Effect of T6 type heat treatment on the Mechanical characterization of Al6061-Al_2O_3 particulate composites

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ABSTRACT

In this paper it is aimed to investigate the mechanical characterization of Al6061alloy with different weight percentage of Al2O3 particles up to 0-9% was processed by stir casting technique. For each composite, reinforcement particles are pre-heated to a temperature of 200ºC and then dispersed in steps of 3 into the vortex of molten Al6061 alloy to improve wettability and distribution. The as cast samples and composite is subject to solutionizing heat treatment at 530^0 C for 2h followed by water quenching. The artificial gaining is again carried out at 199^0C for 6 hours. Hardness test, tensile test, wears behaviour and fatigue properties were examined. Microstructural characterization was carried out for the above prepared composites by taking specimens from central portion of the casting to understand the nature of structure. It has been observed that addition of Al_2O_3 particles significantly improves ultimate tensile strength, hardness along with wear behaviour of with that of unreinforced matrix. With the heat treatment adopted it has been noticed that Al2O3 particles significantly improves the mechanical characterization and wear behaviour of composites.

Keywords: Electrical resistance furnace, Fatigue test, tensile strength, vicker's hardness test, Wear.

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INTRODUCTION

Metal–matrix composites (MMCs) are most promising materials in achieving enhanced mechanical properties such as: hardness, Young's modulus, yield strength and ultimate tensile strength due to the presence of micro-sized reinforcement particles into the matrix. Aluminum-matrix composites (AMCs) reinforced with discontinuous reinforcements are finding increased use in automotive, military, aerospace and electricity industries because of their improved physical and mechanical properties. Among Al-alloys, 6061Al-alloy is widely used in engineering applications such as transport and construction sectors where superior mechanical properties like tensile strength, hardness etc., are essentially required[1-2]. A number of materials such as Sic, Al_2O_3, B_4C, TiB_2, ZrO_2, SiO_2 and graphite are being used as reinforcements to improve the properties of 6061Al alloy. However, the applications of Al_2O_3 or SiC particle reinforced aluminum alloy matrix composites in the automotive and aircraft industries is gradually increasing for pistons, cylinder heads, connecting rods etc. where the tribological properties of the materials are very important[3-5]. Aluminium and oxygen is the chemical compound of Aluminium oxide with the chemical formula Al_2O_3. It is the most commonly occurring of several aluminium oxides called alumina.

The aim of present study is to synthesize 6061Al-Al_2O_3 particulate MMC by stir casting method. In order to improve wettability and distribution of reinforcing particles a novel three stage mixing combined with preheating of the reinforcing particles is being adopted and also study the mechanical characterization on 6061Al-Al_2O_3 particulate composites.

EXPERIMENTAL PROCEDURE

Material preparation

The matrix material used for the present study is 6061Al-alloy. The chemical composition of matrix material is as shown in Table 1 determined using Atomic Absorption Spectrophotometer (model AA-670, Varian, The Netherlands). Al_2O_3 particles with size of 125µm and with varying amounts of 3, 6 and 9 wt% are being used as reinforcing material in the preparation of composites. Stir casting technique has been used for the preparation of composites as shown in the fig1. Initially calculated amount of 6061Al alloy was charged into Gr crucible and superheated to a temperature of 750^0C in an electrical resistance furnace.

The furnace temperature was controlled to an accuracy of $\pm 50^0$C using a digital temperature controller. A novel three stage mixing combined with preheating of the reinforcing particles is followed. Ceramic Al_2O_3 particulates were preheated to a temperature of 250^0C in an oven to remove the adsorbed gases from the particle surface and to avoid high drop of temperature after addition of particulates. Preheated Al_2O_3 particles were introduced into the vortex of the molten alloy after effective degassing using solid hexachloroethane (C_2Cl_6). Vortex is generated with the help of a zirconia coated steel impeller. The extent of incorporation of Al_2O_3 particles in the matrix alloy was achieved in steps of 3. i.e. Total amount of reinforcement required was calculated and is being introduced into the melt 3 times rather than introducing all at once. At every stage before and after introduction of reinforcement, mechanical stirring is carried out for a period of 10 min. The stirrer was preheated before immersing into the melt, and is located approximately to a depth of 2/3 height of the molten metal from the bottom and run at a speed of 200 rpm. Composite mixture was poured into permanent cast iron moulds having diameter 12.5mm and length of 125mm at a pouring temperature of 750^0C. Cast and composite ingots were T6 heat treated in a muffle furnace for 2 hours at 530^0C, followed by water quenching and then aged at 199^0C for 6 hours.

