Mechanical and tribological properties of As-cast Al6061-Tungsten carbide metal matrix composites

A.R.K. SWAMY[1]*, A. RAMESHA[2], J.N.PRAKASH[3] and G.B.VEERESH KUMAR[4]

[1]Dr. M.G.R. University, Chennai and Department of Mechanical Engineering,
Don Bosco Institute of Technology, Bangalore - 560 074 (India).
Email: dsarkswamy@yahoo.com
[2]GATES Institute of Technology, Gooty, (India).
Department of Mechanical Engineering, Alpha College of Engineering,
[3]Doddagubi Post, Hennur – Bagalur Road. Bangalore, Karnataka - 562 149 (India).
[4]Department of Mechanical Engineering, S B M J College of Engineering,
Jain Global Campus, Jakkasandra (P), Kanakapura (Tq), Ramanagram (Di) (India).

(Received: March 09, 2010; Accepted: April 17, 2010)

ABSTRACT

The Aluminum (Al) and its alloys are finding extensive applications in industries like automobile, aerospace and marine fields. Aluminum-based Metal Matrix Composites (MMC's) reinforced with hard particulates offer superior operating performance and resistance to wear. Al based MMC materials provide higher abrasive resistance and provide a longer service life compared to other materials. The popularity of composites may be the reason that these composites possess good mechanical properties, good corrosion resistance, wear resistance in addition they are light-in-weight. In this paper it is aimed to present the experimental results of the studies conducted related to hardness, tensile strength, and compression strength of Al6061-Tungstan Carbide (WC) composites. The composites were prepared using the liquid metallurgy technique (stir casting technique), in which 0-4 wt. % of reinforcing tungsten carbide particulates were dispersed into the base matrix alloy in steps of 1%. The obtained cast composites of Al6061-WC and unreinforced base alloy was subjected mechanical tests and composites were subjected to microstructural examination. The test results reveal that the hardness and strength of the alloy has increased monotonically. The wear resistance obtained using computerized pin on disc wear tester with counter surface as EN31 steel disc (HRC60) and the composite pin as specimens, demonstrated the superior wear resistance property of the composites.

Key words: Al6061-WC, hardness, tensile strength, compression strength, microstructure.

INTRODUCTION

Aluminum alloys are preferred engineering material for automobile, aerospace and mineral processing industries for various high performing components and are being used for these varieties of applications owing to their lower weight, excellent thermal conductivity properties. Among several series of aluminium alloys, Al6061 is much explored for their excellent properties. These alloys are heat treatable. Al6061 alloy are highly resistant to corrosion and are of excellent extricable in nature and exhibits moderate strength. Al6061 founds much useful in the fields of construction (building and high way), automotive and marine applications[1]. The composites made out of aluminium alloys are of wide interest owing to their high strength, fracture toughness, wear resistance and stiffness. Further these are superior composite suitable for elevated temperature application when reinforced with ceramic particulates[2].

G.Straffelini *et.al.,*[3] found that the matrix hardness has a strong influence on the dry sliding wear behaviour of Al_2O_3 particulate 6061 Al MMCs. A. Martin *et.al.,*[4] in their investigation on the tribological behaviour on Al6061 reinforced with Al_2O_3 particles concluded that a characteristic physical mechanism exists during the wear process. S.Y.Yu *et.al.,*[5] clearly demonstrated the effects of applied load and temperature on the dry sliding wear behavior of 6061 aluminum alloy matrix composites reinforced with SiC whiskers or SiC particulates and concluded that, the wear rate decreases with increased applied load. H.C.How, T.N.Baker[6] in their investigation of wear behaviour of aluminium alloy AA6061 filled short fiber saffil concluded that saffil as a reinforcing material are significant in improving wear resistance of the composite. M.R. Rosenberger *et.al.,* [7] after incorporating Al_2O_3, B_4C, Ti_3Al, and B_2Ti in AA6061, and showed that mechanically mixed layers (MML) are generated during sliding wear condition.

The above discussion and survey reveals very meager data on the mechanical properties of particulate reinforced aluminum (Al6061) alloy. Hence, the present paper is aimed at the investigation of mechanical properties of Al6061-Tungsten Carbide (WC) composites.

EXPERIMENTAL

The properties of materials adopted and methods followed in the present studies are presented in the following sections.

Materials

The base matrix selected was Al6061 and the chemical composition and properties are presented in table 1 and 2. The reinforcing material selected was tungsten Carbide (WC) of particle size of 5 µm, table 3 gives the properties of WC.

