

Hardness, Tribology and Microstructural studies on Aluminium – Flyash metal Matrix Composites

K A R Kumar^{1*}, K Balamurugan² and D Gnanaraj³

¹Department of Mechanical Engineering, Vivekanandha Engineering College for Women, Sankari West, Tamilnadu, India

²Department of Mechanical Engineering, Institute of Road and Transport Technology, Erode

³Department of Mechanical Engineering, Vivekanandha College of Technology for Women, Thiruchengodu

Received 25 March 2013; revised 20 June 2014; accepted 28 December 2014

Flyash reinforced aluminium metal matrix composites (Al-MMC) have been synthesized by stir casting method and was fabricated by sand casting in to required sizes. Flyash content with various compositions (9, 14 and 19 wt %) was used with aluminium metal by adding magnesium content 1% for the present investigations. Flyash content with various compositions of Al-MMCs were tested for its hardness using Vicker's microhardness tester. It was found that the hardness increases with increase in flyash content. The surface morphology of the samples were investigated by scanning electron microscope (SEM) and optical microscopic techniques. Tribological properties such as coefficient of friction and wear rate for various flyash compositions were obtained and the results were discussed in detail.

Keywords: Flyash, Metal matrix composites, Microhardness, Wear analysis.

Introduction

Metal matrix composites (MMCs) are materials results in the combination of two or more materials in which at least one of which is a metal to enhance physical properties¹⁻³. MMCs tend to have higher strength/density and stiffness density ratios, compared to monolithic metals. They also tend to perform better at higher temperatures, compared to polymer matrix composites. It is well known that the particle-reinforced metal matrix composites have excellent mechanical properties and other tribological properties⁴⁻⁶. Light weight metal matrix composites (especially aluminium composites) have the potential to be used as replacements for steel and cast irons components⁷⁻⁸. Among these materials, metal matrix composites (MMCs) have been developed to a level of commercial production in automotive, electronic packaging, aerospace, and recreation equipment industries⁹⁻¹⁰. Aluminum alloy MMCs is one of the best materials to substitute the conventional structural alloys¹¹⁻¹². More recently developed MMCs, especially cast aluminum-fly ash composites, have the potential of being cost effective, ultra light composites, with significant applications¹³⁻¹⁴. Fly ash, an industrial solid waste by-product, is produced

during the combustion of coal by thermal power plants. Due to the fact that the cenosphere fly ash has a lower density, it was selected for this research in order to produce materials with the lowest possible densities. A wide variety of fabrication techniques have been explored for Al MMCs, which include vapour state methods, liquid phase methods (infiltration of preforms, rheocasting/thixoforming, melt stirring and squeeze casting) and solid state methods (powder forming and diffusion bonding)¹⁵⁻¹⁸. The present paper is focused to investigate the flyash effect which is mixed in the required composition in the molten state which is then further fabricated to desired shapes and sizes by sand casting method. The mechanical and tribological behavior of Aluminium metal matrix composites was investigated in detail.

Materials and Methods

Sample preparation by sand casting method

In the present investigation sand casting is used which involves pouring molten metal into a sand mold. Many metal casters prefer using sand casting over many of the other forms of processes because it's cheap and the sand used is readily available.

In sand casting, a mould is created inside the frame of the mould (flask) as shown in the figure 1 which are filled with sand. The top and the bottom of the

* Author for correspondence
E-mail: karameshkumar77@gmail.com

mould (cope and drag) are tightly packed so, that the molten metal does not creep outside the parting line. Green sand is a type of casting sand that is widely used to retain the shape of the mold is far better than normal sand. Green sand usually contains bentonite clay, sand, and water. One of the benefits of using bentonite in green sand is that it makes the sand more permeable which allows more gas to escape. Care should be taken such that too much water can ruin the mold and possibly destroy it while too little water will create a poor casting. After the sand is packed, the pattern or original is removed carefully. Then a series of channels or gates, to carry the molten metal to the cavity, is incorporated. Molten metal is poured through the pouring cup which flows through the vertical channel called sprue. The runner guides the molten metal in to the core. The vents provided allows the air and the gasses that is formed during the molten state. After the required time the mold is allowed to cool. The metal caster is then shaken out after which the required forms of samples were prepared.

Experimental Sample compositions used in the present investigation

Aluminium, flyash and magnesium with different compositions of 90:9:1, 85:14:1 and 80:19:1 were mixed by the stir casting process and were named as Sample-1, Sample-2 and Sample-3 respectively. Standard flyash particles were used for the present study which was procured from thermal power plant from SALEM, India, was used in the present investigation. Sand casting process was adopted to fabricate the samples in to require sized which was then used for mechanical and tribological analysis. In

all the samples, the magnesium content was added small in quantity and was maintained at 1 % to increase the wettability of flyash with the metal matrix. The flyash content is increased, thus by decreasing the aluminium content to ascertain the variation in tribological properties. The mechanical properties of the matrix and the reinforcement particles are shown in Table 1.