Table1- Shows the Chemical Composition of Al6061 alloy assessed using Atomic Absorption Spectrophotometer (Model AA-670, Varian, the Netherlands)

Elements	Si	Fe	Cu	Mn	Ni	Pb	Zn	Ti	Sn	Mg	Cr	Al
Percentage	0.43	0.7	0.24	0.139	0.05	0.24	0.25	0.15	0.001	0.802	0.25	Balance

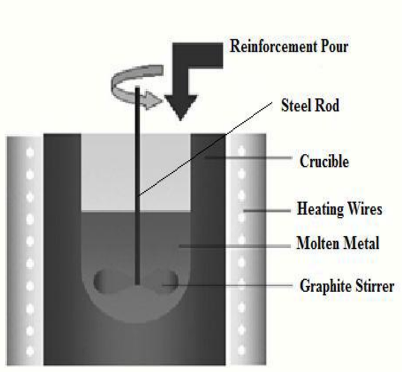


Fig 1 shows the graphical representation of Stir casting and Resistance Furnace

Testing

The prepared composites were characterized by microscopic studies. Specimens of 12mm diameter and thickness of 10mm were cut from the central portion of the casting by an automatic cutter device. The specimen surfaces were prepared by grinding through 300, 600 and 1000 grit papers and then by polishing with 3 μm diamond paste by using a specimen polishing machine. Now, fine polished samples were cleaned with distilled water, the samples so prepared were etched by using Keller's reagent (2.5%HNO_3+1.5%HCl+1%HF+95% H_2O by volume) to obtain better contrast and then they were taken for optical microscopy. The tensile test was conducted at ambient temperature using computerized uni-axial tensile testing machine at a strain rate of 0.51 mm/min. Each test was repeated twice and average response value was considered. The dimensions of the specimen used for tensile studies were diameter 9mm and gauge length 45mm as per ASTM standard E-8 is shown in fig.1. The Vickers hardness were measured on the polished samples using diamond cone Indentor with a load of 10N for a period of 10 seconds was applied on the specimens and the value reported is average of the five readings taken at different locations.

Dry sliding wear tests for different number of specimens was conducted by using a pin-on-disc machine (Model: Wear & Friction Monitor TR-20) supplied by DUCOM[6], as per ASTM G99-95 standards was shown in Figure 2. The pin was held against the counter face of a rotating disc (EN32 steel disc) with wear track diameter 80mm. The pin was loaded against the disc through a dead weight loading system. The wear test for all specimens was conducted under the normal load of 2kg and a fixed sliding velocity of 1.256 m/s. Wear tests were carried out for a total sliding distance of approximately 3000m under similar conditions as discussed above. The pin samples were 25 mm in length and 8 mm in diameter. The Fatigue tests were carried out using Rotating beam fatigue testing machine as per ASTM standards as shown in the fig.3. Two specimens were used for each test and average value is reported.