Composite Preparation

Liquid metallurgy route were adopted to prepare the cast composites. Mechanical stirring of the molten alloy was achieved by using ceramic-coated steel impeller to create vortex. The preheated particles were introduced into the vortex and stirred for eight minutes at a speed of 500 rpm. A pouring temperature of 720°C was adopted and the molten composite was poured into preheated cast iron moulds. The extents of incorporation of particles in to the matrix alloy were varied from 1 to 4 wt % in the steps of 1. The cast composites of Al6061-WC obtained were cylinders of dia 22mm and length of 220mm.

Testing of Composite

The composite specimens as per ASTM E10-07a standards for the Brinell's hardness, microstructure and mechanical property tests were obtained by machining the cast composites. Brinells hardness tester with ball indenter and 500 kg load was used to obtain the hardness of the composites. The micro-photographs of the composites were obtained with the help of metallurgical microscope of Lobo make attached with Pentax camera. The specimens for these studies were prepared by following the standard procedure of polishing using abrasive papers of decreasing grit size and abrasive diamond lapping. The Tensile (ASTM E8/E8M-08) and Compression (ASTM E9-89a (2000)) tests were evaluated using a computerized UTM of 60-ton capacity. Magnam make computerized pin on disc wear testing machine with test material as pin and high carbon EN31 steel (HRC60) as counter-surface, equipped with LVDT and digital display system served to record the wear height loss in microns, the wear tests were conducted according to ASTM G-99 standards.

RESULTS AND DISCUSSIONS

The test results of base matrix Al6061 and its composites containing WC at various weight percentages are presented in the following sections.

Hardness

From the Figure 1 it is observed that the hardness of the composite is increasing with the increase of reinforcing particulate content. The hardness value of the composite is higher than that of its matrix alloy. This increase in hardness of the composite may be due attributed to the reason that the reinforcement materials used is much harder than that of the matrix materials [8, 9, 10].

Further it was observed that the hardness value improved up to 3 wt % of WC and again the hardness is decreased for 4 wt. % of WC. Better hardness was found at 3 wt. % of WC. Hence from the studies it can be concluded that upto 3 wt. % of WC can be successfully incorporated into the matrix.

Microstructure studies

The Figure 2a clearly indicates the characteristic features of aluminum alloy Al6061. The Figure 2b to 2e shows the microphotographs of the cast Al6061-1% WC to Al6061-4% WC composites respectively. From these photographs the reinforced WC can be identified. The photographs reveal the clear distribution of WC and also homogeneity of the composites. It is observed from the study of the micro structure that the distribution of WC is more uniform and homogeneous upto 3wt % of WC (figures 2b-d). From the Figure 2e we can observe the non uniformity of the WC particulates.

Mechanical Properties

The results of tensile and compression tests conducted are discussed in the following sections.

Tensile strength of Al6061 alloy and its composite containing WC

From Figure 3 it can be observed that the tensile strength of the composites are higher than that of the base alloy and further it can be observed that with increase in WC content the composites tensile strength also increases. This improvement in tensile strength of the composites may be attributed to the fact that the fillers (WC) possesses higher strength and also may be due to the better bonding strength due to lower fineness of dispersed WC particulates [7,11,12]. Finer the grain size better is the hardness and strength of composites leading to lowering of wear rates.

Figure 3 is presented with tensile strength property of Al6061 alloy and its composite containing WC as a function of % weight. The variation in tensile strength of the composites with varying wt. % of WC is shown in Figure 3. It was observed that as the wt. % of WC is increased from 1 wt. % to 4 wt. % it was observed that the tensile strength value improved up to 3 wt. % WC and the tensile strength decreased for 4 wt. % WC. Better tensile strength was found at 3 wt % WC. The decrease in tensile strength of the composites beyond 3 wt. % WC is attributed to improper bonding between the matrix and reinforcement materials.

Decrease in the Elongation of Al6061 alloy and its composite containing WC

Figure 4 is presented with decrease in elongation of Al6061 alloy and its composite containing WC as a function of % weight.

Figure 4 reveals that the elongation of the composite material is less as compared to that of the cast Al6061 alloy. It is clear that the composite material exhibits higher brittleness with increased filler content, in other words the matrix material suffers with ductility due to the influence of the reinforcement material. Further, The strength of particle dispersed Al-composites are found increased by increased volume percentage of ceramic phase and by decreasing the size of the

Table 1: Chemical composition of Al6061 by Wt%

Chemical Composition	Al6061
Si	0.62
Fe	0.23
Cu	0.22
Mn	0.03
Mg	0.84
Cr	0.22
Zn	0.10
Ti	0.1
Al	Bal

Table 2: Properties of Al6061

Properties	Al6061
Elastic Modulus (Gpa)	70-80
Density g/cc	2.7
Poisson's Ratio	0.33
Hardness (HB500)	30
Tensile Strength (Mpa)	115

