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Development and Characterization of Aluminium Based Matrix Using 5% Fly Ash

Karamjot Singh[1*], Gagandeep Kaushal[2] and Hazoor Singh Sidhu[3]
[1]M.Tech Student, [2]Assistant Professor, [3]Associate Professor,
Mechanical Engineering Section, Yadavindra College of Engineering, Punjabi University, Guru Kashi Campus, Talwandi Sabo, Punjab, India
** Corresponding author email:* karamjotgrewal@gmail.com
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Abstract - Stir casting technique is a conventional and cheap method for the fabrication of Metal Matrix Composites (MMCs). In the present research, Al-6063 as matrix material and fly ash as particulate reinforcement was fabricated with the help of stir casting technique to produce low cost AMC. In this work, the effect of height of stirring blades was investigated with variable speeds. The wt% of fly ash kept constant to 5%. To obtain the influence of these parameters on the mechanical properties of cast samples, hardness test, Charpy Impact test and SEM/EDS were performed on the cast samples.

Keywords: MMCs, AMC, Stir Casting, Al-6063, Fly ash

I. INTRODUCTION TO COMPOSITES

In recent years, development of monolithic material is shifted to composite materials which are used in aerospace industry and in automotive industry [1]. In automotive industry, when there are environmental issues then it is necessary to increase the fuel efficiency of the automobiles by reduction in the weight of automobile [2]. To meet such demands Composites are reliable solutions.

Composite material can be defined as the material made up of two or more distinct materials. The material can be organic, metals and ceramic. The composites can be classified as:

- Organic Matrix composites (OMCs)
- Metal Matrix composites (MMCs)
- Ceramic Matrix composites (CMCs)

Composite material has mechanical properties superior to the base metal. These properties of composites are affected by the size, shape and volume fraction of reinforcement, matrix material and reaction at the interface [3]. It is possible to obtain desirable mechanical properties either by varying the weight percentage of reinforcement or by changing the reinforcement or matrix material. From the literature study it was found that particulate matrices have advantage of being machinable and workable and are easy to produce.

A.Metal Matrix Composites

Metal matrix composites are engineered materials formed by the combination of two or more materials, at least one of which is a metal, to obtain enhanced properties [4]. Metal matrix composites consist of two phases known as matrix phase and dispersed phase. The main types of MMC are:

- Aluminium Matrix Composites (AMCs)
- Magnesium Matrix Composites
- Titanium Matrix Composites
- Copper Matrix Composites

B.Aluminium Matrix Composites

Fly ash is the waste product of coal which remains after the combustion of coal in the thermal power plants. It forms at temperature of 920-1200 °C [14]. The fly ash reinforced aluminium matrix composites are termed as 'Ash alloys' [5]. Over 90 million tones of fly ash is produced each year in thermal power plants, most of which is land filled [6]. So it easily available with little or no cost as compared to other reinforcements and also hazardous if remains in the open environment. Fly ash particles generally contain either solid spheres/precipitator (density 2.1-2.6 g/cm3) or hollow spheres termed cenosphere (density 0.4-0.6 g/cm3) [7]. Since fly ash represents inexpensive resource material, this new composite is likely to overcome the cost barrier for widespread applications in automotive and small engine applications [8].

The cast aluminium-fly ash composites have potential of being cost effective, ultra light composites with significant applications [4]. Aluminium-fly ash composites have potential applications as covers, pans, shrouds, casings, pulleys, manifolds, valve covers, brake rotors and engine blocks in automotive [9].

II. LITERATURE REVIEW

From the literature review, it was found that Aluminium with fly ash can be fabricated with the help of stir casting method. Ramachandra and Radhakrishna successfully synthesized Aluminium based metal matrix composite containing up to 15% of fly ash particulates using vortex method and found that with addition of fly ash particles there is an increase in micro hardness along with decrease in the density of the cast composite. K. V. Mahendra and K. Radhakrishna observed that there is increase in hardness, tensile strength, compression strength and impact strength with increase in the fly ash content also there was increase in resistance to dry wear, slurry erosive wear and corrosion with increasing in fly ash content. It was concluded by Sudarshan and M.K. Surappa that the dry sliding wear resistance of Al-fly ash composite was almost similar to that of Al_2O_3 and SiC reinforced Al-alloy. The effect of particle size of reinforced fly ash was investigated by H.C. Anil

Kumar et al., and it was found that the tensile strength, compressive strength, ductility and hardness of Al 6061 composites decreased with the increase in particle size of the reinforced fly ash. David Raja Selvam. J et al., fabricate the AMCs reinforced with various weight percentages of SiC particulates and a constant weight percentage of Fly Ash by modified stir casting. It was also found that the wet ability of SiC and Fly ash particles in the matrix can be improved by adding magnesium into the melt. P.K. Rohatgi et al., also found that fly ash can be incorporated into an aluminium-alloy matrix using stir casting and pressure infiltration techniques for producing differential covers, intake manifolds, brake drums etc. up to 10 vol.% fly-ash particles.

