Preparation and Characterization of Al-Fly Ash Metal Matrix Composite by Stir Casting Method

D. Mohana Rao, Bapi Raju Bandam M.E

Abstract- Composites involve two or more component materials that are generally combined in an attempt to improve material properties such as stiffness, strength, toughness. Composed of a discrete reinforcement & distributed in a continuous phase of matrix, composites are the most successful materials used for recent works in the industry. There has been an increasing interest in composites containing low density and low cost reinforcement. Among various reinforced materials used, fly ash is one of the most inexpensive and low density reinforcement available in large quantities as waste product during combustion of coal in thermal plant. In this paper AL- fly ash composites produced by fly ash were observed with the help of optical microscopy. The hardness, tensile, toughness tests were carried on the composite. Physical and mechanical properties of composite were obtained.

Keywords: composite material, fly ash, metal matrix composites, stir casting.

I. INTRODUCTION

Conventional monolithic materials have limitations in achieving good combination of strength, stiffness, toughness and density. To overcome these shortcomings and to meet the ever increasing demand of modern day technology, composites are most promising materials of recent interest. Metal matrix composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. There has been an increasing interest in composites containing low density and low cost reinforcements. Among various discontinuous dispersoids used, fly ash is one of the most inexpensive and low density reinforcement available in large quantities as solid waste by-product during combustion of coal in thermal power plants. Hence, composites with fly ash as reinforcement are likely to overcome the cost barrier for wide spread applications in automotive and small engine applications. Now a days the particulate reinforced aluminum matrix composite are gaining importance because of their low cost with advantages like isotropic properties and the possibility of secondary processing facilitating fabrication of secondary components. Cast aluminum matrix particle reinforced composites have higher specific strength, specific modulus and good wear resistance as compared to unreinforced alloys .While investigating the opportunity of using fly-ash as reinforcing element in the aluminum melt, observed that the high electrical resistivity, low thermal conductivity and low density of fly-ash may be helpful for making a light weight insulating composites. Among the entire liquid state production routes, stir casting is the simplest and cheapest one.

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The only problem associated with this process is the non uniform distribution of the particulate due to poor wet ability and gravity regulated segregation.

Composite material is a material composed of two or more distinct phases (matrix phase and reinforcing phase) and having bulk properties significantly different from those of any of the constituents. Many of common materials (metals, alloys, doped ceramics and polymers mixed with additives) also have a small amount of dispersed phases in their structures, however they are not considered as composite materials since their properties are similar to those of their base constituents (physical property of steel are similar to those of pure iron) . Favorable properties of composites materials are high stiffness and high strength, low density, high temperature stability, high electrical and thermal conductivity, adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc.

II. EXPERIMENTAL WORK

The matrix material used in the experiment investigation was commercially pure aluminum. The fly ash was collected from SAMKRG, India. The particle size of the fly as received condition lies in the range from (0.1-100 μm).

In the modified two-step stir casting method, Al was charged in to the graphite crucible and the furnace temperature was raised up to liquids temperature (670°C) of Al in order to melt the Al scraps completely. During stirring, preheated fly ash particles were added into the crucible at the side of the vortex. 1.5 wt. % Mg was incorporated to the melt to promote the wetting action between Al matrix and fly ash particles. The melt temperature was brought down to 620°C to achieve the semisolid state. Stirring was done for 5 minutes in the semisolid state. The composite slurry was again reheated to the liquids temperature of 655°C and stirred at 300 rpm for 5 minutes. Finally, the composite slurry was poured into the steel mould to solidify. Argon gas was continuously blown at the rate of 2cc/min into the furnace during the process to minimize the high temperature oxidation problems.

Fig .1. Stir Casting setup

Stir Casting is a liquid state method of composite materials fabrication, in which a

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dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. During the stirring process, the impeller was continuously moved vertically within the slurry at a rate of 2 mm/s by means of stirrer position control unit. Was employed to achieve the sufficient turbulence in the margin area and prevent deposition of the fly ash clusters on the wall surface of the crucible. Reciprocating as well as rotary movement of impeller in the composite slurry during stirring was done using a mechanism. It prevents the settling of wetted fly ash particles and maintains the particles in a state of suspension to enhance the uniform distribution. Stir Casting is characterized by the following features:

- Content of dispersed phase is limited (usually not more than 30 vol. %).
- Distribution of dispersed phase throughout the matrix is not perfectly homogeneous:

1. There are local clouds (clusters) of the dispersed particles (fibers);

2. There may be gravity segregation of the dispersed phase due to a difference in the densities of the dispersed and matrix phase.

- The technology is relatively simple and low cost.