Table 3: Properties of reinforcing particles

Properties	WC
Elastic Modulus (Gpa)	627
Density g/cc	14.9
Hardness (HB500) Mohr's scale	1630
Compressive Strength (Mpa)	5000

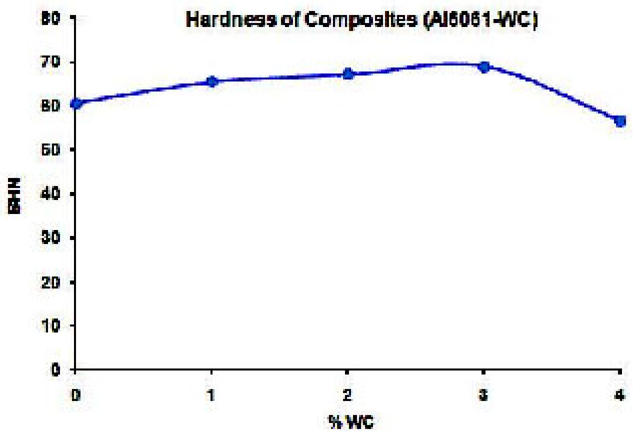

Fig. 1: Effect of WC on the hardness of Al6061- WC composites

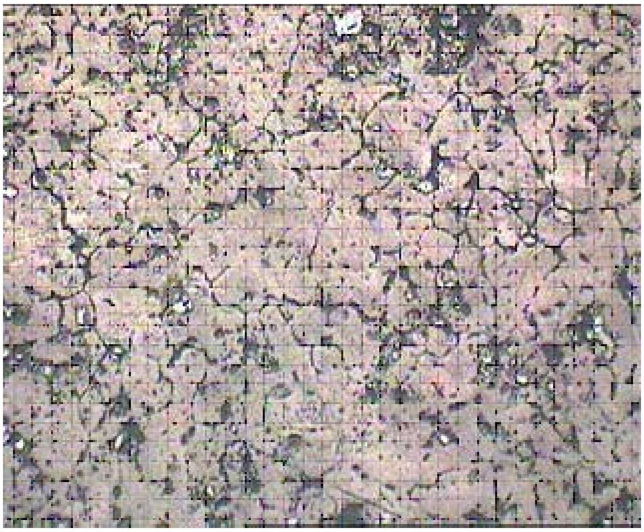

Fig. 2(a): Microphotograph of cast Al6061 alloy (100X)

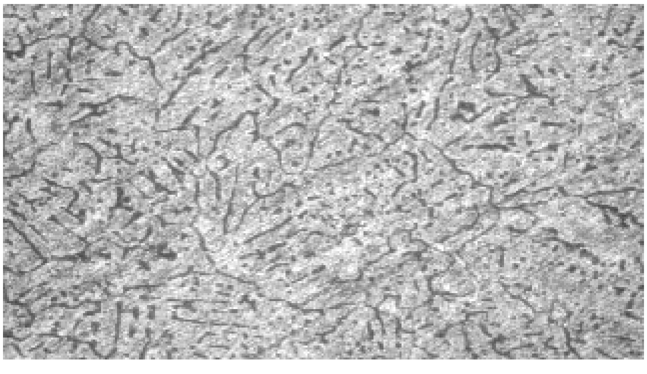

Fig. 2(b): Microphotograph of cast Al6061-1% WC Composite (100X)

reinforcement (at the cost of reduced ductility) in the composite[13-6].

Compressive strength of Al6061 alloy and its composite containing WC

Figure 5 shows the variation of compression strength with % increase of WC. From figure 5, it can be observed that the compressive strength of the composites are higher than that of the base alloy and further it can be observed that with increase in WC content the composites compressive strength also increases. As the wt. % of WC is increased from 1 % to 4 wt. %, the compressive strength value improved up to 3 wt. %

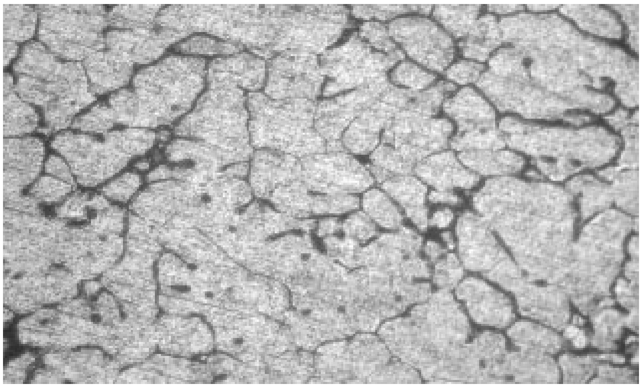

Fig. 2(c): Microphotographs of cast Al6061-2% WC Composite (100X)

