ISSN 2229-5518

# Investigation of Mechanical and Wear properties of Aluminum-Fly Ash composite material produced by Stir Casting Method

M. Raja Kumar[a], M. Shunmuga Priyana, A.Mani[b]
[a]Department of Mechanical Engineering, James College of Engineering and Technology, Navalcadu, Tamil Nadu, India
[b]Department of Mechanical Engineering, Dr.Sivanthi Aditanar College of Engineering,
Tiruchendur, Tamil Nadu, India

**Abstract:** 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 byproduct during combustion of coal in thermal power plants. Hence, composites with fly ash as reinforcement are likely to over come the cost barrier for wide spread applications in automotive and small engine applications. Now a days the particulate reinforced aluminium 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. The present investigation has been focused on the utilization of abundantly available industrial waste fly-ash in useful manner by dispersing it into aluminium to produce composites by stir casting method. The dry sliding wear behavior of the composites in the cast conditions was studied at different loads and different sliding velocities with the help of Pin-On-Disc wear test machine.

**Index Terms-** Composite Materials, Fly ash, Pin-On-Disc, Wear, Tensile

---

## 1. INTRODUCTION

The matrix in these composites is a ductile metal. These composites can be used at higher service temperature than their base metal counterparts. These reinforcements in these materials may improve specific stuffiness specific strength, abrasion resistance, creep resistance and dimensional stability. The MMCs is light in weight and resist wear and thermal distortion, so it mainly used in automobile industry. Metal matrix composites are much more expensive those PMCs and, therefore, their use is somewhat restricted. [1]. In the present investigation, the effect of three different stir casting routes on the structure and properties of fine fly ash particles(13 lm average particle size) reinforced Al–7Si–0.35Mg alloy composite is evaluated. Among liquid metal stir casting, compo casting (semi solid processing), modified compo-casting and modified compo-casting followed by squeeze casting routes evaluated, the latter has resulted in a well-dispersed and relatively agglomerate and porosity free fly ash particle dispersed composites. Interfacial reactions between the fly ash particle and the matrix leading to the formation of MgAl2O4 spinel and iron intermetallics are more in liquid metal stir cast composites than in compo cast composites [2]. It reported that magnesium played an important role during the synthesis of aluminum alloy matrix composites with dispersoids such as zircon (ZrSiO4), zirconia (ZrO2), titania (TiO2), silica (SiO2), graphite, alurninium oxide (Al203) and silicon carbide (SiC). Magnesium is one of the important alloying elements in aluminium [3]. In A1-Si casting alloys Mg2Si is the key phase for alloy strengthening. Magnesium addition to aluminium reduces its casting fluidity at the same time as it reduces the surface tension of the aluminium sharply [24]. The Effect of reinforcement of fly ash on sliding wear, slurry erosive wear and corrosive behavior of aluminium matrix composite. Al (12 wt% Si) as matrix material and up to 15 wt% of fly ash particulate composite was fabricated using the stir casting [4, 5]. The mechanical properties and dry sliding wear and come into brief idea that Fly ash with narrow size range (53–106µm) show better properties compared with the wider size range (0.5–400µm) particles [6]. In this studied the coefficient of thermal expansion of pure Al containing 65 vol% of hollow fly ash particles and suggested that Composites with a lower coefficient of thermal expansion can be made by incorporating cenospheres under controlling the processing parameter for a given volume fraction of reinforcement [7]. Fly ash is one of the most inexpensive and low density reinforcement

ISSN 2229-5518

available in large quantities as solid waste by-product during combustion of coal in thermal power plants has been successfully dispersed into cast and wrought aluminium alloys to make aluminium-alloy–flyash(ALFA) composites [8]. Studied characterization of A356 Al - fly ash particle composites with fly ash particles of narrow range (53-106μm) and wide size range(0.5-400 μm) and reported that addition of fly ash lead to increase in hardness, elastic modulus and 0.2% proof stress [9]. The corrosion behaviour of metal-matrix composite is determined by several factors such as the composition of the alloy, the matrix microstructure, the dispersoid and the matrix, and the technique adopted for preparing the composite. A very small change in any one of these factors can seriously affect the corrosion characteristics of the metal [10-15]. The addition of fly ash particles to the aluminium alloy significantly increases its abrasive wear resistance and the improvement in wear resistance to the hard aluminosilicate constituent present in fly ash particles[16]. In this paper present investigation of aluminum matrix composites with fly ash materials to improve the mechanical properties and wear resistance in various composition at different conditions.

