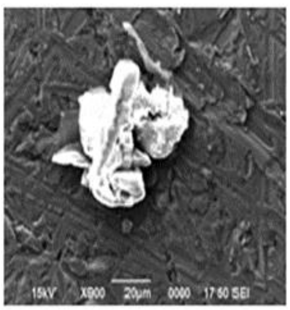
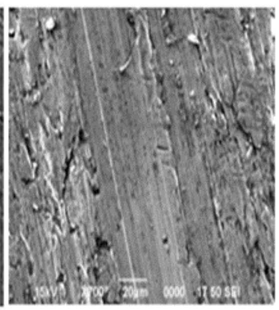
Scanning Electron Microscopy is carried out to study the surface morphology of the worn-out surfaces, microscopic images of wear debris and specimen, give a clear insight into contact surfaces and subsequent microstructural implication of the specimen.

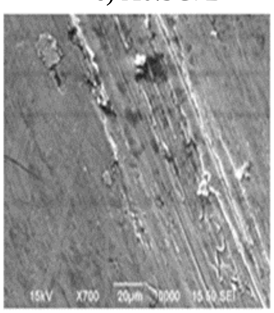
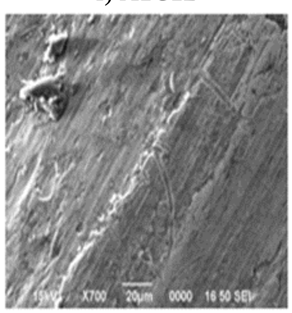
a) A0C0B b) A0.5C1B

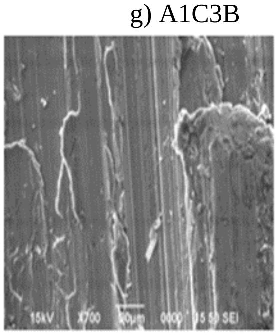
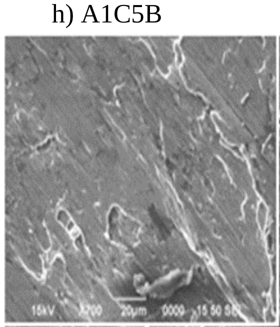
c) A0.5C3B d)A0.5C5B

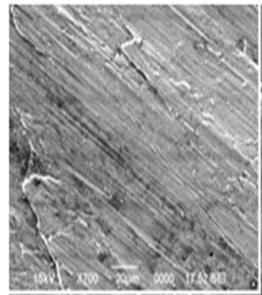
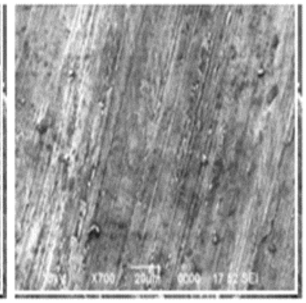
e) A0.5C7B f) A1C1B

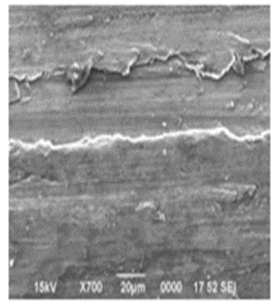
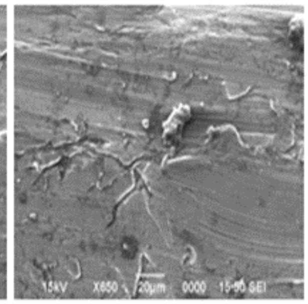
g) A1C3B h) A1C5B

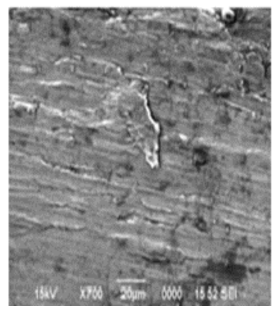
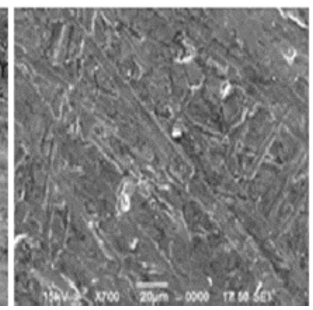
i) A1C7B J) A1.5C1B

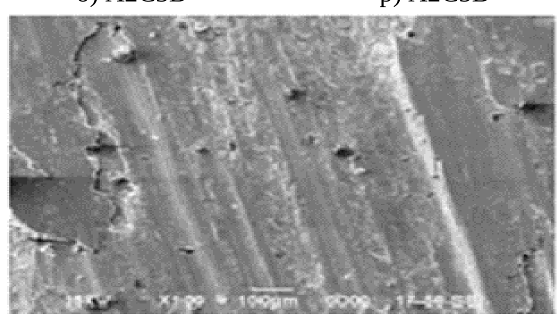
k) A1.5C3B l) A1.5C5B

m) A1.5C7B n) A2C1B

o) A2C3B p) A2C5B



q) A2C7B

Fig.5 SEM images of wear tested specimens (a-q)

SEM image of the worn-out surface of the Al/ boron fiber/CNT reinforced metal matrix composites are visualized in Fig. 5.

Micrograph shows that there is small micro crack due to the stress developed during the periodical motion of the hard substrate. The repeated loading causes fatigue wear on the surface and subsurface region leads to the formation of micro cracks as in Fig.5(d). It also shows fine grooves in the surface and plastic deformation at a few places and presence of deep grooves in different size observed repetitively on the worn surface of the composites. The structure of such grooves propagates subsurface crack along the sliding direction as in Fig.5(f). Further increasing load leads to the process of delamination

In pure aluminum composites showed the larger size of cavity in the surface as in Fig.5 (a) which indicating the severe losses in the materials. Larger size cavity occurred due to when the material sliding over another material with higher velocities that soften the parent material due to increases in temperature as in Fig. 5 (q). The temperature rise resulted in particle pull out was observed. when load increase gradually the morphology of the worn-out surface of the composites appeared from fine scratch to distinctive grooves. When the plastic flow of the material increased which required to higher shearing action to peel off the wearing surface and leads to delamination mechanisms

VI. CONCLUSION

The CNT and Boron fiber reinforced Al metal matrix composites was prepared using stir casting techniques with different reinforcing % of CNT and Boron fibers successfully. The addition of CNT and Boron fiber to Al matrix enhances the effective bonding between reinforcements and matrix by allowing the larger interfacial area of contact, and there by increasing the wear resistance of the composites. From SEM images of worn surface, it can be observed that the main wear mechanism is due to delamination wear.

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