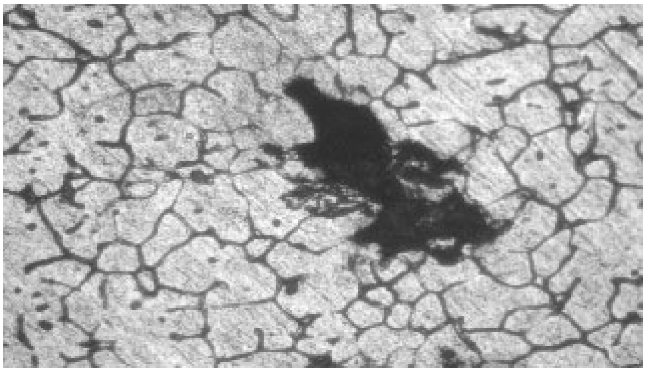

Fig. 2(d): Microphotograph of cast Al6061-3% WC Composite (100X)

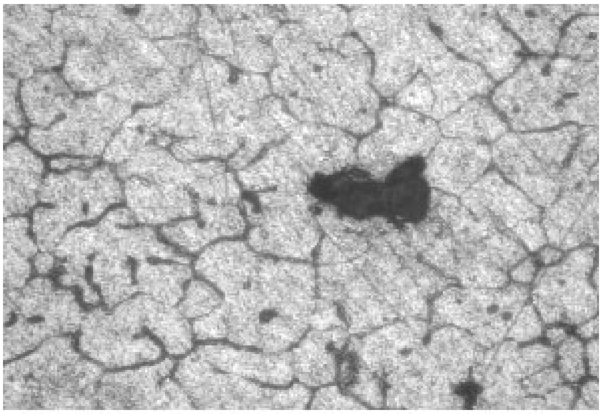

Fig. 2(e): Microphotograph of cast Al6061-4% WC Composite (100X)