## 2. EXPERIMENTAL PROCEDURE

### 2.1 Raw Materials and Preparation

The matrix material used in the experiment investigation was commercially pure aluminium.The fly ash was collected from thermal power plant, tuticorin, India. The particle size of the fly as received condition lies in the range between (0.1-100 μm). The following table 2.1 shows the chemical analysis of aluminium alloy 6063. The specimen was tested by using Optical Emission Spectrometry in a Metrology Laboratory (Roots Industries India Limited, Ganapathy, Coimbatore-6). From the table it was clear that the matrix material used for composites has three major constituents and the authors was reported in the table 2.2 shows the chemical composition of fly ash (reinforcing phase) used for making composites. The major constituents present in the fly ash are the oxides of silicon, aluminium, iron, calcium etc.Table-2.1 Chemical Analysis of Aluminium Alloy 6063.

| Elements Present in Aluminium alloy | Percentage (%) |
|---|---|
| Si | 0.560 |
| Fe | 0.276 |
| Cu | 0.108 |
| Mn | 0.404 |
| Mg | 0.560 |
| Cr | 0.0110 |
| Ni | 0.0180 |
| Zn | 0.118 |
| Ti | 0.0320 |

Table-2.2 Chemical Analysis of Fly Ash

| Fly Ash Compounds | Percentage (%) |
|---|---|
| $SiO_2$ | 55.9 |
| $Al_2O_3$ | 30.2 |
| $Fe_2O_3$ | 5.4 |
| $K_2O$ | 2.7 |
| CaO | 1.3 |
| MgO | 1.0 |
| $TiO_2$ | 1.6 |
| $Na_2O$ | 0.2 |
| $P_2O_3$ | 0.4 |
| $Mn_2O_3$ | 0.1 |
| SrO | 0.1 |

### 2.2 Melting and Casting

The figure 2.1 shows the matrix material melt was stirred vigorously to form a vortex at the surface of the melt, and the reinforcement particle was introduced at the side of the vortex. i.e. Fly-ash particles were added little by little to the melt at the time of formation of vortex in the melt due to stirring action. The melt temperature was maintained about 800-900°C during the addition of fly ash particles. Then the melt was casting in a die kept inside another electric furnace which was secluded from the furnace at the time of pouring. The temperature of the die was preheated about 300°C in order to prevent cracking during hot metal pouring. The casting was removed from the die after solidification. For the 10% of aluminium fly ash composite, the above mentioned procedure was followed by taking 140 grams instead of 70 grams. For the comparison of aluminium fly ash composites with aluminium alloy, a separate casting was made by the same procedure without addition of fly ash.

## 2.3 Particle size analysis

**Figure 2.1 Stir casting furnace with raw materials set up**

Particle size of the milled powder was measured by Malvern particle size analyzer (Model Micro-P, range 0.05-550 micron). Firstly, the liquid dispersant containing 500 ml of distilled water was kept in the sample holder. Then the instrument was run keeping ultrasonic displacement at 10.00 micron and pump speed 1800 rpm. The figure 2.2 shows the determination of optical micrograph structure of fly ash particles at 100X magnification.

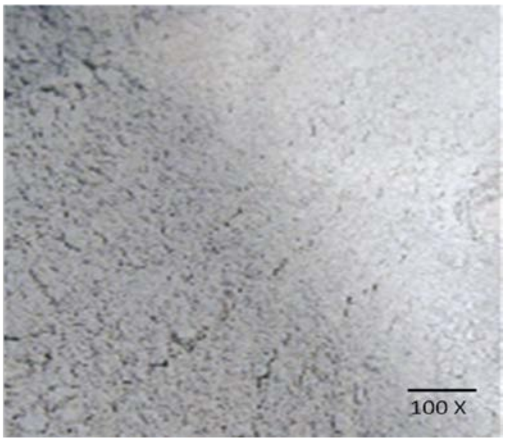



Figure 2.2 Optical micrograph structures of Fly Ash particles

## 2.4 Microstructural Characterization

The composite samples were metallographically polished prior to examination. Characterization is done in etched conditions. Etching was accomplished using Keller's reagent. The SEM micrographs of composite and wear debris were obtained using the scanning electron microscope. The images were taken in both secondary electron (SE) and back scattered electron (BSE) mode according to requirement. Microscopic studies to examine the morphology.

