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Characterization Study of Aluminium 6061 Hybrid Composite

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***Abstract*—**Aluminium matrix composites with alumina reinforcements give superior mechanical & physical properties. Their applications in several fields like automobile, aerospace, defense, sports, electronics, bio-medical and other industrial purposes are becoming essential for the last several decades. In the present work, fabrication of hybrid composite was done by Stir casting technique using Al 6061 as a matrix with alumina and silicon carbide (SiC) as reinforcement materials. The weight percentage of alumina is varied from 2 to 4% and the silicon carbide weight percentage is maintained constant at 2%. Hardness and wear tests are performed in the as cast and heat treated conditions. Age hardening treatment was performed on the specimen with solutionizing at 550°C, aging at two temperatures (150 and 200°C) for different time durations. Hardness distribution curves are drawn and peak hardness values are recorded. Hardness increase was very sensitive with respect to the decrease in aging temperature. There was an improvement in wear resistance of the peak aged material when aged at lower temperature. Also increase in weight percent of alumina, increases wear resistance at lower temperature but opposite behavior was seen when aged at higher temperature.

***Keywords*—**Hybrid composite, hardness test, wear test, heat treatment, pin on disc wear testing machine.

I. Introduction

THE incorporation of different types of reinforcements into a single matrix has led to the development of hybrid composites. Also, using a hybrid composite that contains two or more types of reinforcements, the advantages of one type of reinforcement could complement with what are lacking in the other. The properties of a hybrid composite mainly depend upon the reinforcement content, size of reinforcement and wettability of the reinforcement. Hybrid composite materials have extensive engineering application where strength to weight ratio, low cost and ease of fabrication are required. Hybrid composites provide combination of properties such as tensile modulus, compressive strength and impact strength which cannot be realized in conventional composite materials [1].

Al 6061 is a medium to high strength heat-treatable alloy. It has very good corrosion resistance and weldability although reduced strength in the weld zone. It has got medium fatigue strength and good cold formability in the heat treated condition T4, but limited formability in T6 condition [2]. Generally, these alloys are not suitable for very complex cross sections. Al 6061 is widely used for construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft. It is also used for yacht construction, including small utility boats, bicycle frames and components. Composition of Al 6061 alloy is given in Table I.

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TABLE I
COMPOSITION OF AL 6061 ALLOY

Element	Cr	Cu	Fe	Mg	Mn	Si	Ti	Al
Wt. (%)	0.003	0.24	0.16	0.89	0.48	0.63	0.014	Balance

Aluminum is the most popular matrix for the metal matrix composites due to its lightness (density one-third of iron), superior ductility, good electrical and thermal conductivity and good corrosion resistance [3].

A metal matrix composite (MMC) is a composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as a ceramic or organic compound. When there are a minimum of three materials, it is called as hybrid composite. The composite used here is a hybrid composite with three constituents. Al 6061 as the base matrix material and aluminum oxide (alumina) and silicon carbide as the reinforcement material. Alumina weight percentage is varied (2 and 4 % by weight) and the weight percentage of silicon carbide is held constant (2 % by weight).

II. Methodology

Composites reinforced with silicon carbide and alumina are produced using stir casting process.

A. Stir Casting

Stir casting is a liquid state method of composite materials fabrication whereby the reinforcement material is incorporated into the molten metal by stirring. Since most metal reinforcement systems exhibit poor wetting, mechanical force is required to combine the phases, generally through stirring. This method is currently the most inexpensive manner in which to produce metal matrix composites (MMCs), and lends itself to production of large quantities of material, which can be further processed via casting or extrusion. The simplest dispersion process in current use is the Vortex method, which consists of vigorous stirring of the liquid metal and the addition of particles in the vortex [4], [5].

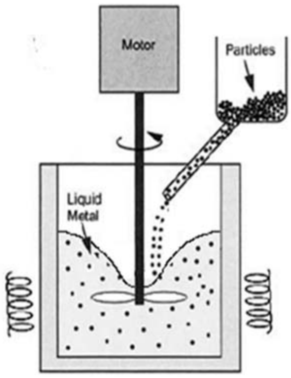

Fig. 1 Stir casting set up

Fig. 2 Vickers hardness testing equipment

Base metal is heated in the crucible to 800°C. The mechanical stirrer is actuated to stir the melt. During the vortex formation stage the preheated reinforcements are added one by one slowly during continuous and constant stirring. During stirring in the pouring stage degassing tablet (Hexa-Chloro-Ethene) is added to remove the slag and gas in the molten state. The stirrer speed is maintained at 550-650 rpm and stirring duration of 5 min is maintained. The melt is solidified in the crucible and the casting was removed after solidification.