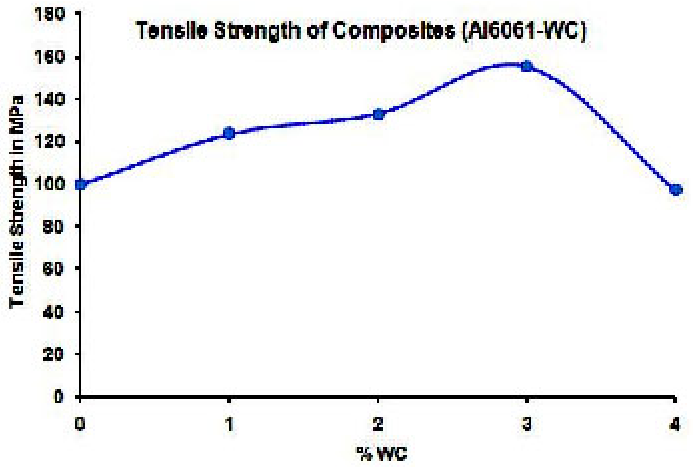

Fig. 3: Variation in Tensile Strength of Al6061 with increasing % of WC

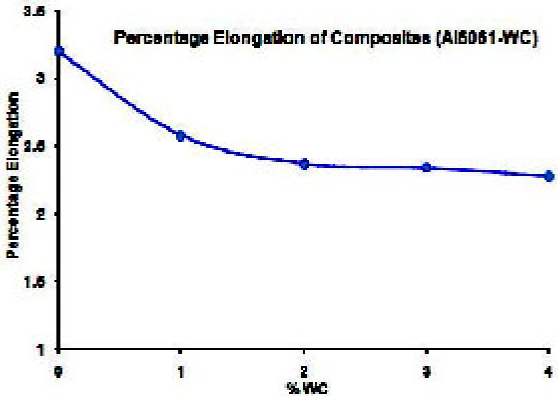

Fig. 4: Variation in the % Elongation with different Wt% of WC in Al6061

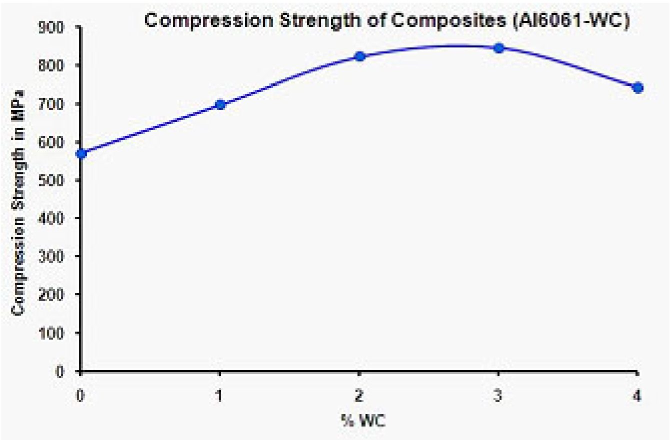

Fig. 5: Variation in compressive strength of Al6061 with increasing % of WC

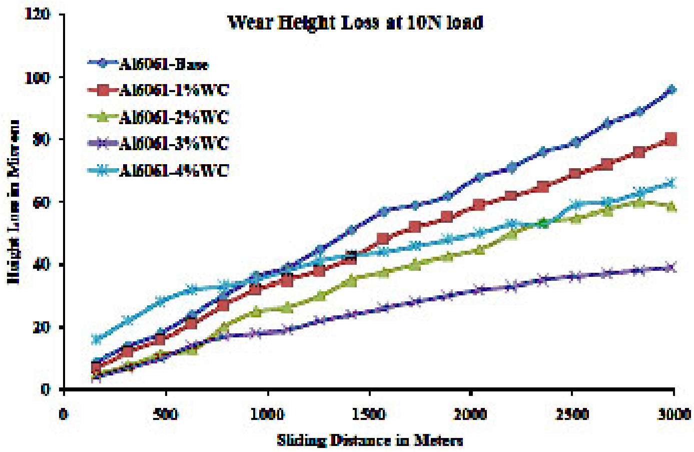

Fig. 6(a): Height loss of Al6061 alloy and its composites sliding at 500 rpm and an applied load of 10N

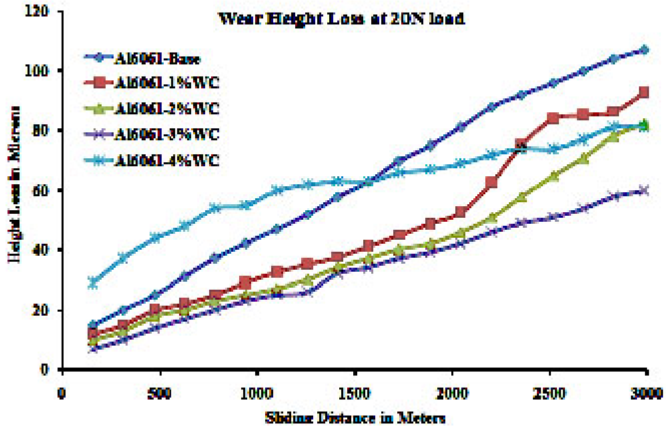

Fig. 6(b): Height loss of Al6061 alloy and its composites sliding at 500 rpm and an applied load of 20N

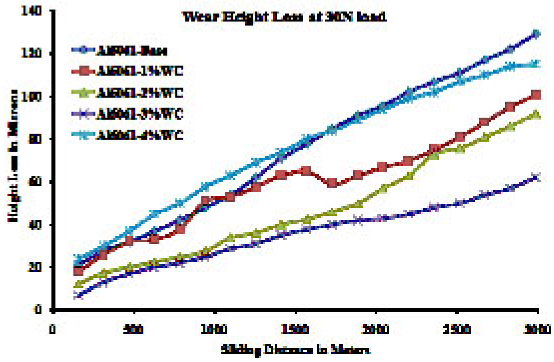

Fig. 6(c): Height loss of Al6061 alloy and its composites sliding at 500 rpm and an applied load of 30N

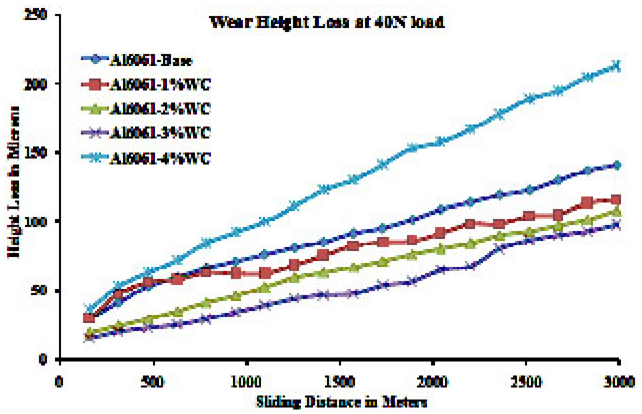

Fig. 6(d): Height loss of Al6061 alloy and its composites sliding at 500 rpm and an applied load of 40N