particle size and micro structure were done by a JEOL 6480 LV scanning electron microscope (SEM). The casting procedure was examined under the optical microscope to determine the casr structure. A section was cut from the castings. It is first belt 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.

## 2.5 Wear Testing

Al and composite specimens were prepared in the size of 12mm diameter and 15mm length and loaded in a computer interfaced pin on –disc wear testing machine. The test piece were secured to the instrument at the normal loads of 5, 10, 15 N and sliding speeds were 0.5, 1.0, 1.5 m/s. Wear test carried out at room temperature.

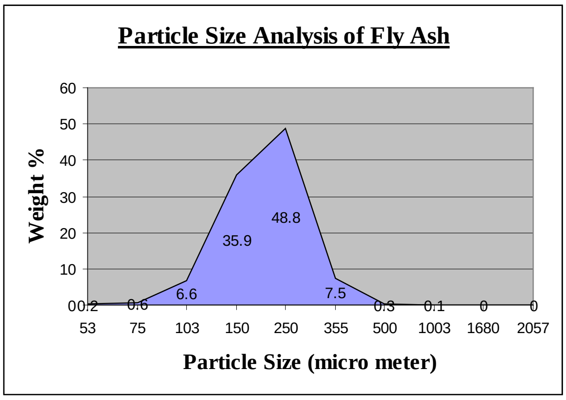
Figure 2.3 Pin –on-Disc wear testing machine

## 3. RESULTS AND DISCUSSION

### 3.1 Particle size analysis

Fly ash particle size was analyzed using Sieve shaker apparatus. The initial quantity was taken for analyzing the size was 100 grams. The sieves in the apparatus were arranged according to BS number (British Standard) from top to the bottom. i.e. in the decreasing order of the micro meter size of the mesh. 100 grams of the available fly ash were dropped on the sieve and closed it with the lid. The closing should be tight enough to withstand the vibratory motion provided were settled in sieves according to their size due to the machine vibrations. Each and every sieve was weighed separately and quantity of fly ash retained in each sieve was calculated. The following figure shows 3.1 (a) shows the weight of the fly ash retained in corresponding sieves according to their sizes. From the graph it was clear that the fly ash used in Aluminium fly ash composite has the size ranges from 150 to 350 µm (both narrow and wide sizes) and the corresponding meshes are -44# and +100# (in BS).

The SEM image (Figure 3.2) was determined the size range of the particles was very wide i.e. from 53 microns to 1003 microns. The size ranges of the fly ash particles indicate that the composite prepared can be considered as dispersion strengthened as well as particle reinforced composite. From the particle size distribution of fly ash it was clear that, it contains very fine particles as well as coarse ones. Dispersion strengthening is due to the incorporation of very fine particles, which help to restrict the movement of dislocations, whereas in particle strengthening, load sharing is the mechanism. Strengthening of matrix may occur because of solid solution strengthening.



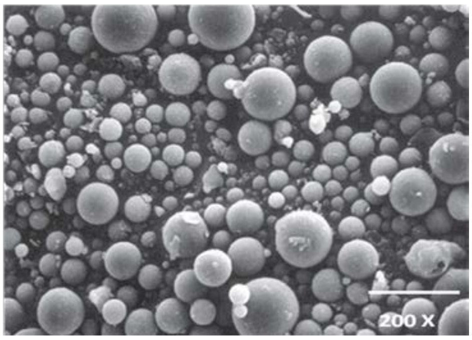



Figure 3.1 Particle size analysis of Fly Ash particles Figure 3.2 SEM micrograph of Fly Ash particles (15-55µm

