EFFECT OF FLYASH AND CENOSPHERE WITH LM6 ON WEAR AND MECHANICAL PROPERTIES

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Abstract This work pertains to the experimental investigation of flyash and Cenosphere with LM6 on wear and mechanical properties accompanied with a review on AMC (Aluminium matrix composites). In the present investigation, processing and preparation of Metal Matrix Composite (MMC) Material was carried out by stir cast technique. LM6-Aluminium alloy having silicon content of 10 to 12% was selected as the base matrix. Low density particulates viz., Cenosphere and Flyash material was used as reinforced agents. The MMC materials were prepared at two different volume concentrations of particulate in the matrix. The LM6 alloy was melted in a crucible-heating furnace and the particulates were mixed to the liquid metal, while the liquid metal was kept under stirring conditions. The mixing was continued for various lengths of time to ensure thorough mixing. The metal was then poured into a cylindrical metal mould. Specimen were prepared from these castings and evaluated for mechanical, friction and wear properties. The dispersion of particulate in the matrix was observed under a high-resolution microscope. The results have indicated that the cenosphere added MMCs have shown improved wear resistance property compared to that of matrix alloy. However, the mechanical properties viz., tensile strength and ductility were slightly affected by the reinforcements.

Keywords: Flyash, Cenosphere, Aluminium Matrix Composites

INTRODUCTION

Aluminium matrix composites (AMC) have attracted the attention of scientists due to their improved stiffness, strength and wear resistance in addition to high temperature capability [Rohatgi, (1993)]. However, the industrial development of these materials has remained limited owing to high cost of fibrous reinforcements and problems related to high temperature processing.

Among the different grades of Aluminium most suitable for castings are found to be LM series [Girot et. al. (1987)]. Presently, LM6 finds increasing importance in Automobile industries because of its excellent wear resistant properties. Keeping this in view LM6 material is chosen for our purpose, which is pressure die cast, available in the form of Billets. Thermal power plants in India mainly follow wet disposal technique wherein the ash is mixed with water (5-10% solids by weight and sluiced to the ash pond. Since the ash contains a fair amount of cenospheres (low density material), they are often seen floating as ash ponds, which can be collected easily. Cenospheres are most versatile cost reducing, filter materials which are widely used for various end applications., These cenospheres have density of about 0.4 gm/cm^3. most of the cenospheres have a small gas bubble (nitrogen or carbon dioxide in the centre and are termed floaters. They have a specific gravity of 0.3 gm/cc to 0.7 gm/cc as compared to the specific gravity of 2 to 2.7 gm/cc of commercially used filters. Typical physical and chemical properties of cenospheres and commercially available glass spheres is given the Table-1.The utilisation of cenospheres as fillers imparts certain extraordinary characteristics such as low density, thermal insulation, excellent electrical properties, low slump and non-sagging properties, workability, heat stability, corrosion and chemical resistance, etc [Lavernia, (1993)].

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Table –1 Chemical Analysis of Cenosphere Fly Ash

Constituents	Percentage
Silica	54-55
Alumina	25-30.9
Lime	7-10
Magnesia	2-3
Sodium Oxide	0-1
Pottassium Oxide	1-3
Titania	0.7-1.2
Iron Oxide	0.45-1.8
Sulpher	1.2-1.25
Carbon	-----

Fly Ash Composites

Cenosphere fly ash is a primarily by product separated from flyash by suitable thermal treatment/chemical separation. Particles are very light material with density in the range of 0.4 – 0.6 g/cm^3. Loosely packed beds of cenosphere fly ash (above 55 vol. % in the composite) were successfully infiltrated by molten aluminium under pressure in the range of 0.3 – 0.7 Mpa. The density of infiltrated aluminium – fly ash composite (1.4 g/cm^3) us roughly half of the density of aluminium (2.68 g/cm^3) making it a very attractive low density low cost material for automotive application. The density, hardness and compressive strength were found to vary along the length of the composite with the position in the composite. The portion with high density (bottom part) exhibits higher hardness and compressive strength.