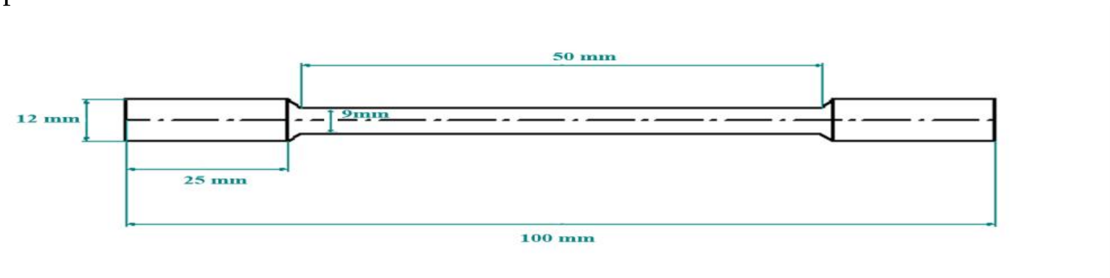


Fig.1-showing the Tensile test Specimen as per ASTM standard –E8

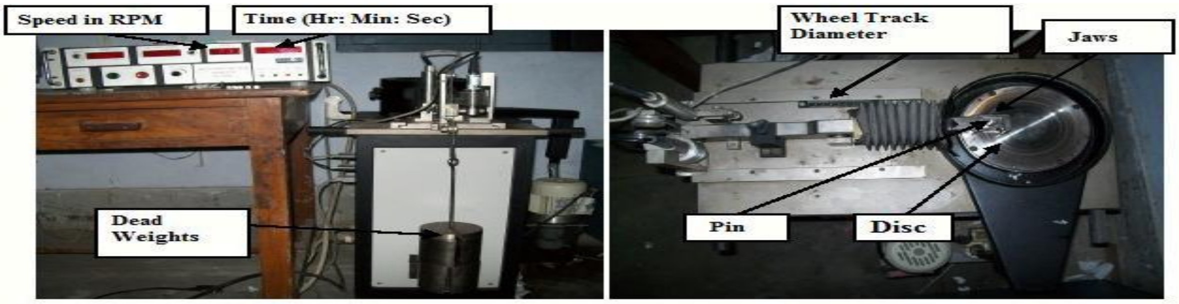


Fig. 2 - Showing Wear Testing Machine

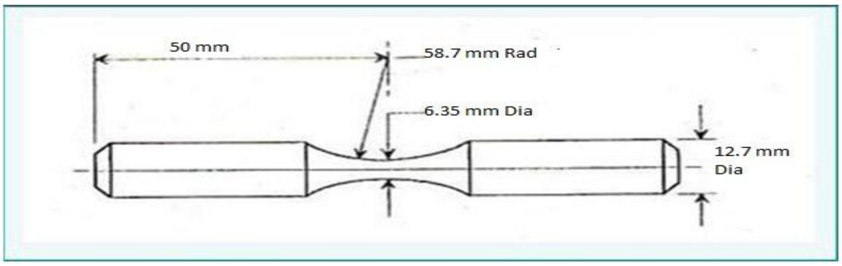
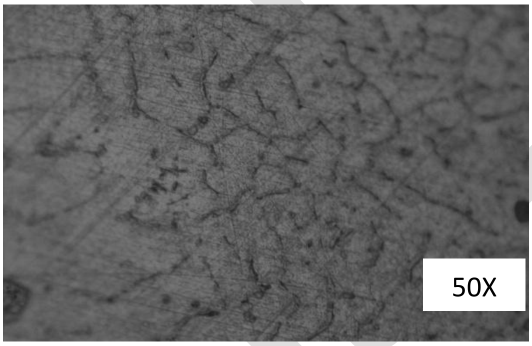


Fig.3- showing the Fatigue test Specimen as per ASTM standard

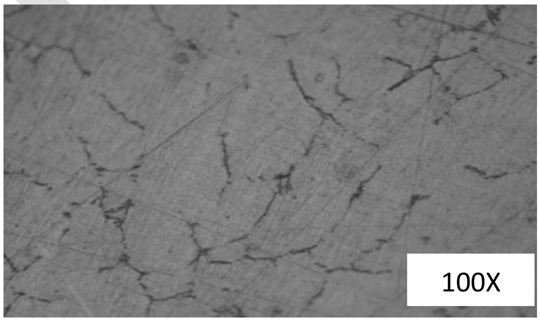
RESULT AND DISCUSSION

Microstructure

The optical micrographs of the 6061Al alloy with 0, 3, 6 and 9wt. % Al_2O_3 particulates were shown in Fig 4(a-h).



(a)



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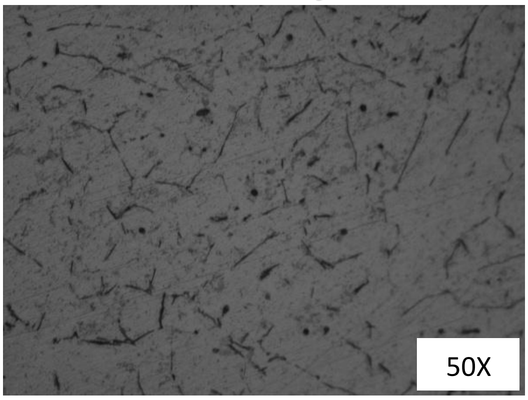