### 3.2 Hardness measurement

The fly ash particles in Aluminium matrix cause reasonable increase in hardness. The strengthening of the composite can be due to dispersion strengthening as well as due to particle reinforcement. Four samples were taken in each casting composites. (ie.from 5% and 10% of Aluminium fly ash composites and unreinforced aluminium alloy) and performed hardness test on it. All samples hardness was measured in Rockwell Hardness Testing machine and the readings were noted from the B-scale. For Aluminium alloys the load applied for hardness measurement was 100 kg. The above Fig 4.4 shows the average reading of tested samples of particular composites and unreinforced aluminium alloy and appropriate increase in the hardness of the composites due to the increasing percentage of the fly ash particle. The fly ash particle present in the composites shares the load of the matrix material and restricts the motion of dislocation. From the table-4.4 the Rockwell hardness readings of fly ash composites were compared with the hardness of the unreinforced aluminium alloy. Thus the fly ash acts as filler in Aluminium casting reduces cost, decreases density and increase hardness which are needed in various industries like automotive, aerospace etc.

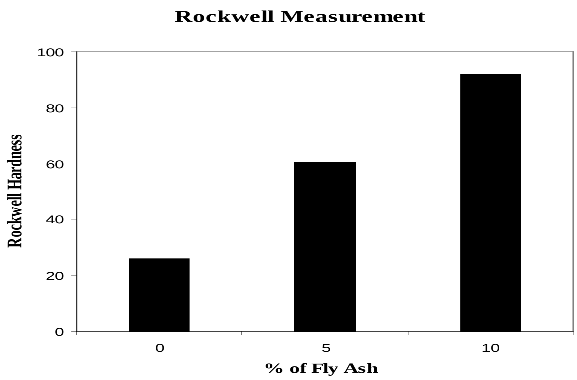



Figure 3.3 Hardness value of composite material sample with different composition

### 3.3 Wear behavior

Wear behavior is the surface damage or removal of material from one or both of two solid surfaces in a sliding, rolling, or impact motions relative to one another. So it is surface phenomenon that occurs by displacements and detachments of materials. Wear problems generally differ from those entailing outright breakage, as wear usually a progressive loss of weight and alterations of dimensions over a periods of time. Wear is undesirable behavior in almost all machine applications such as bearings seals gears, and cams etc. Wear of those components may range from mild polishing type attrition to rapid and severe removal of material accommodating with surface roughing. Some components gets failure may depend upon the wear which deleteriously affects the ability of the components to function.

Table-3.1 Wear Behavior of Composites

| Composites | Wear(in microns) |
|---|---|
| Unreinforced Alloy | 1123.5 |
| Aluminium-5% Fly ash | 766 |
| Aluminium-10% Fly ash | 272 |

Table-3.2 Wear Resistance and Specific Wear Rate

| | Unreinforced Alloy | 5% Fly Ash | 10% Fly Ash |
|---|---|---|---|
| Force (N) | 50 | 50 | 50 |
| Velocity (m/s) | 2 | 2 | 2 |
| Sliding distance (m) | 1500 | 1500 | 1500 |
| Time (sec) | 750 | 750 | 750 |
| Track diameter (m) | 0.1 | 0.1 | 0.1 |
| Speed (rpm) | 382 | 382 | 382 |
| Area (sq.mm) | 144 | 144 | 144 |
| Wear (microns) | 1123.5 | 766 | 272 |
| Wear rate (cu.mm/m) | 0.10785 | 0.07355 | 0.0261 |
| Specific wear rate (cu.mm/Nm) | 0.002155 | 0.00147 | 0.00052 |
| Wear resistance (m/cu.mm) | 9.287 | 13.6665 | 38.447 |