Recently fly ash from coal combustion has been combined with aluminium alloys using foundry process to produce a class of MMCs called Ash alloys. Ash alloys offer the advantages of reducing disposal volumes of the electric utility industry, providing a high-value-added use of fly ash, and at the same time generate a class of new materials with improved properties at a cost. Addition of fly ash particles results in a decrease in the density, increase in modulus, and increase in abrasion resistance of aluminium alloys. Literature study carried out on ash-alloy MMCs shows that the stir casting technique has been successfully used to synthesize aluminium alloy – fly ash composites. However, one of the recurring problems in liquid metallurgy technique of synthesizing composities and subsequent casting is lack of uniformity of distribution of fly ash particles throughout the casting volume. On the micro scale, fly ash particles tent to segregate in the interdendrite regions due to lack of nucleation of **alpha** – aluminium dendrites on the surface of fly ash and the pushing of flyash particles by the growing alpha – aluminium dendrites during solidification. Similar pushing of reinforcement particle is observed during solidification of Al-SiC and Al-Al_2O_3 composites [Rohatgi et. al. (1993)].

Basically fly ash particles are lighter than molten aluminium. Density varies from 0.4 to 2.3 g/cm^3 depending upon whether they are solid particles (precipitator ash 2.0 – 2.3 g/cm^3) or hollow particles (cenosphere 0.4 – 0.8 g/cm^3). In addition, fly ash particles are not easy to mix in aluminium alloy because, being ceramic in nature. Aluminium wiil not readily wet the particles. Both the lightness and the non-wetting nature of the fly ash particles tent to cause rejection and flotation of fly ash in aluminium melt. This results in a non-homogeneous particle distribution in the composite.

Thus, in stir casting, the experimental process variable must be closely controlled to combat the tendency of fly ash particles to float, segregate and become a part of the aluminium oxide slag that forms invariable in the aluminium melting process. In addition it is difficult to introduce above 25% volume fraction of flyash using stir casting techniques. The tendency of flyash to segregate in the casting can be reduced by the use of pressure infiltration technique. The use of flyash preforms in synthesizing composite by liquid metallurgy route will significantly help in producing composites with higher volume fractions of flyash which better distribution of flyash after solidification.

Processing Techniques of MMC

A number of composite fabrication techniques have been developed that can be placed into four broad categories. These are : (i) liquid metallurgy, (ii) powder metallurgical techniques, (iii) diffusion bonding of filament and foils, and (iv) vapour phase infiltration. The liquid metallurgy techniques include unidirectional solidifications to produce directionally alligned MMCs, suspension of reinforcement in melts followed by solidification, compocasting, squeeze casting, spray casting, and pressure infiltration. The liquid metallurgy techniques are the least expensive of all, and the multi-step diffusion bonding techniques may be the most expensive.

Reinforcing phase for MMCs fall into three important categories (I) continuous and discontinuous filament, (ii) whiskers, and (iii) particulate. The important improvements in mechanical properties are obtained from filaments in the direction of their alignment, with whiskers and particulates offering lesser strength with greater isotropy.

From a technological standpoint of property-performance relationship, the interface between the matrix and the reinforcing phase (fibre or particle) is of primary importance. Processing of MMCs sometimes allows tailoring of the interface between the matrix and the fibre in order to meet specific property –

performance requirements. The cost of producing cast MMCs has come down rapidly, especially with the use of low cost particulate reinforcement like graphite, alumina and silicon carbide. Low cost, large tonnage composites with SiC, Al_2O_3 and graphite particle are now commercially available.

The literature survey conducted on aluminium MMCs have indicated that there is a lot of scope for improvement of Aluminium composites especially LM6 which has wide application in engineering industry and suitable for casting components.