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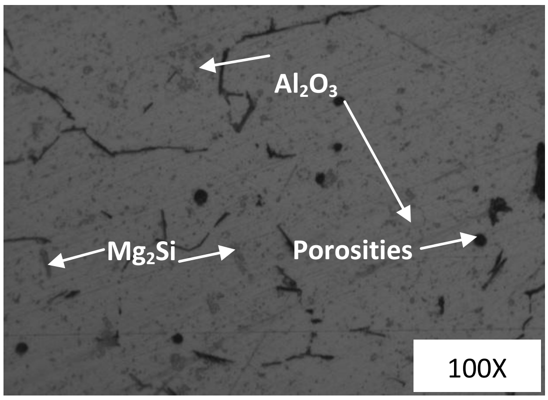

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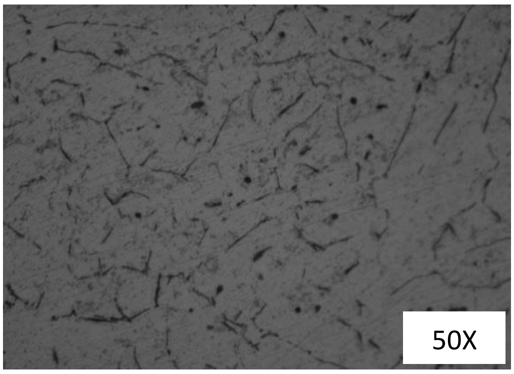

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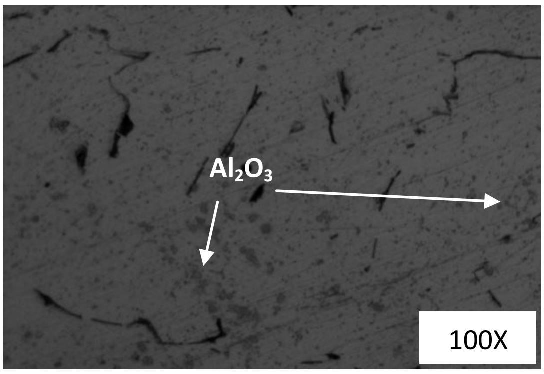

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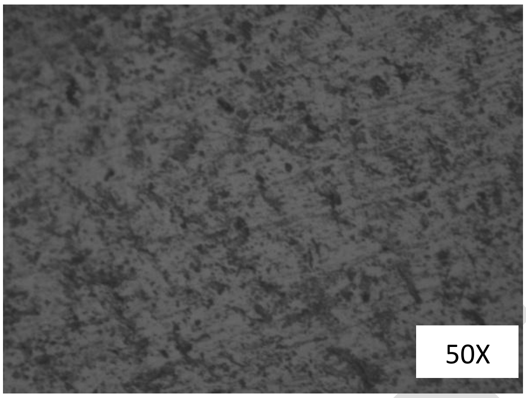

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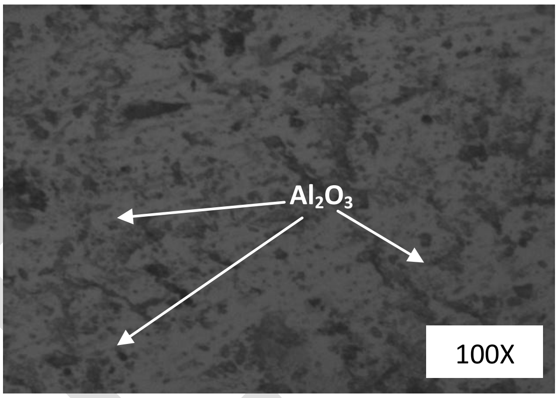

(h)

Fig.4- a-h Showing the optical microphotographs of 6061Al with and without Al_2O_3 particulates at 50X & 100X (a-b) as-cast, (c-d) with 3wt% of Al_2O_3p, (e-f) with 6wt% of Al_2O_3p & (g-h) with 9wt% of Al_2O_3p at 100X.