B. Heat Treatment Process

The heat treatment (Age hardening) process consists of two steps like solutionizing and aging.

C. Solutionizing Heat Treatment

The cast was cut into slabs and subjected to heat treatment process, where the respective samples of the composite are taken and put into the furnace at a temperature 550 °C for duration of 2 hours and quenched in water to form supersaturated phase [6].

D. Aging Treatment

The quenched specimens are isothermally held at 150 and 200°C for different time durations [7]. The specimens are removed from the furnace at an interval of every 30 min and quenched in water. Hardness number (VHN) was noted for all specimens. The experiment was repeated till sufficient points are obtained to plot the hardness distribution curve at two different temperatures with respect to time interval. The graphs are analyzed to get the peak hardness values at these two temperatures.

E. Vickers Hardness Test

Vickers Hardness apparatus was used to determine the hardness of the composites fabricated with 2% silicon carbide and 2 & 4% alumina & with aging at 150 and 200°C. Three trials are taken for each specimen at different locations. All the possible errors during experimentation are eliminated. Finally, the average of three trials is recorded as hardness [8], [9].

F. Wear Test

Standard Pin-On-Disc wear testing equipment was used for wear test in dry sliding wear mode. The parameters on which the test was conducted are as follows:

- Load = 1 kg
- Speed = 200 rpm
- Track Distance = 60 mm

Initially weight of specimen was recorded. The experiment was conducted at a dead weight of 1 kg. The speed adjusted to 200 rpm and the tracking diameter set to 60 mm. Then the specimen was run for 15 minutes on the Pin-On-Disc equipment and the readings are taken for every 15 minutes interval [10], [11].

Fig. 3 Wear testing (Pin-On-Disc) equipment

III. Results and Discussions

Results of the hardness tests are provided in Table II.

Fig. 4 shows the graphical representation of hardness distribution with aging temperature during different aging durations. There is an increase in hardness of the specimen, reaching maximum and then decreasing. Also hardness of the heat treated (peak aged) specimen is very high compared to as-cast specimen. It is seen that for composite of 2% alumina and 2% SiC, maximum hardness of 57.1 VHN is obtained for a duration of 5 and half hours at 150°C and 56.9 VHN for samples exposed for a duration of 2 and half hours at 200°C.

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At higher temperature (200°C) there is a small decrease in hardness but the composite gets hardened to the maximum extent within a short period of time.

TABLE II
HARDNESS VALUES WITH AND WITHOUT HEAT TREATMENT FOR DIFFERENT DURATIONS

Condition of the specimen	Vickers Hardness Number (VHN)			
	2 % alumina and 2 % SiC		4 % alumina and 2 % SiC	
	150 °C	200 °C	150 °C	200 °C
Without heat treatment	49.96	49.9	56.1	56.1
After solutionizing at 550 °C for 2 hours	41.5	41.5	54.7	54.7
Aging: 1 h	50.12	50.4	56.5	56.5
1.5 h	50.23	51.5	56.8	57.9
2 h	50.80	52.1	57.0	61.3
2.5h	51.10	56.9	57.2	58.7
3 h	51.50	52.3	57.9	51.7
3. 5 h	51.90	46.8	60.8	48.5
4 h	52.30	46.3	64.6	46.8
4.5 h	53.3	45.7	57.3	45.4
5 h	55.7	43.6	50.9	43.8
5.5 h	57.1	42.3	46.7	42.6
6 h	51.3	41	43.2	41.5
6.5 h	46.2	39.8	40.6	40.1

TABLE III
WEAR TEST RESULTS WITHOUT HEAT TREATMENT

Time (min)	2 % alumina and 2 % SiC			4 % alumina and 2 % SiC		
	Weight (g)	Weight loss (g)	Cumulative weight loss (g)	Weight (g)	Weight loss (g)	Cumulative weight loss (g)
0	4.412	0	0	3.96	0	0
15	4.405	0.007	0.007	3.956	0.004	0.004
30	4.399	0.006	0.013	3.952	0.004	0.008
45	4.393	0.006	0.019	3.947	0.005	0.013
60	4.386	0.007	0.026	3.943	0.004	0.017
75	4.378	0.008	0.034	3.937	0.006	0.023

TABLE IV
WEAR TEST RESULTS AT 150°C

Time (min)	2 % alumina and 2 % SiC			4 % alumina and 2 % SiC		
	Weight (g)	Weight loss (g)	Cumulative weight loss (g)	Weight (g)	Weight loss (g)	Cumulative weight loss (g)
0	3.864	0	0	4.158	0	0
15	3.862	0.002	0.002	4.157	0.001	0.001
30	3.86	0.002	0.004	4.155	0.002	0.003
45	3.859	0.001	0.005	4.154	0.001	0.004
60	3.857	0.002	0.007	4.153	0.001	0..005
75	3.854	0.003	0.010	4.151	0.002	0.007