In the present study, Aluminium (LM6) has been selected as the base material keeping in view of increased hardness, wear resistance and abundant usage in automotive industries. Low density particulates, viz., Cenosphere and Flyash were selected as the reinforcements. The weight percentage of particulates was varied at two different levels in order to study the variation in mechanical and wear properties.

EXPERIMETNATION

In the present study infiltration of cenosphere flyash particles with aluminium alloy were done using stir cast techniques.

An attempt has been made to prepare Al alloy composite using vortex method. Impeller mixing and bottom discharge casting technique is chosen in the current study. This is based on the principle of preparing homogeneous slurry of base metal and the slag by rigorous mixing. SiC, flyash, cenosphere are added at suitable temperature. The experimental setup consists of a crucible heating muffle furnace of rectangular construction. The top cover of the furnace was designed to accommodate stirring support mechanism. Stainless steel stirrer having 4 Blades with belt driven mechanism mounted on ball and thrust bearing was adopted for the purpose of stirring in the process.

Preparation of MMCs

Initially, the charge material viz., LM6 base material of required quantity was cut from the billet castings. The precautions were taken prior to melting process to ensure the safety of the unit. The charge material was put inside the stainless steel crucible and a temperature of 690^0 C was set in the temperature contoller. Melting process was closely monitored wearing safety glasses through the opening provided in the top lid. The melting point was observed by the production of bubbles in the crucible. In order to ensure complete melting of LM6 charge material, the temperature was held at same temperature for about 30 minutes [Rack, (1988)] and its speed was increased slowly through the dimmer stat. The stirrer speed increased till proper vortex is observed.

Weighted proportion of particulates, which were pre-heated to 120 degree centigrade, were added gradually into the liquid metal using the long quartz funnel such that it reaches bottom surface of the vortex and gets mixed up thoroughly. Stirring was continued for 30 minutes to get a homogeneous mixture of composite. Furnace was switched off and the molten metal was poured into cylindrical and pencil moulds which were pre-heated to 320^0 C. Pre-heating was done to reduce chilling effect at the surface of the mould. The arrangement was allowed to settle to room temperature.

Preparation of Specimens

Specimens were cut from the castings. The dimensions of various specimen machined for tests as per ASTM standards. The casting obtained in the pencil mould was 85 mm long and 15 mm in diameter. The casting for tensile and wear test specimen were 80 mm long and 14 mm in diameter while 160 mm long and 30 mm in diameter for rubber abrasion specimens. These were then machined to the required standard sizes as per ASTM standard as shown Fig. 1. Tensile test, wear test (pin on disk), rubber wheel abrasion test, microstructural analysis and chemical analysis were conducted on the specimens.

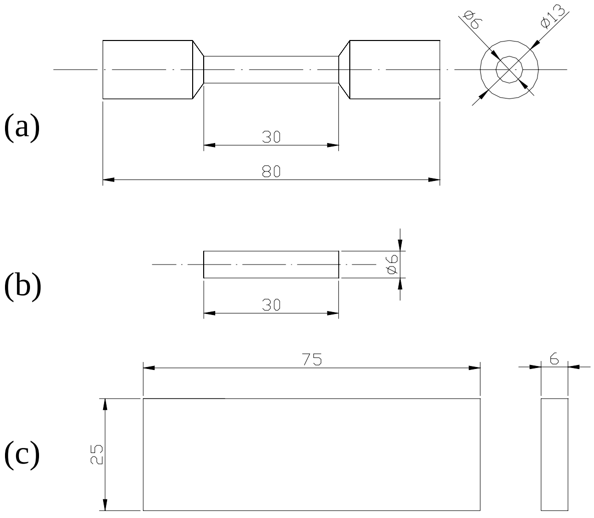

Fig. 1 Final sizes of specimens used in various tests. (a) tensile test specimen (b) wear test specimen (c) rubber wheel abrasion test specimen.