Fig2. Aluminum Matrix Composite

In the present study, aluminium based metal matrix (ALFA) composites containing 5%, 10% and 15 wt. % fly ash particulates were successfully synthesized by stir cast (vortex) method. The matrix materials used in this study was commercial pure aluminium (99.5%). The reinforcement material was fly ash particulates, which were procured from SAMKRG piston rings manufacturing industry, vizianagaram. The chemical composition of the as received fly ash sample was given in Table 1. A 500 grams weight of fly ash sample was taken in a graphite crucible and allowed to preheat in the muffle furnace at 8000 C for 3 hours to find out the loss on ignition and it was found to be 2.4%. Preheated fly ash after cooling to room temperature was washed in distilled water and removed the carbon that creamed up during washing. It was then dried at 1100 C for 48 hours to get rid of water. Dried fly ash has been sieved for 15 minutes using BSS meshes ranging in size from 100 to 350. The results show that more than 70% by weight retained in -200 +350 mesh with an average particle size of 60μm; hence this size was chosen as reinforcement for synthesis of Al- fly ash composites. The colour of fly ash can be tan to dark grey, depending on its chemical and mineral constituents. Tan and light colours are typically associated with high lime content. A brownish colour is typically associated with the iron content. A dark gray to black colour is typically attributed to elevated unburned carbon content. Fly ash colour is usually very consistent for each power plant and coal source. Figure 3 shows the appearance of fly ash before and after heat treatment; from this figure it is evident that after heat treatment (preheat in the muffle furnace at 8000 C for 3 hours) colour was changed from dark grey to brownish due to the departure of unburnt carbon content associated in the as received condition. The figure 3(b) fly ash was used for making of ALFA composites.

TABLE I Chemical components of as received fly ash, wt. %

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	Loss on Ignition
58.41	30.40	8.44	2.75	1.3	1.53	1.0	1.98	2.4

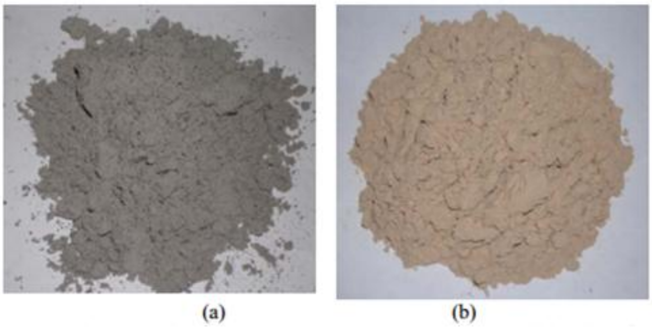

Fig3: The fly ash powder used for synthesis of ALFA composites (a) as received condition (b) After heat treatment condition

III. MICRO STRUCTURAL CHARACTERIZATION

Fly ash is one of the residues generated in the combustion of coal. It is an industrial by-product recovered from the flue gas of coal burning industries. Depending upon the source and makeup of the coal being burned, the components of the fly ash produced vary considerably, but all fly ash includes substantial amounts of silica (silicon dioxide, SiO2) (both 30 amorphous and crystalline) and lime (calcium oxide, CaO). In general, fly ash consists of SiO2, Al2O3, and Fe2O3 as major constituents and oxides of Mg, Ca, Na, K etc. as minor constituent. Fly ash particles are mostly spherical in shape and range from less than 1 μm to 100 μm [22] with a specific surface area, typically between 250 and 600m2/kg. The specific gravity of fly ash vary in the range of 0.6-2.8 gm/cc. Physical properties of fly ash mainly depend on the type of coal burned and the burning conditions. Class F fly ash is generally produced from burning high rank (containing high carbon content) coals such as anthracite and bituminous coals, whereas, Class C fly ash is produced from low rank coals. Fly ash particles are classified into two types, precipitator and cenosphere. Generally, the solid spherical particles of fly ash are called precipitator fly ash and the hollow particles of fly ash with density less than 1.0 g cm-3 are called cenosphere fly ash. One common type of fly ash is generally composed of the crystalline compounds such as quartz, mullite and hematite, glassy compound such as silica glass, and other oxides.

The precipitator fly ash, which has a density in the range 2.0–2.5 g cm-3 can improve various properties of selected matrix materials, including stiffness, strength, and wear resistance and reduce the density. Cenosphere fly ash, which consists of hollow fly ash particles, can be used for the synthesis of ultra-light composite materials due to its significantly low density, which is in the range 0.4–0.7 g cm-3, compared with the densities of metal matrices, which is in the range of 1.6–11.0 g cm-3 [23]. Coal fly ash has many uses [24]including as a cement additive, in masonry blocks, as a concrete admixture, as a material in lightweight alloys, as a concrete aggregate, in flowable fill materials, in roadway/runway construction, in structural fill materials, as roofing granules, and in grouting. The largest application of fly ash is31 in the cement and concrete industry, though, creative new uses for fly ash are being actively sought like use of fly ash for the fabrication of MMCs.