The addition of fly ash acts as a barrier to the movement of dislocations and thereby increases the strength and hardness of the composite. Thus addition of fly ash particles to the aluminium melt significantly increases its abrasive wear resistance. The improvement in wear resistance is due to the hard aluminosilicate constituent present in fly ash particles. From the view of material, influencing factors on friction force are mechanical properties of the matrix, hardness, chemical stability of the particles, composition and strength of the interface. Interaction between these and tribological parameters (such as load and speed, environment and the properties of the counter faces materials) are responsible for the overall response. The sizes of the specimens were used for finding wear resistance were 12x12x 40 cu.mm. and the surface of the specimens were polished by means of belt grinder, silicon carbide sheet (series 1000, 1200 &1500) and wet polishing machine. After polished, the specimens were mounted one by one on the wear testing machine. The parameters such as Load 5 kgf, rotating speed of the disc 382 rpm, velocity 2 m/s were set. The specimen was made to come into contact with the disc by releasing load. The run time of wear testing machine was set as 720 seconds (12 minutes) for each specimen. The wear in microns were noted for each specimens and the average value of particular aluminium fly ash composites were compared with unreinforced aluminium alloy for calculating the improvement in wear resistance, specific wear rate, etc. due to the incorporation of fly ash into aluminium alloy. Table-3.1 shows the average of the sample readings of 5% and 10% fly ash incorporated composites and aluminium alloy without addition of fly ash. Comparison was made between wear rate of unreinforced alloy, 5% fly ash aluminium composites and 10% fly ash aluminium composites. The improvement in wear resistance in composites is clearly shown in fig 3.2 by means of bar chart by taking unreinforced alloy and fly ash composites in x-axis and wear in microns in y-axis.

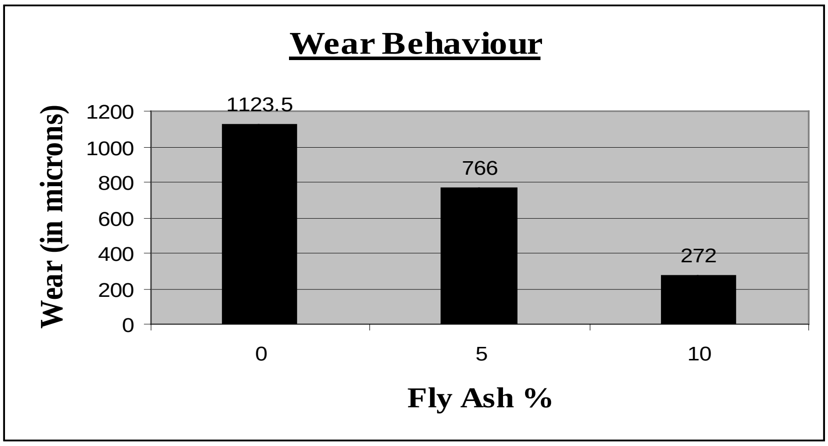



Figure 3.4 Wear behavior of composite material with fly ash in various composition

### 3.4 Tensile strength

The tensile strength of composites are mainly affected by the factors such as particle size, shape and volume fraction of reinforcement, matrix material, reaction at the interface and distribution of reinforced particle into the matrix. Very large size particles reduce ductility whereas small size particles have little influence on ductility. Generally compressive yield strength is higher than the tensile yield strength and compressive ductility is greater than the tensile ductility. The standard tensile specimen used in tensile test is shown below with appropriate dimensions.

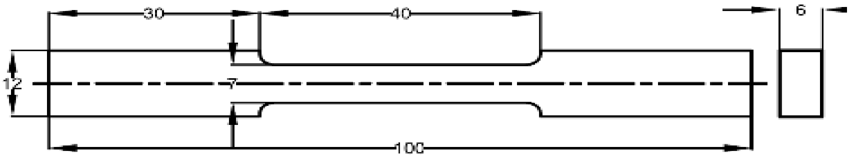
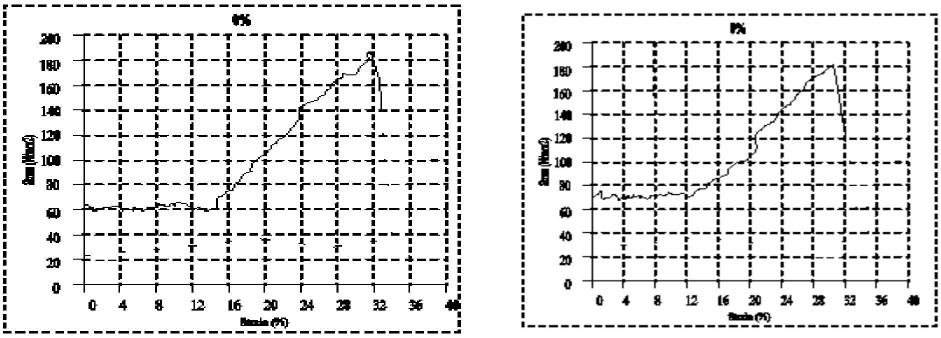
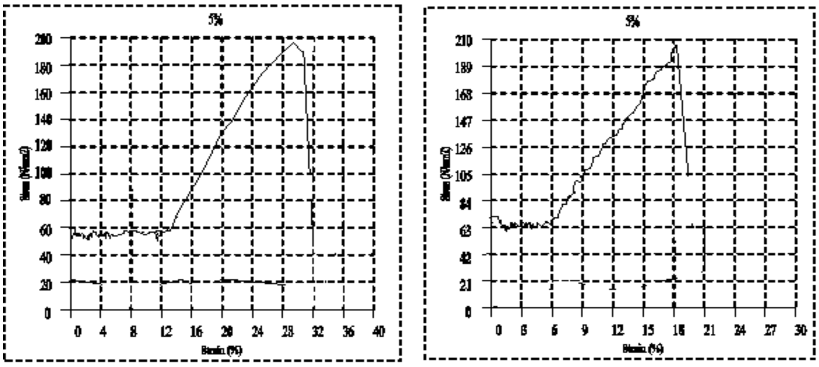