RESULTS AND DISCUSSIONS

Chemical Analysis of the Base matrix alloy (LM6) used in analysed in Optical Emission Spectrometer and the results are given in the table 2.

Table –2 Result of Chemical Analysis of base Metal Aluminium (LM6)

Chemical Element	Percentage Composition	Chemical Element	Percentage Composition
Fe 3	0.609	Cu1	0.035
Si2	13.86	Mg1	0.228
Mn1	0.058	Pb1	0.016
Cr1	0.007	Sn1	0.02
Ni3	0.002	Ti	0.005
Al2	84.9	Zn	0.02

Tensile Test

The tensile test was conducted as per the guidelines of ASTM E-8. In the universal testing machine, the uniaxial tensile load at a uniform rate was applied on to the test specimen through the actuator, till the specimen failed. The results are shown in Table 3. All the values reported in table 3 are average of two tensile specimen tested. It has been observed that there is slight reduction in the ultimate tensile strength of MMC material (less than 6 %) compared to the base matrix alloy. However, the percentage elongation remains unaffected because of the particulate infiltration in the matrix [Majumdar et. al., (1984)].

Wear Test (Pin on Disk)

Wear test using pin-on-disc machine to measure the relative friction and wear properties of different alloys under test conditions were carried out as specified by ASTM G:99–95a. In this test, the sliding wear and frictional properties of sample pin against a hard disc were measured. The sliding occurs between the stationary pin and a counter surface viz., hard steel disc of hardness 58 to 62 HRC. The pin sample is surface finished (400 emery or better) and weighed in a high precision digital balance to record its initial weight after cleaning (ultrasonically cleaned for metallic materials). The hard steel disc and the sample pin are mounted in their positions respectively. The normal load to the pin is applied through a pivoted loading lever to which a pan is pulled down by string and dead weights are placed in the pan as per the test requirements. With the loading lever slightly lifted, the motor of the machine is started and the rpm of the disc is controlled to the desired value. When all the conditions like wear track, rpm, and load are satisfactory, the loading arm is engaged. Under load, the speed of the disc is immediately adjusted to the desired value to commence the test. The time spent in adjusting the speed of disc under load (approx. 10-15 sec) is not accounted against test duration. There is a provision of direct measurement of the height loss of pin sample using LVDT (Linear Variable Differential Transducer). The frictional force is measured using a 20 KG capacity load cell, which is positioned normal to the specimen holder in the plane of the hard steel disc. The friction force is measured under conditions of steady state. Provision also exists in this set up to feed the outputs of the frictional load cell and LVDT to a strip chart XY recorder to study the variation with respect to time.

The test is conducted at a constant rpm (i.e., constant sliding speed) of the hard disc with fixed normal load, under laboratory conditions. The test parameters employed were, normal load: 2.6 Kg, speed of the disc: 200 rpm, and duration of the test: 20 min. Quantities measured were height loss of the specimen in microns and Coefficient of friction.

The results of wear test are tabulated in table 4. The cenosphere added MMCs have shown improved wear resistance compared to that of base matrix alloy. The increased wear resistance, i.e. lower height loss in the specimen during the test was attributed by the decrease in frictional load during the test. In the case of fly ash added samples, there is only marginal increase in the wear resistance property.

Rubber Wheel Abrasion Test

This test covers laboratory procedures for determining the resistance of metallic polymer and ceramic materials to scratching abrasion by means of dry sand/rubber wheel test. The results obtained in this test depend upon abrasive characteristics like particle shape and distribution, rubber wheel conditions and hardness, material homogeneity, uniformity in dynamic loading during the abrasion test etc. The equipment consists of a wheel with rubber beading around the circumferential periphery of the wheel as shown in the photograph. The Specimen was suitably held against a rotating wheel. Pressure was applied to the wheel by loads suspended over the lever arrangement. At the top of the equipment an abrasive reservoir was provided.