The preference to use fly ash as a filler or reinforcement in metal and polymer matrices is that fly ash is a byproduct of coal combustion, available in very large quantities (80 million tons per year) at very low costs since much of this is currently land filled. Currently, the use of manufactured glass microspheres has limited applications due mainly to their high cost of production. Therefore, the material costs of composites can be reduced significantly by incorporating fly ash into the matrices of polymers and metallic alloys. However, very little information is available on to aid in the design of composite materials, even though attempts have been made to incorporate fly ash in both polymer and metal matrices. Cenosphere fly ash has a lower density than talc and calcium carbonate, but slightly higher than hollow glass. The 20cost of cenosphere is likely to be much lower than hollow glass. Cenosphere may turn out to be one of the lowest cost fillers in terms of the cost per volume.

1. The high electrical resistivity, low thermal conductivity and low density of fly-ash may be helpful for making a light weight insulating composites.

2. Fly ash as a filler in Al casting reduces cost, decreases density and increase hardness, stiffness, wear and abrasion resistance. It also improves the machinability, damping capacity, coefficient of friction etc. which are needed in various industries like automotive etc.

3. As the production of Al is reduced by the utilization of fly ash. This reduces the generation of green house gases as they are produced during the bauxite processing and alumina reduction.

3.1 Optical Microscopy:

The casting procedure was examined under the optical microscope to determine the car structure .A section was cut from the castings. It is first belted grinded followed by polishing with different grade of emery papers. Then they were washed and polished in clothes and then washed, dried and etched with Keller‘s solution and then examined though optical microscope.

IV. RESULTS AND DISCUSSIONS

4.1. Toughness Test:

The toughness is the energy requires breaking the material. The energy is calculated in jouls. The energy consumed is calculated by the difference between total energy supplied to the energy available at the end. The measure of toughness can be found with the help of Charpy and Izod impact tests. The standard specimen size for Charpy impact testing is 10mm×10mm×55mm. and for Izod impact testing 10mm×10mm×75mm.

4(a) Charpy Specimen **4(b) Izod Specimen**

Fig4. 4(a) Izod And 4(b) Charpy Test Specimen Before and After Testing

4.2. Hardness test:

Hardness is the measure of how resistant solid matter is to various kinds of permanent shape change when a force is applied. Macroscopic hardness is generally characterized by strong intermolecular bonds. There are three types of tests used with accuracy by the metals industry; they are the Brinell hardness test, the Rockwell hardness test, and the Vickers hardness test. But in our present work we considered only Rockwell hardness test. The Rockwell scale is a hardness scale based on the indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. Bulk hardness measurements were carried out on the base metal and composite samples by using standard Brinnel hardness test. Brinnel hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness. Load applied was 750kgs and
Indenter was a steel ball of 5 mm diameter.

(a) **(b)**

Fig 5. Hardness Test Specimen 5(a) Before and 5(b) After Testing

4.3. Tensile Test:

The tensile testing of the composite was done, on Instron testing machine. The sample rate was 9.103pts/sec and cross-head speed 5.0 mm/min. Standard specimens with 30mm gage length were used to evaluate ultimate tensile strength. The comparison of the properties of the composite material was made with the commercially pure Al. Tensile testing, also known as tension testing, is a fundamental materials science test in which a sample is subjected to uni-axial tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation & reduction in area.

Tensile Strength

- Tensile strength of long-fiber reinforced composite in longitudinal direction σc = σm*Vm + σf*Vf

Where , σc, σm, σf – tensile strength of the composite, matrix and dispersed phase (fiber) respectively.

- Tensile strength of short-fiber composite in longitudinal direction (fiber length is less than critical value Lc) 14

  Lc = σf*d/τc

Where d – diameter of the fiber;
τc –shear strength of the bond between the matrix and dispersed phase (fiber).

σc = σm*Vm + σf*Vf*(1 – Lc/2L)

Where L – length of the fiber

- Tensile strength of short-fiber composite in longitudinal direction
  (Fiber length is greater than critical value Lc)
  σc = σm*Vm + L* τc*Vf/d

Fig 6(a) before testing

Fig 6(b) after testing

Fig 6. Tensile Test Specimen 6(a) Before and 6(b) After Testing

TABLE II Experimental Data for AL-Fly Ash Composites

SAMPLE	IZOD TEST(mpa)	CHARPY TEST (mpa)	TENSILE TEST(mpa)	HARDNESS(HRB)
S1	3.15	3.56	126	70
S2	5.45	5.24	142	78
S3	4.30	4.73	135	76
S4	4.00	3.78	132	69

4.4. Mechanical Properties of AL- Fly Ash Composites:

Fig.7 shows the effect of fly ash on the strength of AL.As we earlier studied about the tests we made on composites, 7(a) & 7(b) shows for izod and charpy. From both of graphs, we can conclude that as the ash content increases strength of the composites also increases but up to some level and after this it reduces. The level up to it increases is the 30gm of ash content for one sample of Al - fly ash composite.