Figure 3.5 tensile strength specimen preparations (ASTM)



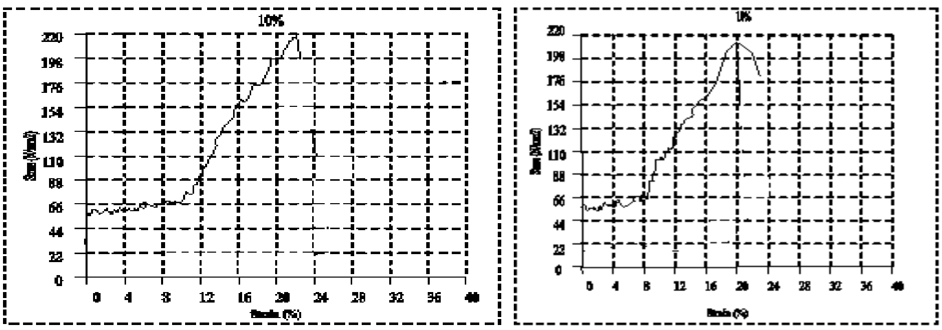
Tensile Strength=185.71 N/mm$^2$ Tensile Strength=185.23 N/mm$^2$
Peak Load=7.80 kN Peak Load=7.78 kN

Figure 3.6 Tensile Strength of Unreinforced Aluminium Alloy



Tensile Strength=195.23 N/mm$^2$ Tensile Strength=209.52 N/mm$^2$
Peak Load=8.20 kN Peak Load=8.80 kN

Figure 3.7 Tensile Strength of 5% Aluminium Fly Ash Composite



Tensile Strength=219.52 N/mm$^2$ Tensile Strength=216.42 N/mm$^2$

Peak Load=9.22 kN Peak Load=9.09 kN

Figure 3.8 Tensile Strength of 10% Aluminium Fly Ash Composite

From the above tensile test reports, the strength of the fly ash aluminium composite increases gradually with the incorporation of fly ash particles into the soft aluminium metal matrix. Fig 3.6 shows the standard dimensions of the tensile specimen where as fig 3.7 shows the result of tensile test of unreinforced aluminium alloy and fig 3.7 (d) & (e) shows the result of tensile test of 5% fly ash imbedded in aluminium matrix and finally fig 3.8 shows the result of tensile test of 10% fly ash imbedded in aluminium matrix metal. The above stress strain graph shows the ultimate strength of the specimens and the corresponding load at which the specimen fails were noted and tabulated below. From the above graph 6.6 (b), (c), (d), (e) (f) & (g) it was clear that the addition of fly ash leads to the improvement in the strength of the material. 10% fly ash aluminium composite shows higher tensile strength than another composite and unreinforced alloy. The comparison of tensile strength readings of the two different composites and unreinforced aluminium alloy were made and it was obvious that the fly ash particle restricts the motion of dislocation and needs additional stress for failure of the material and hence greater tensile strength.