The intent of this test was to produce data that would aid in relative ranking of the materials based on their resistance to scratching abrasion under specified set of test conditions. The details of the test are as given under.

Dimensions of specimen	75 x 25 x 6 mm
Abrasive use	Silica sand AFS 50
Normal load	4.5 kg
Mass flow rate	0.25 Kg / min.
RPM of rubber wheel	200
Duration	10 min.

The results of the rubber wheel test obtained are tabulated in table 5. In the case of Rubber Wheel Abrasion Test, the improvement in the performance of MMC material was not quite clearly visible as the conditions were severe. However, no attempts were made in this study to change the test conditions so as to see the clear distinction in the performance.

Microstructure Analysis

The microstructures of the casted MMCs was studied using microscope shown in the photograph. The specimen preparation for the metallographic study consists of rough grinding, intermediate and fine grinding and fine polishing. In rough grinding, the flat surface on the specimen was obtained by grinding on a motor driven coarse and fine emery belt. Intermediate and fine grinding were carried out using water-proof emery papers of 400 grit (particle size 25 microns) and 600 grit (particle size 17 microns). Water-proof emery paper of 400 grit was laid over a flat glass plate and a continuous uniform flow of water from a tap was maintained on the surface of the emery paper to provide flushing action and carry away the particulates from the surface. The final stage was the fine polishing. In this stage a small quantity of diamond paste (particle size 1 micron) was placed on the cloth covered table of the rotating polishing wheel. Kerosene was used as a lubricant. The specimen was polished by holding it against the rotating wheel and then slowly turning it often until all the previous scratches were removed.

Table –3 Results of tensile test on various MMC composites

Melt No.	Composition	% Vol. Particulate **	Dia mm	GL in mm	FL in mm	Max. Load in Kgs.	% Elongation	Max. stress Kgf/mm^2
1.	LM6		6.5	20	21.8	746		22.5
			6.54	20	20.8	627		18.7
2.	LM6 + F.A	2	6.2	20	21.16	540	5.8	17.87
	1000 + 10.2		6.32	20	21.4	480	7	15.3
3.	LM6 + CS	6	6	20	20.7	440	3.5	15.35
	600 + 7.995		6.04	20	20.4	440	2	15.35
`4.	LM6 + CS	12	14.2	20	20.8	940	4	12.319 *
	600 + 16							

* Failed at lower load due to the presence of blow hole within the guage length.

** % of Volume indicates particulate % w.r.t. base metal.

FA= Flyash CS= Cenosphere

Table –4 Results of Wear Test (Pin on disc)

Melt No	Composition In grams	Sample No.	% Volume of particulates*	Height Loss In microns	Frictional Force In Newtons
1	LM6(un alloyed)			118	8.5
2	LM6 + FA	1	1	126	9.5 – 10.3
	1000 + 5.2	2			
3	LM6 + FA	1	2	94	8.5 – 9.5
	1000 + 10.2				
4	LM6 + CS	1	6	94	9.3 – 10.5
	600 + 8.7	2		94	10.5 – 14.4
5	LM6 + CS	1	12	82	9.3 – 10.5
	600 + 16	2		81.5	10.5 - 1

* % of Volume indicates particulate percentage with respect to base metal.

CS = Cenoshphere FA = Fly ash

Table –5 Results of Rubber wheel abrasion test

Melt No.	Composites	Sample No.	% Volume	Initial wt. in gms.	Final wt. In gms	Wt. Lost
1	LM6	1		29.8918	29.3480	0.5438
	(Unalloyed)	2		28.1190	27.837	0.282
2	LM6 + FA	1	1	29.3395	29.0725	0.2670
	(1000 + 5.2	2		29.0592	28.0592	0.2601
3	LM6 + FA	1		28.9221	28.6423	0.2798
	(1000 + 10.2)	2	2	29.0167	28.7437	0.2730
4	LM6 + CS	1		29.9187	29.6491	0.2696
	(1100 + 14.5)	2	6	29.1677	28.9012	0.2666

Then the specimen was washed with soap water and dried with alcohol. The specimens were dried using portable heater.