Experimental evaluation the composites

The aluminium-flyash metal matrix composites were subjected to hardness test. To evaluate the Vicker's hardness number, the samples were subjected to static indentation test at room temperature using MITUTOYO (MVK-H11) hardness tester fitted with Vicker's diamond pyramidal indenter. Optical microscope patterns were also measured for the samples simultaneously. JEOL (JSM – 6390LV Scanning Electron Microscope was used to observed the microstructural pattern of the flyash and the samples which is under investigation. Tribological studies were carried out using Wear & Friction (TR-20LE-PHM 200) set-up by carrying various loads (10 N, 20 N and 30 N) and also simultaneous measurement was carried out by varying the velocity ($V = 1 \text{ m/s}$, 1.5 m/s and 2 m/s) of the sample plates.

Results and discussion

Aluminium-magnesium alloy reinforced with flyash particulate composites were successfully fabricated. The metallurgical, mechanical and tribological behavior of the fabricated flyash aluminum-metal matrix composites used was of ratio 90:9:1, 85:14:1 and 80:19:1 for which they were named as Sample-1, Sample-2 and Sample-3 respectively. In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement material in the matrix alloy must be uniform, the wettability or bonding between these substances should be optimized and the porosity levels need to be minimized⁸.

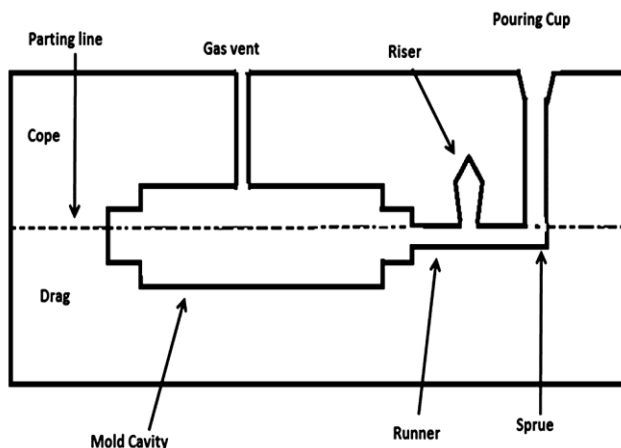


Fig. 1—Mould for the sand casting method used for the present investigations

Table 1—Mechanical properties of the matrix and the reinforcement particles

Properties	Aluminium	Flyash	Magnesium
Density (g.cm^3)	2.70	0.9 – 1.0	1.738
Tensile strength (MPa)	324	-	150 - 250
Coefficient of thermal expansion ($10^{-6}/^\circ\text{C}$)	23.6	-	25.6
Modulus of elasticity (GPa)	68.9	-	42

Hardness profile

Microhardness Measurements Hardness is an important solid state property and plays a vital role in industrial fabrication and hence Vicker's microhardness measurement was carried out for the composites to assess its mechanical strength. Several indentations were made on the surface at different points and the average hardness number (Hv) with respect to the flyash composition is shown in Fig. 2. The effect of weight percentage of flyash on micro hardness shown in the above figure clearly facilitates the increase is hardness number. When the flyash content is increased from 9 to 19 %, (when the flyash content is zero, the hardness number is around 48 which is a well known fact), the hardness increases from 81 to 110. The increase in hardness may be explained on the basis of difference in thermal expansion coefficients of aluminium and flyash. Due to this difference, strains are created during solidification. As this strain increases, the dislocation occurs and during this process flyash particles offer resistance to the propagation of cracks during tensile loading¹⁹⁻²¹.

Microstructure of flyash-AMCs

The composition of the flyash was obtained from the scanning electron microscopy fitted with EXAX measurement and is given in Table 2. Scanning electron microscopic image (not shown in figure) in the SEM image reveals that the flyash particulates are of spheroidal nature. These flyash particles contain both solid spheres (precipitators) and hollow spheres (cenospheres). The purchased flyash was used as they were uniform in nature. The particle size distribution of the flyash composite is shown in Figure 2 (inset). The microstructure depicts the plate-like structure caused solidification which primarily consists of α -Al and Al-Mg intermetallics¹⁹. The common casting defects are not seen in the micrograph which indicates that the samples were homogeneously distributed in the aluminium matrix as composites. During solidification of the melt flyash particles influence the solidification pattern of the semi solid composite melt. Fly ash particles act as a grain nucleation site and the aluminum grains solidify on it. When the percentage of flyash increases, number of nucleation sites also

increases. This homogeneity favors the good mechanical and thermal stability while fabricating these MMC in automobile parts²². The optical microscopic images of the cast Al-MMCs were measured for different flyash compositions. The optical microscopic investigation (figure not shown) reveals the uniform pattern of the surface which is due to the homogeneous flyash distribution in the metal matrix composites. In the present case, we have obtained this homogeneity whereas, several authors have reported for the presence of flyash on the surface of the hardened samples. As the weight percentage of flyash is increased, it increases the surface hardening behavior which inturn reflects on the microhardness measurements²³.