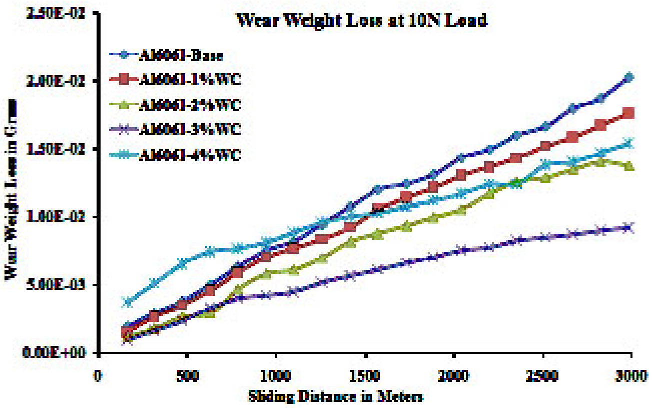

Fig. 7(a): Variation of Weight loss Al6061-WC composites sliding at 500 rpm speed and 3km sliding distance at an applied load of 10N

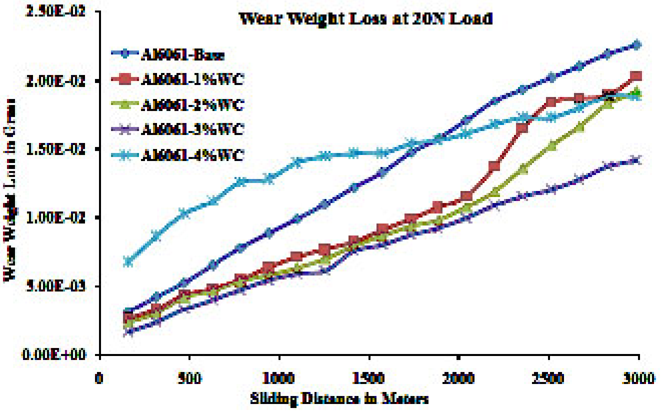

Fig. 7(b): Variation of Weight loss Al6061-WC composites sliding at 500 rpm speed and 3km sliding distance at an applied load of 20N

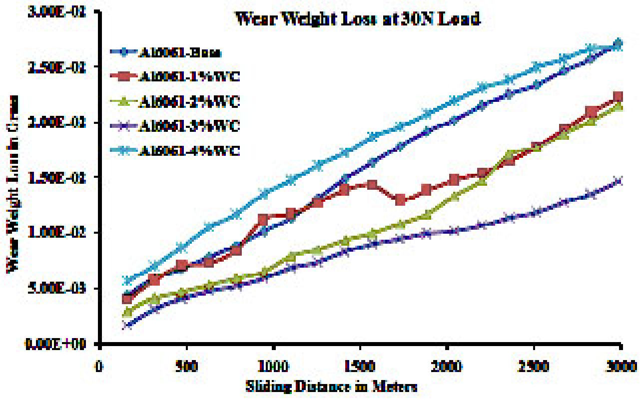

Fig. 7(c): Variation of Weight loss Al6061-WC composites sliding at 500 rpm speed and 3km sliding distance at an applied load of 30N

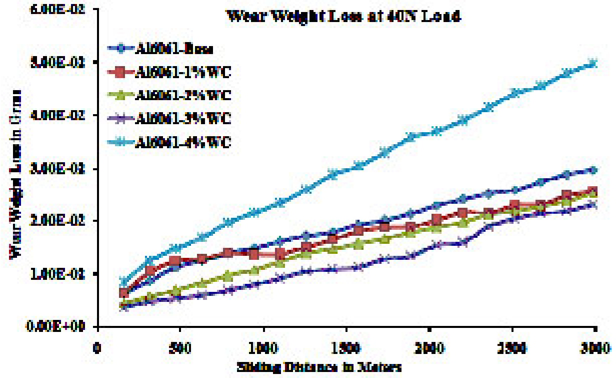

Fig. 7(d): Variation of Weight loss Al6061-WC composites sliding at 500 rpm speed and 3km sliding distance at an applied load of 40N

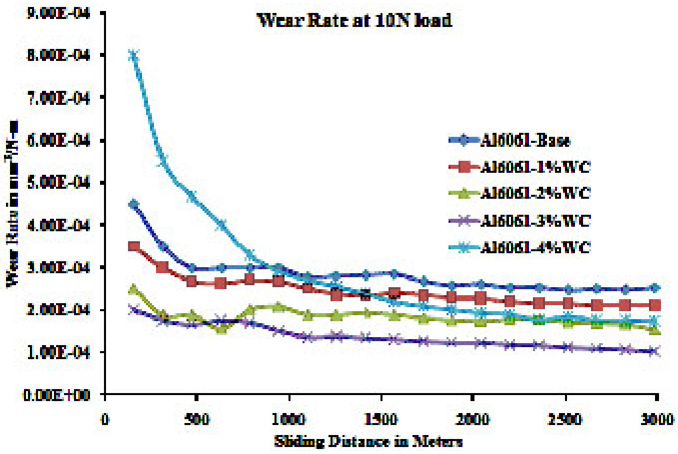

Fig. 8(a): Variation of Wear rate of Al6061-WC composites sliding at 500 rpm speed and for 3km sliding distance at an applied load of 10N