The microstructure of the prepared composites contains primary α-Al dendrites and eutectic silicon, while Al_2O_3 particles are separated at inter-dendritic regions and in eutectic silicon. The stirring of melt before and after introducing particles has resulted in breaking of dendrite shaped structure into equiaxed form, it improves the wettability and incorporation of particles within the melt and also it causes to disperse the particles more uniformly in the matrix. Fig. 4 (c-h) reveals the distribution of alumina particles in different specimens and it can be observed that there is fairly uniform distribution of particles and also agglomeration of particles at few places were observed in both the composites reinforced with 3 wt%, 6wt% and 9wt% Al_2O_3. The microphotographs also indicate that the Al_2O_3 particles have tendency to segregate and cluster at inter-dendritic regions which are surrounded by eutectic silicon (Fig.4.1.c-h). Further, the micrographs show that grain size of the reinforced composite (Fig.4.1.a-h) is smaller than the alloy without alumina particles (Fig. 4 a-b) because, Al_2O_3 particles added to melt also act as heterogeneous nucleating sites during solidification.

Tensile Test

Table 2- Tensile test values of composites before aging

Sl.No	Material	Tensile Strength (MPa)	Yield Strength (MPa)
1	AL6061	130.01	110.03
2	AL6061 +3%AL_2O_3	143.99	128.07
3	AL6061 +6%AL_2O_3	159.99	142.37
4	AL6061 +9%AL_2O_3	190.29	142.37

Table 3- Tensile test values of composites after aging

Sl.No	Material	Tensile Strength (MPa)	Yield Strength (MPa)
1	AL6061	152.64	123.14
2	AL6061 +3%AL_2O_3	161.25	147.57
3	AL6061 +6%AL_2O_3	178.98	163.07
4	AL6061 +9%AL_2O_3	204.29	186.15

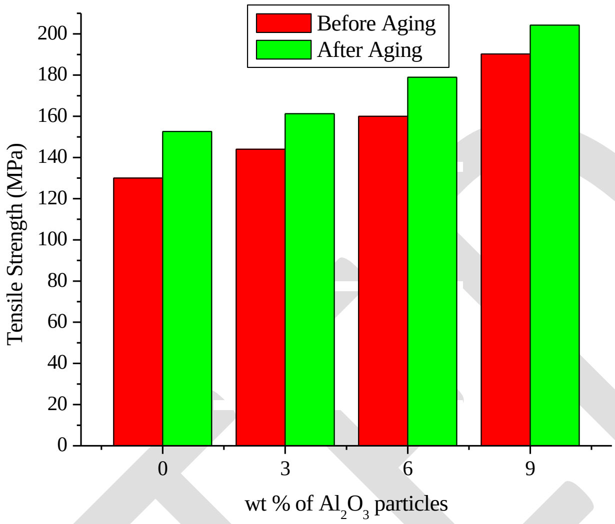

Fig.5-Effect of wt% of Al2O3 particles on tensile strength of composites

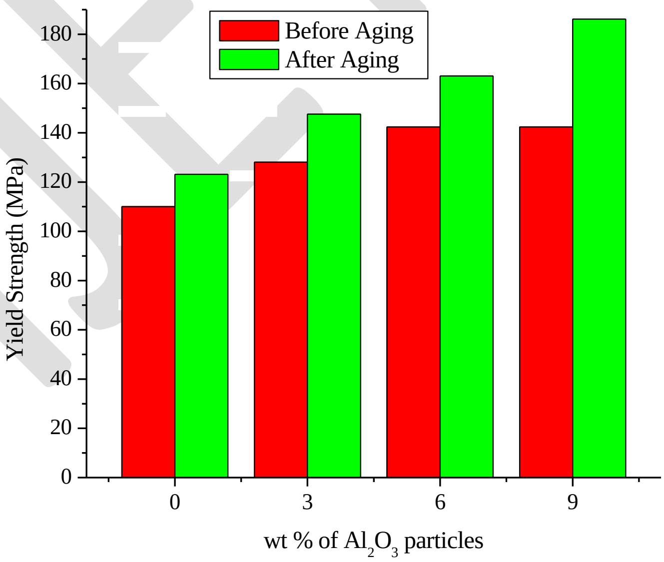

Fig.6-Effect of wt% of Al_2O_3 particles on yield strength of composites

Fig.5 & fig.6 shows the effect of wt% of Al_2O_3 particles on tensile strength of composites. It can be noticed from the fig that as increase in the wt% of Al_2O_3 contributes in increasing in the tensile strength and yield strength both with and without aging. Increase in the composite strength due to dispersion of hard ceramic particles in a soft matrix[8]. The strengths were increased due to the large stress developed during solidification and due to mismatch of thermal expansion between the metallic matrix and the reinforcement, which is a major mechanism for increasing the dislocation density of the matrix[9]. Wettability is a major factor that contributes towards good bonding between the matrix and reinforcement[10]. All the aged samples exhibit higher strength values when compared with before aging and its composites.