Photographs (a) to (e) in Fig. 2 show the polished sections of as cast specimen of LM6 alloy and particulate added matrix alloy (MMC). Both the base matrix alloy and he MMC have no visible porosity, small dendrite arm spacing due to rapid solidification in the steel mould. In addition, the MMC materials has a fairly uniform dispersion of particulates with clean interfaces between the particles and the matrix. In the case of MMCs added with cenosphere, the particles were near spherical in shape, which are clearly different from the samples added with fly ash particles. No agglomeration of particles were seen in the sample tried.

CONCLUSIONS

Effect of flyash and cenosphere with LM6 alloy has been studied and the mechanical properties of the alloy have been analysed. The addition cenosphere to aluminium base alloy is found to result in an increase in the adhesive wear resistance property, whereas, the addition of flyash does not show any improvement in the wear resistance. A slight decrease in the tensile strength is reported with the inclusion of cenosphere and flyash in various proportions. The rubber wheel abrasion test did not indicate the effect of particulates in the wear performance. The ductility of MMC materials is shown unaffected by the particulate infiltration. Finally, the coefficient of friction of base alloy was slightly reduced especially in case of cenosphere added MMCs.

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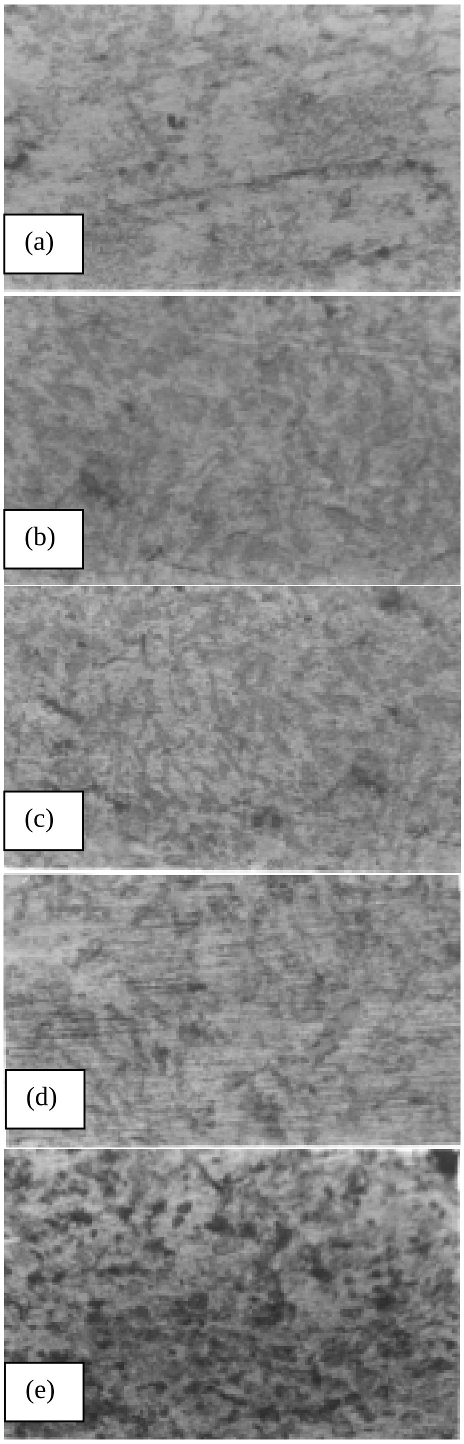

Fig. 2 Microphotographs of alloys. (a) LM6 base Matrix alloy (b) Flyash composite (5 gms) 1% (c) Flyash composite (10.2 gms) 2% (d) Cenosphere Composite (8 gms) 6% (e) Cenosphere Composite (16 gms) 12%, (Magnification 800X).