Wear test ratio and surface analysis

Tribological studies such as coefficient of friction and wear rate were measured and calculated by varying the frictional force (10 N, 20 N and 30 N) applied and also the velocity of sample at which it rotates ($V = 1$ m/s, 1.5 m/s and 2 m/s). At first, the velocity of rotating spindle was maintained at 1 m/s (191 RPM) for which the load was varied and the coefficient of friction was calculated for various flyash compositions. As the load increases, the coefficient also increases. The increase in the fly ash content from 9 % to 14 wt % increases the coefficient of friction significantly and due to this increased flyash content failure of the composite under compression occurs and thereby cracks are formed by

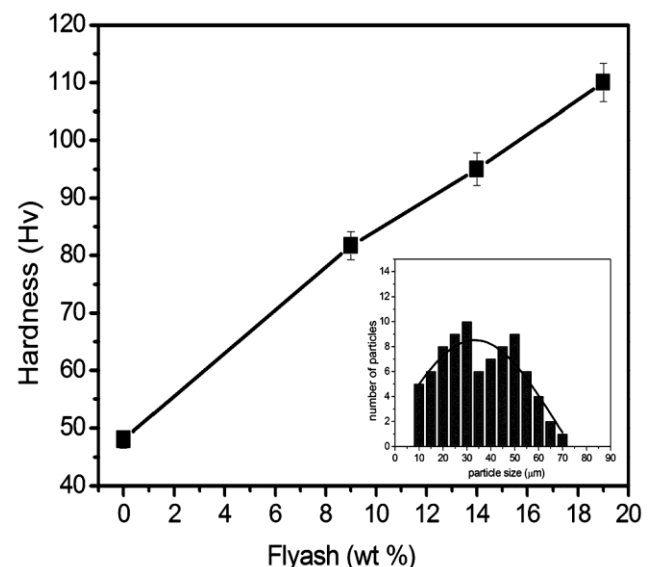


Fig. 2—Hardness number (Hv) Vs flyash composition and (Inset) Particle size distribution of flyash

Table 2—Chemical composition of Class flyash

Chemical compound	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O & K ₂ O
Percentage	54.9	25.8	6.9	8.7	1.8	0.6	0.6

normal void nucleation and growth. The cracks avoid cenospheres, favoring propagation through the matrix, leading to composite fracture.

The SEM images (not shown in figure) were obtained for all the experimental samples after the application of frictional force for different. The flyash sits on the surface lattice of the metal matrix composites which ejects out of the surface after the application of the frictional force. The worn surface features are in accordance with the material loss observed during the tribological results. The SEM photographs exhibit the features and give a relative idea of the damage due to sliding wear which is lower in the case of the increased flyash content. Also from the SEM picture it can be inferred that the material removal in the case of composites appears from the surface only. This is an clear indication that the required composition can be retained even after the application of load at higher velocities in engineering parts²⁵. The velocity of rotating spindle was increased from 1 m/s to 2 m/s (RPM 191 to 382) for which the load was maintained at 10 N for various flyash compositions. The experimental trial was repeated by increasing the load to 20 N and 30 N for which the coefficient of friction was also measured. Non uniform distribution of the flyash particles can be a result of poor stirring of the particles into the metal matrix during the fabrication process. Segregation of particles may also occur during the solidification of the composite, when the Al dendrites solidify first, thus rejecting the particles by the solid-liquid interface, causing segregation of inter-dendritic region. As seen from the SEM image, there were no dendritic particulates there by confirming the uniform distribution of the metal matrix composites. In the present investigation, the sample is a surface of a three-dimensional specimen, and the proper interpretation of the structure measurements is based on stereological rules. Modern stereological procedures emphasize the efficient and unbiased sampling of the specimen, and make use of relatively simple measurement or counting procedures, often using grids placed on the sample, to obtain the desired results. The metric properties of a structure such as the volume fraction, surface area, length, and curvature, can all be determined by the examination of representative section planes. Topological properties such as the number of discrete objects and the connectivity of networks require at a minimum the comparison of two parallel sections. The total area of