Hardness

Table4-Table Hardness test values of composites

Sl.No	Material	Hardness before aging (VHN)	Hardness after aging (VHN)
1	AL6061	60.29	75.34
2	AL6061 +3%AL_2O_3	70.58	81.63
3	AL6061 +6%AL_2O_3	74.45	89.55
4	AL6061 +9%AL_2O_3	76.43	95.32

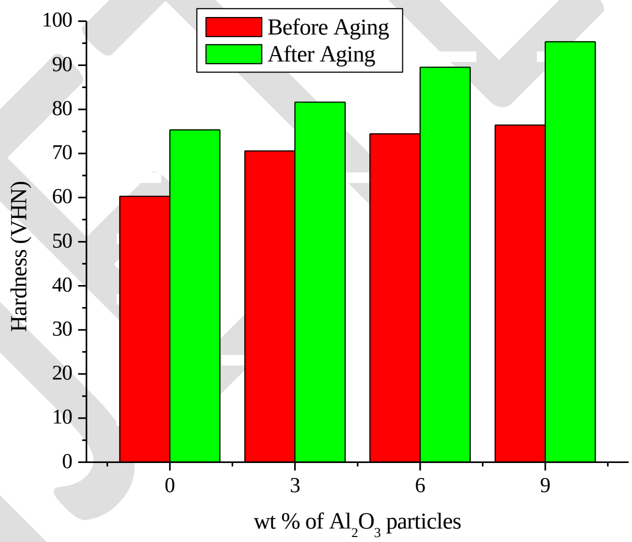

Fig.7-Effect of wt% of Al2O3 particles on hardness (VHN) of composites

The hardness value of Al6061 alloy and their composites containing 3 to 9 wt% as shown in the table 4. It can be observed from the fig.7 that the hardness of the composites is higher than that of its alloy. The composite having higher wt% of Al2O3 exhibits higher hardness. This may be due to addition of filler particles, which are harder than the matrix material and render their inherent property of hardness to soft metal matrix and makes the composite more brittle[11]. All the aged samples possess higher hardness values when compared with before aging and its composites.

Wear properties

Table 5- wear test values of composites

Sl.No	Material	Load (N)	Speed (RPM)	Time (sec)	Wear Before aging (µm)	Wear After aging (µm)
1	AL6061	19.62	480	745	252	196
2	AL6061 +3%AL_2O_3	19.62	480	745	224	176
3	AL6061 +6%AL_2O_3	19.62	480	745	194	162
4	AL6061 +9%AL_2O_3	19.62	480	745	170	144

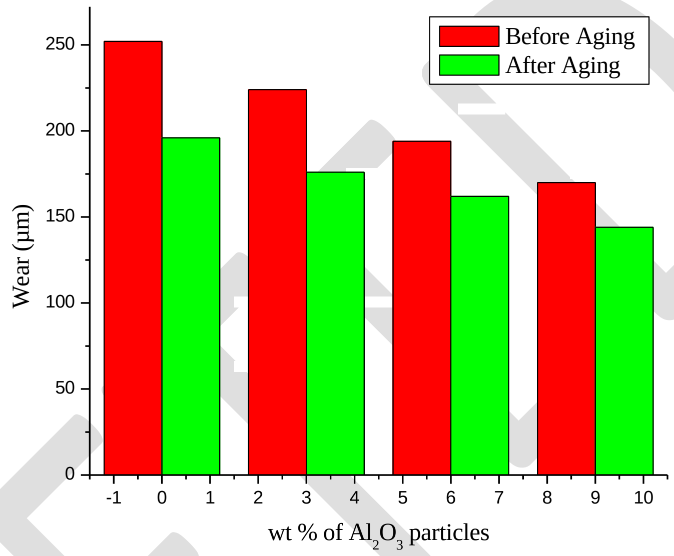

Fig.8-Effect of wt% of Al2O3 particles on wear of composites

The wear tests were performed using pin-on-disc testing machine. In this test we made an attempt of finding the wear rate by keeping load and sliding distance constant [i.e. load =19.62N ,sliding distance =1.256m corresponding speed is 480 RPM] then the result values of wear rate in microns get compared between the various compositions of composite and hybrid composites. It can be found from the fig.8 that as wt% of filler material increases there is a decrease in the wear rate. This is due to the dispersion of hard Al_2O_3 particles in the Al6061 alloy restricts such ploughing action of hard steel counterpart and improves the wear resistance. The wear resistance also increases with the heat treatment when compared with the samples before heat treatment.