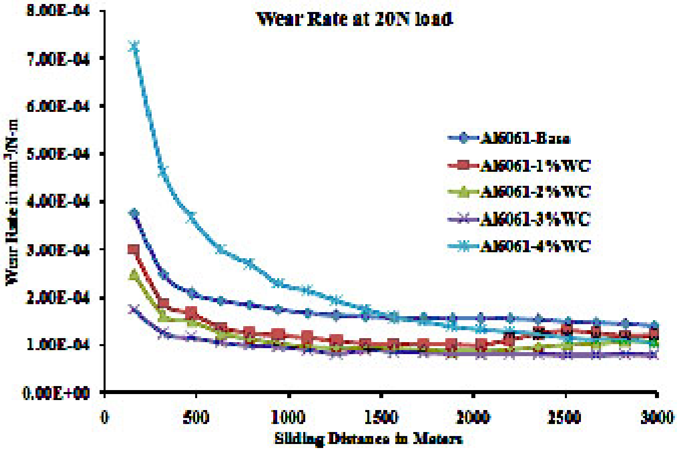

Fig. 8(b): Variation of Wear rate of Al6061-WC composites sliding at 500 rpm speed and for 3km sliding distance at an applied load of 20N

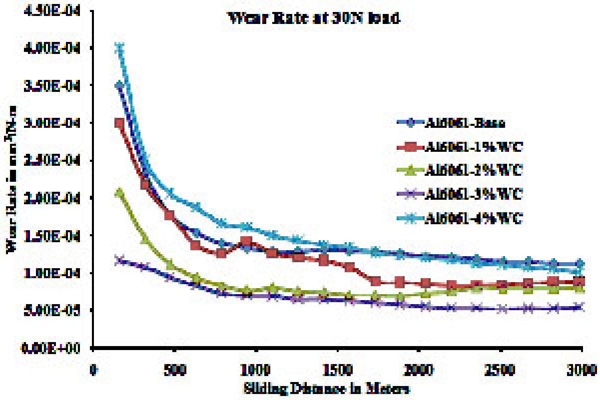

Fig. 8(c): Variation of Wear rate of Al6061-WC composites sliding at 500 rpm speed and for 3km sliding distance at an applied load of 30N

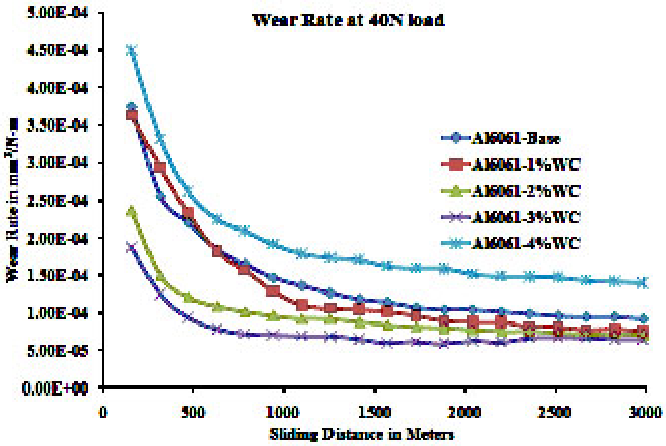

Fig. 8(d): Variation of Wear rate of Al6061-WC composites sliding at 500 rpm speed and for 3km sliding distance at an applied load of 40N

WC and the compressive strength decreased for 4 wt. % WC. Better compressive strength was found at 3 wt. % WC. The increase in the compressive strength is mainly due to the WC reinforcement because the WC is having very high compressive strength then the matrix material.

Tribological Properties

The cast pins of 10mm diameter and 25mm length were the specimen for the tribological test. The height loss experienced by the specimen as a function of material parameter (filler content) and the test parameters (sliding distance) for various applied load (10-40N in steps of 10) and with 500rpm rotational speed, for the base alloy and its composites are presented in figures 6 a-d.

Figure 6 a-d presents the variation of wear loss of the Al6061 alloy and its composites under an applied constant load of 10 to 40N in the steps of 10N and a sliding distance of 3km, for sliding speed of 500 rpm.

From figure 6a, it can be observed that, the wear height loss experienced by the composites are lesser than that of the base alloy also it can be found that the wear height loss for the composites decreases as a function of filler content. Further, it can also be observed from the figure that, for given filler content, the composites wear height loss increases with increased sliding distance. From figures 6 a-d, it can be observed that the trend of wear loss of the base alloy and composites are more or less same as compared to the trend of figure 6a.