the SEM image is determined by counting pixels. Assuming that the images are representative of the specimen, the volume fraction is measured by the area fraction. The settling of the reinforcement particles during melting or during casting is one of the problems encountered in metal matrix composite. This arises as a result of density differences between the reinforcement particles and the matrix alloy melt. The reinforcement distribution is influenced during several stages including (a) distribution in the liquid as a result of mixing, (b) distribution in the liquid after mixing, but before Solidification and (c) redistribution as a result of solidification. Proper dispersion of the particles in a matrix is also affected by pouring rate, pouring temperature and gating systems. The method of the introduction of particles into the matrix melt is one of the most important aspects of the casting process. It helps in dispersing the reinforcement materials in the melt. The vortex method is one of the better known approaches used to create and maintain a good distribution of the reinforcement material in the matrix alloy. In this method, after the matrix material is melted, it is stirred vigorously to form a vortex at the surface of the melt, and the reinforcement material is then introduced at the side of the vortex. The stirring is continued for a few minutes before the slurry is cast¹². Wear rate was measured by varying the frictional force (10 N, 20 N and 30 N) for the velocity of sample were simultaneous increased from $V = 1$ m/s to 2 m/s. As the load was increased, it increases the wear rate which may be accounted for the loss of sample on the surface. The wear rate for different flyash mixture is shown in Figure 3(a). This wear rate plays a major role while fabricating commercial production of engine parts in automotive applications. Tribological properties of coefficient of friction and wear rate were compared with the increase in flyash content. The frictional force was increased from 10 N to 30 N by keeping the velocity of the spindly at 1 m/s is shown in Figure 3(b). As the flyash content increases, the wear rate and coefficient of friction increases at first and then decreases when the weight percentage reaches 19. This shows that at higher composition of 19 %, the wear rate is lowered which favors during fabrication of automobile parts. The wear test for the Al-MMC composites also indicates weight loss of about 0.005, 0.002 and 0.001 g for flyash weight percentage of 9, 14 and 19 respectively for the load of 30 N. This indicates that

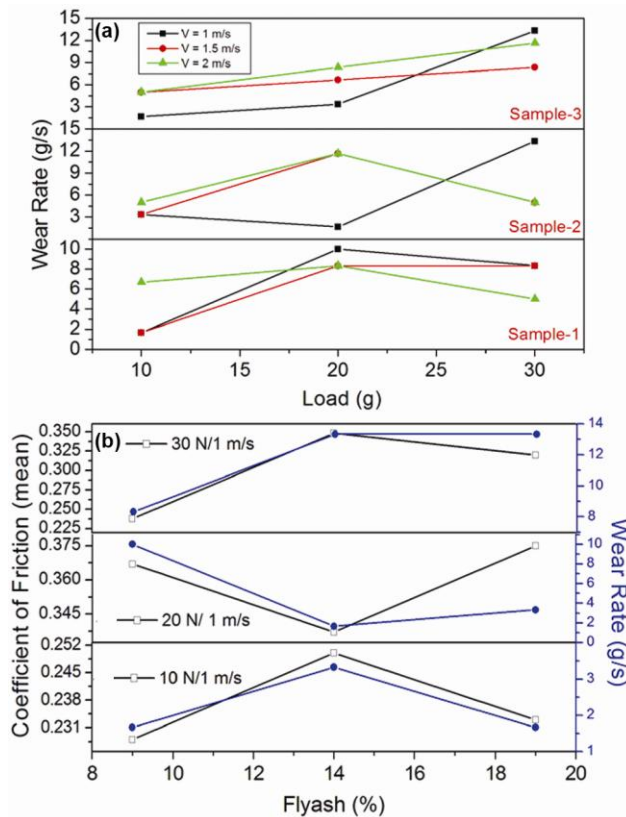


Fig. 3—(a) Wear rate Vs Load at different velocities of the spindle for different flyash compositions ; (b) Coefficient of friction, Wear rate Vs flyash content at different loads

as the flyash composition content increases, the loss of weight of the sample decreases thus confirming the hard nature of the composites. Thus these composites would perform better even at higher speed while making engineering components²⁴.

Conclusions

Sand casting method was successfully applied to develop flyash reinforced aluminium metal matrix composites (Al-MMC). The surface topography was investigated by optical microscopic technique and scanning electron microscopic analysis. These investigations clearly shows the uniform distribution of flyash for various compositions (9, 14 and 19 wt %). Vicker's microhardness measurements were carried out for the above mentioned composition for which higher flyash content metal matrix composites tends to exhibit higher hardness number. Tribological properties such as coefficient of friction and wear rate analysis were carried out and it was found that the composition with higher flyash content proved to be best suited material for component fabrication in terms of highly resistive parts in automobile industries.

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