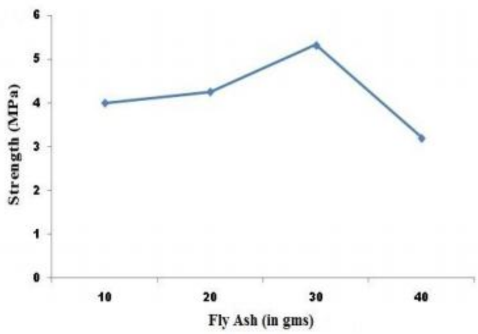

Fig 7(a) Izod Test

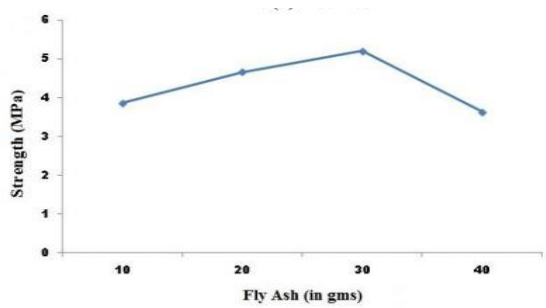

Fig 7(b) Charpy Test

Figure 7: Effect of Fly Ash on the Strength of Al by 7(a) Izod Test and 7(b) Charpy Test

4.5. Physical Properties of AL- Fly Ash Composites:

As earlier studied that we required a light weight composite material which will be used in the automobile and aerospace industries, this AL- Fly Ash composites are best for this applications doe to their low density. Fig.8 shows the effect of fly ash on the density and grain size of the composites we fabricated. Fig. 8(a) shows the effect of fly ash on the density. As the ash content increases the density of the composites reduces which is good for us as they used in the light weight applications. Fig. 8(b) shows the effect of fly ash on the grain size of composite. As we increases the ash content the grain size of composites also increases due to the coarse nature of ash.

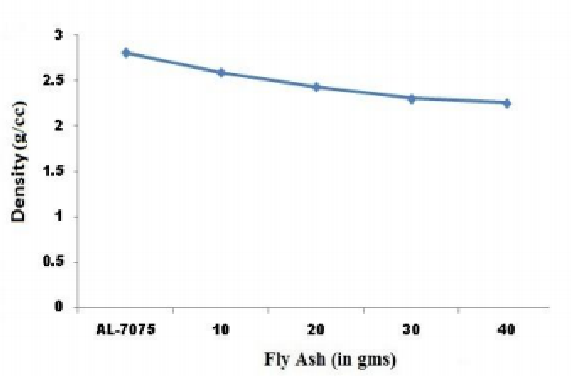

Fig 8(a) Density

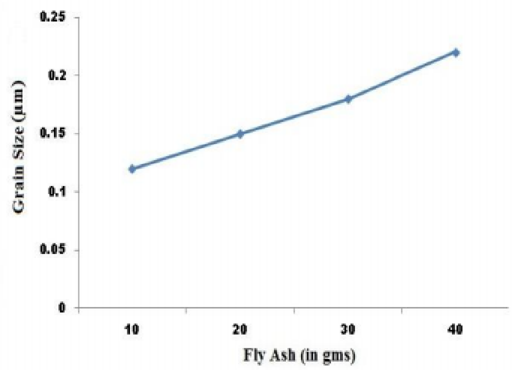

Fig 8(b) grain size

Fig 8. Effect of Fly Ash on the 8(a) Density and 8(b) Grain Size of Al

V. CONCLUSION

Here we successfully fabricated the AL-Fly Ash Composites by using Stir Casting arrangement with proper distribution of ash particles all over the specimen. Also we added the Mg to improve the wet ability of ash particles by reducing its surface tension. We have drawn various conclusions from the various calculations based on the diff. experimental testes:

a) Toughness of the composites was determined by using Izod and Charpy tests. As we increase the amount of ash the toughness value gradually increased up to some level i.e Sample2 but after this it diminishes.

b) Hardness and tensile strength of the composites also showed the same results as like of toughness. As we increased the amount of ash up to Sample2 it increases and after that goes down.

c) The density of the composites decreased with increasing ash content. Hence these light weight composites can be used where weight of an object maters as like in the aero and space industries.

From the above results we find the taking Sample having an good toughness, hardness, tensile strength and also having the low density comparatively alloys without reinforcement. So that these composites could be used in those sectors where light weight and good mechanical properties are required as like in automobile and space industries.

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