For the composite of 4% alumina and 2% SiC, peak hardness of 64.6 VHN is obtained at 150°C at the end of 4 hours and 61.3 VHN at 200°C at the end of 2 hours. Here again higher hardness is obtained at lower temperature than at higher temperature. But the peak hardness obtained at higher temperature is in much lower time duration. Again, it is seen that there is a marginal increase in hardness for the composite with 4% alumina and 2% SiC than the composite with 2% alumina and 4% SiC. Addition of 4 % alumina to the matrix increases the hardness to higher values. Increase in weight percent of alumina increases the peak hardness values with lower aging duration compared to lower percent alumina.

Results of the wear test are given in Tables III-V.

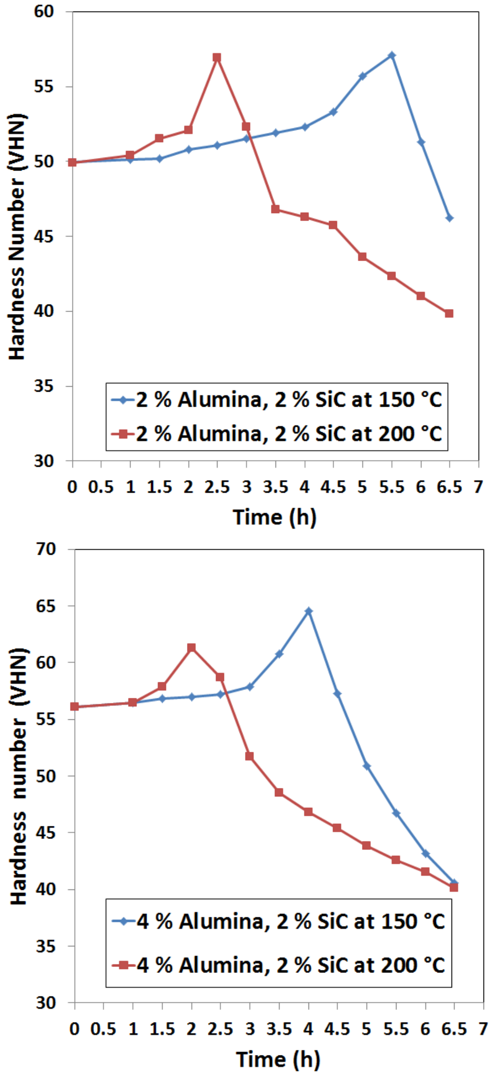
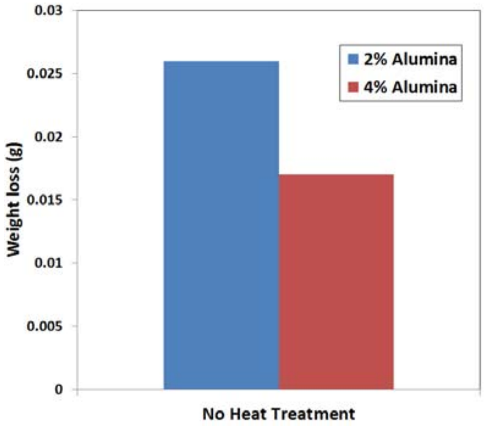


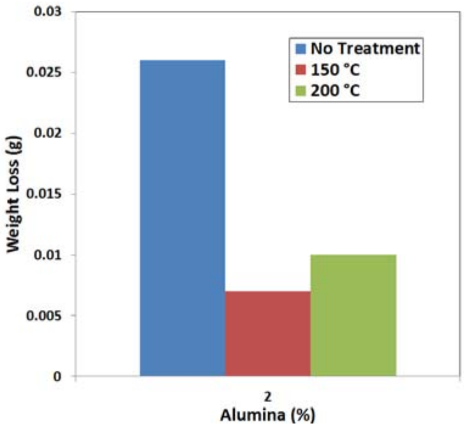
Fig. 4 Plot of hardness number v/s time in hours