Fatigue test

Table6- fatigue test values of composites

Sl.No	Material	Load (N)	Speed (RPM)	Number of cycles before aging	Number of cycles after aging
1	AL6061	122.625	1000	85046	122497
2	AL6061 +3%AL_2O_3	122.625	1000	116278	161742
3	AL6061 +6%AL_2O_3	122.625	1000	155040	196483
4	AL6061 +9%AL_2O_3	122.625	1000	186197	217491

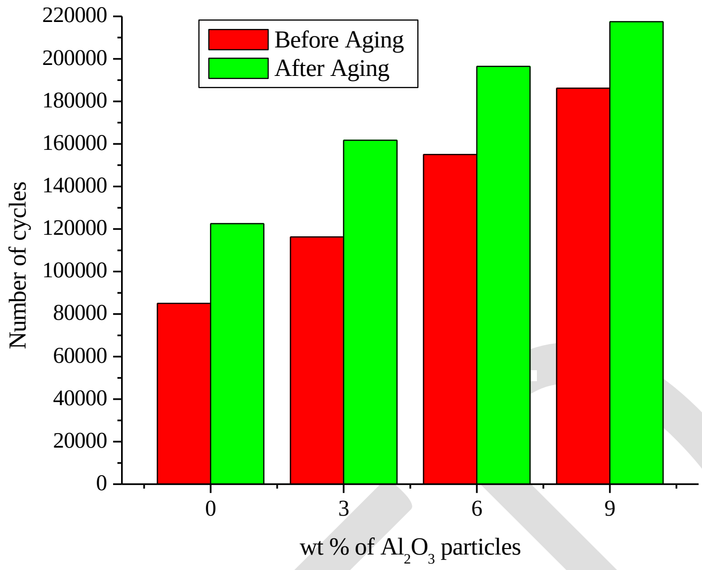

Fig.9-Effect of wt% of Al_2O_3 particles on fatigue behaviour of composites

To carry out a fatigue test a specimen is prepared with ASTM standard dimensions and tested using rotating bending machine with predetermined value of loads for which required stress level and cycles up to failure were documented.

The fig.9 shows the effect of wt% Al_2O_3 particles on fatigue behaviour of composites. In the fatigue test the number of cycles of the aged composites are increased when compare with them with the non aged composites when they are applied with a constant load of 122.625N and speed of 1000 rpm.

CONCLUSION

The present work on Studies of mechanical and wear properties of 6061Al-Al_2O_3 metal matrix composite with precipitation hardening and without precipitation hardening has led to following conclusions:

1. Aluminium based metal matrix composites have been successfully fabricated by Melt stirring method by three step addition of reinforcement combined with preheating of particulates.
2. The optical microphotographs of composites produced by Melt stirring method shows fairly uniform distribution of Al_2O_3 particulates in the 6061Al metal matrix. The microstructure of the composites contained the primary α-Al dendrites and eutectic silicon with Al_2O_3 particles separated at interdentritic regions.
3. 6061Al-Al_2O_3 composites have shown higher hardness when compared to the hardness of 6061Al-alloy. Also hardness of composites increases with increasing wt% of reinforcement.

4. The hardness of composites after subjecting them to the heat treatment also increases with increasing wt% of reinforcement.

5. Strength of prepared composites both tensile and yield was higher in case of composites. Further, with increasing wt% of Al_2O_3, improvements in tensile strength were observed and also the tensile and yield strength of the aged composites are higher than that of the non aged composites.

6. In the fatigue test the number of cycles of the aged composites are increased when compare with them with the non aged composites when they are applied with a constant load of 122.625N and speed of 1000 rpm.

7. It can be found that as wt% of filler material increases there is a decrease in the wear rate. When compared with the age hardening specimen, the wear rate is further decreased with increase of wt% of filler material.

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