- From the study it is concluded that we can use fly ash for the production of composites and can turn industrial waste into industrial wealth. This can also solve the problem of storage and disposal of fly ash.
- Fly ash upto 10% by weight can be successfully added to aluminium alloy 6063 by stir casting route to produce composites.
- Mechanical stirrer is required for quite mixing of fly ash above 10% by weight of the aluminium alloy. For greater percentage of reinforcing phase the mechanical stirrer is efficient.
- The hardness of Al-fly ash composites has increased with increase in addition of fly ash.
- Addition of fly ash into the aluminium alloy shows significant improvement in the strength of the composites.
- Both the frictional forces and the wear rates have decreased significantly with the incorporation of fly ash in aluminium melt.
- Strengthening of composite is due to dispersion strengthening and particle reinforcement.

## Conclusion

Table 3.3Tensile Strength of Composites

| Serial no. | % of Fly Ash | Load (kN) | Tensile Strength (N/sq.mm) |
|---|---|---|---|
| 1. | 0 % | 7.80 | 185.71 |
| 2. | 0 % | 7.78 | 185.23 |
| 3. | 5 % | 8.20 | 195.23 |
| 4. | 5 % | 8.80 | 209.52 |
| 5. | 10 % | 9.22 | 219.52 |
| 6. | 10 % | 9.09 | 216.42 |

## References

ISSN 2229-5518
[1] Hull D, Clyne T W, An Introduction to Composite Materials, Cambridge, UK: Cambridge Univ. Press, 1996

[2] T.P.D. Rajan, R.M. Pillai, B.C. Bai, Fabrication and characterisation of Al–7Si–0.35Mg/fly ash metal matrix composites processed by different stir casting routes Journal of Material Science, Vol.33, (1998) 3491–3503.

[3] Pai B. C, Geetha Ramani, Pillai R. M, Satyanarayana K. G, Role of magnesium in cast aluminiurn alloy matrix composites, Journal of materials science 30 (1995):pp 1903-1911

[4] Korolkov A. M., Casting properties of metals and alloys, Consultant Bureau, New York, (1963): pp. 26, 37.

[5] Radhakrishna M. Ramachandra K., Effect of reinforcement of flyash on sliding wear, slurry erosive wear and corrosive behavior of aluminium matrix composite, Wear 262 (2007), pp1450–1462.

[6] Sudarshan, Surappa M.K., Synthesis of fly ash particle reinforced A356 Alcomposites and their characterization, Materials Science and Engineering A 480 (2008): pp 117–124

[7] Rohatgi P.K., Weiss D., and Gupta Nikhil, Applications of fly ash in synthesizing low-cost mmcs for automotive and other applications,JOM (2006): pp71-76.

[8]. P. K. Rohatgi, J. K. Kim, R. Q. Guo, D. P. Robertson and M. Gajdardziska-Josifovska, "Age Hardening Characteristics of Aluminium Alloy – Hollow Fly Ash Composites", Metallurgical & Materials Transaction A, Vol. 33A, (2002).

[9] R. Q. Guo and P. K. Rohatgi, "Chemical Reactions Between Aluminium and Fly Ash During Synthesis and Reheating of Aluminium-Fly Ash Composite", Metallurgical & Materials Transaction B, Vol. 29B, (1998).

[10] K. H. W. Seah, S. C. Sharma, B. M. Girish, Corrosion Sci. 39, 2 (1997)

[11] A. J. Trowsdale, B. Noble, S. J. Harris, I. S. R. Gibbins, G. E. Thompson, G. C. Wood, Corrosion Sci. 38, 178 (1996).

[12] R. L. Deuis, L. Green, C. Subramanian, J. M. Yellup, Corrosion 53, 880 (1997).

[13] L. H. Hihara, L. M. Latanision, Corrosion 48, 546 (1992).

[14] F. Mansfeld, S. Lin, S. Kim, H. Shih, J. Electrochem. Soc. 137, 78 (1990).

[15] P. Nunes, L. Ramanathan, Corrosion 51, 615 (1995).

[16] Liu. Y.L, Kang. S.B and Kim. H.W, 1999. "Complex Microstructures in As-Cast Al- Mg-Si Alloy", Materials Letters, Vol. 4.