From the above discussions, it can be concluded that the composites containing WC exhibits decreased wear loss and hence exhibits improved wear resistance. From the above discussions it is clear that, the presence of WC in the composite is to reduce the wear loss and hence contributes in improving the wear resistance. The highest wear resistance is exhibited by the composite containing 3 wt% WC. The improvement of the wear resistance can be attributed to the fact that the filler improves the hardness of the composites thus further contributing to the improvement of the wear resistance of the composites.

Also from the graph it can be seen that the Al6061-4%WC composite has higher wear height loss, it is even more than the base material. This is mainly due to the lower hardness of the Al6061-4%WC composite, as it is shown in the hardness figure 1. Further, it can be concluded that lower hardness means higher wear height loss or lesser wear resistance.

Wear weight Loss

Figures 7 a-d are presented with the weight loss experienced by the base and the composites containing WC reinforcement. From the figures it is clear that the weight loss experienced by the base al6061 is more than the al6061-WC composites. Also it can be observed from the figure that, for given filler content, the composites weight loss increases with increased sliding distance. The al6061-4%WC composite has lowest wear resistance and al6061-3%WC composite has highest wear resistance among the composites studied.

The highest wear resistance (lower weight loss) is exhibited by the composite containing 3 wt% WC. The improvement of the wear resistance can be attributed to the fact that the filler improves the hardness and strength of the composites thus further contributing to the improvement of the wear resistance of the composites. Further, the lowest wear resistance of the al6061-4%WC composite is mainly attributed to the lower values of the hardness and strength values.

Wear rate of Al6061-WC composites

This section is presented with the figures showing the variation of wear rate of the al6061 base alloy and its WC filled composites sliding at 500rpm speed and for a 3km sliding distance at an applied load of 10-40N.

The wear rate, defined as the ratio of wear volume (in mm^3) to the product of applied load (in N) and sliding distance (in m), is an important parameter, which quantifies the wear resistance (wear rate). Thus the wear rates of the base alloy and the al6061-WC composite materials studied are presented. Figure 8 a-d shows the wear rate for Al6061 and its composites containing WC and various applied loads (10-40N). From the figures it can be observed that the wear rate of the composites is lower than that of the base matrix, and for a given applied load condition the increased sliding distance for a given material reduces its wear rate, further, for a constant sliding speed the increased applied load tends to reduce the wear rate. From the above discussion it can be concluded that the wear resistance of the material increases with increased filler content and also increased sliding distance, further from the above figures it can be clearly observed that the composite containing 3%WC filler content reaches wear stabilization at a lower sliding distance than that of its matrix indicating its improved wear resistance. Further from the figure it can be noted that the wear rate of Al6061-3 wt% WC is lowest and signifies its highest wear resistance among the materials studied[17].

It has been found that the applied load effects the wear rate of alloy and composites significantly and is the most dominating factor controlling the wear behaviour[18] The wear rate varies linearly [19, 20] with normal load, which is an indicative of Archard's law, and is significantly lower in case of composites[21]. The particle reinforcements are the most effective in improving the wear resistance of MMCs[22- 24] provided that good interfacial bonding between the reinforcement and the matrix exists. The particle reinforcement has the effect of preventing the plastic flow and the adhesion of matrix material, the particle shape was of great advantage for carrying a contact load compared to whisker and fiber reinforcements[22]. The wear resistance of the composites is improved by preventing direct metallic contacts that induce subsurface deformation[25].

CONCLUSIONS

The significant conclusions of the studies carried out on Al6061-WC composites are summarized as follows

1. Al 6061-WC composites were prepared successfully using liquid metallurgy techniques by incorporating the reinforcing particulates upto 4 wt %.
2. The microphotographs of the cast composites revealed the uniform distribution of the particles in the matrix.
3. The properties of the cast Al6061-WC composites are significantly improved by varying the amount of WC. It was found that increasing the WC content within the matrix material, resulted in significant improvement in mechanical properties like hardness, tensile strength, and compressive strength.
4. Highest values of mechanical properties like hardness, tensile strength and compressive strength were found at 3 % WC.
5. From the studies and the test results it can be concluded that upto 3 wt. % WC can be incorporated into the Al6061 alloy by liquid metallurgy technique.
6. The wear resistance of the composites are higher, further, the WC contributed much significantly in improving the wear resistance of Al6061-WC composites.
7. From the studies in overall it can be concluded that Al6061-3% WC composite exhibits superior mechanical and Tribological properties.

ACKNOWLEDGEMENTS

The authors express their thanks to staff of Mechanical Engineering Department, to the Principal of DBIT and to the Management of Wayanamac Education Trust, Bangalore, for the support and encouragement during this research studies.

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