TABLE V
WEAR TEST RESULTS AT 200°C

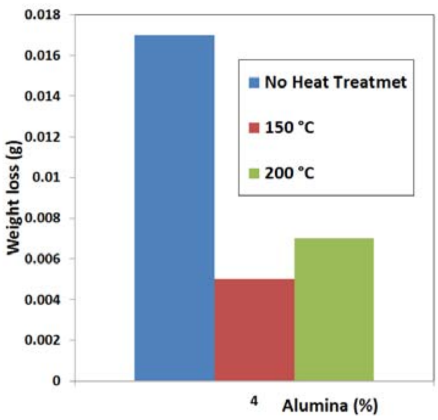
Time (min)	2 % alumina and 2 % SiC			4 % alumina and 2 % SiC		
	Weight (g)	Weight loss (g)	Cumulative weight loss (g)	Weight (g)	Weight loss (g)	Cumulative weight loss (g)
0	3.864	0	0	4.158	0	0
15	3.861	0.003	0.003	4.156	0.002	0.002
30	3.858	0.003	0.006	4.154	0.002	0.004
45	3.856	0.002	0.008	4.153	0.001	0.005
60	3.854	0.002	0.010	4.151	0.002	0.007
75	3.851	0.003	0.013	4.148	0.003	0.010



(a)



(b)



(c)

Fig. 5 Plot of weight loss v/s alumina (%) for (a) No heat treatment (b) 2 % alumina, 2 % SiC; (c) 4 % alumina, 2 % SiC

From Figs. 5 and 6, it is clear that the wear rate is higher for the composite when it is not subjected to heat treatment. In addition, the composite with 4% alumina displays lower wear rate compared to the other with 2% alumina.

Both the composites display lower wear rates at 150 °C than at 200°C. But the composite with 4 % alumina shows lesser wear than with 2% alumina at all the conditions. Also increase in Alumina as reinforcement decreases wear at lower aging temperatures whereas increases wear at higher aging temperatures. Hence, heat treatment variables have considerable impact on wear properties of both the composites considered.

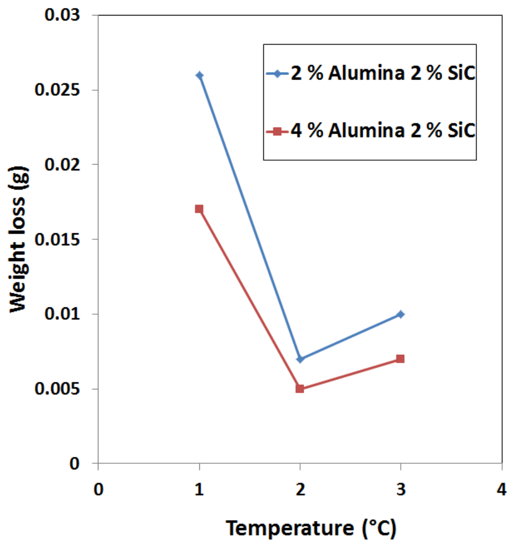


Fig. 6 Graph of weight loss v/s heat treatment temperature

A. Microstructure Study

Microstructure recorded (Fig. 7) by inverted metallurgical microscope at 100X shows equiaxial grains in alloy and good dispersion of reinforcements in the matrix for the composites. There is no indication of agglomeration of reinforcements and porosity in the microstructure recorded.

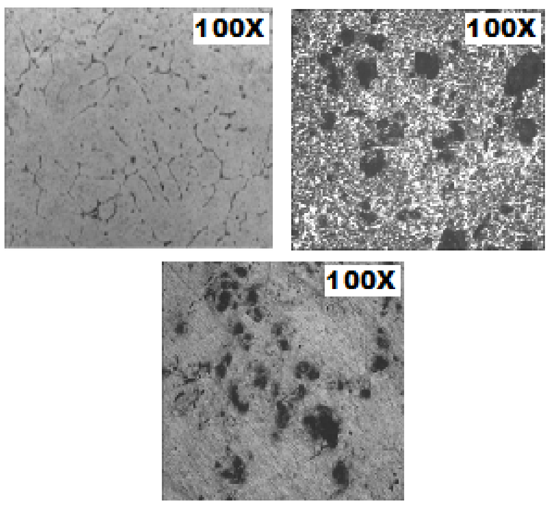


Fig. 7 Optical micrographs of (a) Unreinforced Al6061 alloy (b) Al6061-SiC (2%)-alumina (2%), (c) Al6061-SiC (2%)-alumina (4%) at 100X

IV. Conclusions

The specimens are successfully cast by stir casting method and subjected to age hardening treatment. The heat treatment and the tests performed are successful and the following conclusions are drawn:

Lower the aging temperature, higher is the peak hardness value. Higher the aging temperature, shorter is the peak aging duration for the peak hardness. Higher the weight percent of the alumina, higher is the peak hardness value. Lower the weight percent of alumina longer is the peak aging duration. Wear resistance of the composite is better when aged at lower temperature. Both wear resistance and hardness are better in heat treated condition compared to as-cast condition. Microstructure recorded shows good dispersion of reinforcements in the matrix without agglomeration and porosity.

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