III. STIR CASTING PROCESS

Stir casting is a liquid state process which is used to fabricate MMCs conveniently. To prepare AMCs, aluminium matrix is completely melted and ceramic particles are added into molten metal in a vortex created by using a mechanical stirrer [10]. This method is most economical to fabricate composites with particulates fibers [11]. The following figure 1.1 shows the basic layout of stir casting setup which contains a furnace, crucible, a motor which can be operated at variable speeds, a stirrer attached to motor which stirs the molten metal in crucible.

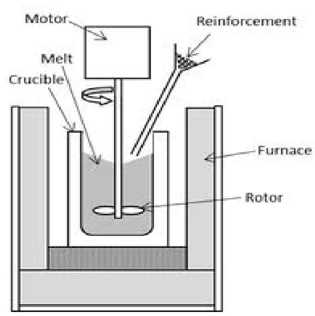

Fig. 1.1 Stir casting setup [18]

Among the manufacturing processes, the conventional stir casting is an attractive processing method for producing AMCs as it is relatively inexpensive and offers a wide selection of materials and processing conditions [13]. The stir casting technique is suitable for up to 30% of reinforcement by weight addition used in the fabrication of MMCs [14]. However in stir casting there is problem arises in the distribution of the reinforcement. The problem becomes significant when the reinforcement size decreases due to greater agglomeration tendency and reduced wet ability [5]. Because the weight of fly ash or particulates are less as compared to weight of matrix [15]. To overcome this problem Magnesium (Mg) can be added which increases the wetability of fly ash particles in matrix [16].

IV. MATRIX MATERIAL

For the preparation of AMC the matrix material was taken as Al-6063. The chemical composition of Al 6063 is given in the table. The reason for the usage of Al 6063 is that small number of researches has been done by taking it as base metal.

TABLE I CHEMICAL COMPOSITION OF AL 6063

Al	Si	Mg	Fe	Cu	Mn	Zn	Ni
98.4	0.52	0.45	0.40	0.08	0.02	0.08	0.01

Reinforcement: Fly ash was used as reinforcement. It is the waste product of thermal power plants which is mostly land filled and creates pollution. It was provided from N.F.L. Bathinda, in particle size range from 0.1 to 100 µm [4]. The chemical composition of fly ash is given in the table 2.

TABLE II CHEMICAL COMPOSITION OF FLY ASH

Al_2O_3	SiO_2	Fe_2O_3	TiO_2	Carbon/LOI
29.9	56.92	8.44	2.75	1.99

V. PREPARATION OF SETUP

The stir casting setup was prepared in the institute as shown in figure1;

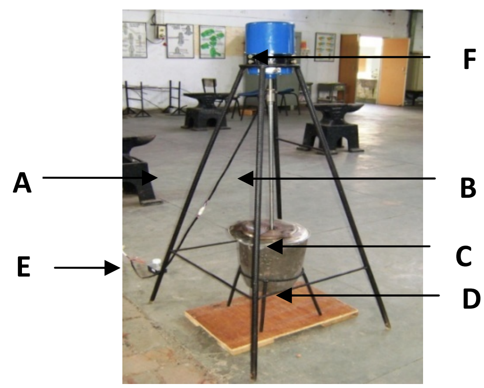

Fig. 1.1: Stir Casting setup

The stir casting setup consists of following parts:

A. Main frame
B. Stirring rod
C. Graphite crucible
D. Crucible stands
E. Speed controller
F. Motor

To investigate the effect of process parameters like height of the stirring blade, two mild steel crucible stands were used and speed controller was used to adjust the rotation of the stirring rod.

VI. EXPERIMENTATION

For the preparation of AMC, Al 6063 was placed in the preheated 10 no. graphite crucible in pit furnace. Then preheating of 5 wt% of fly ash and 1wt% of Magnesium was done in the core baking oven to eliminate the moisture contents and to escape gases from materials for an hour at temperature of 300ºC. Magnesium was added to increase the wetability of the fly ash with aluminium. Then manual stirring was done for the mixing of fly ash into melt. After half an hour, the crucible withdrawn from the furnace and placed below the stir casting setup. Then stirring was done at 300 rpm speed and at height of 30mm from the bottom of the crucible. In this way, by varying the height, speed and wt% of reinforcement four samples were prepared which were shown in table 3.

TABLE III SAMPLES WITH ALL PARAMETERS

SAMPLE No.	FLY ASH (wt%)	FLY ASH (gms)	Al-6063 (kg)	HEIGHT (mm)	SPEED (rpm)
1	5	200	3.800	30	250
2	5	200	3.800	30	500
3	5	200	3.800	60	250
4	5	200	3.800	60	500

VII. RESULTS

A. Charpy Impact test

The Charpy impact test was performed on the Impact testing machine provided by the institute. This result is shown in the figure 1.2, in the form of bar chart with all process parameters.

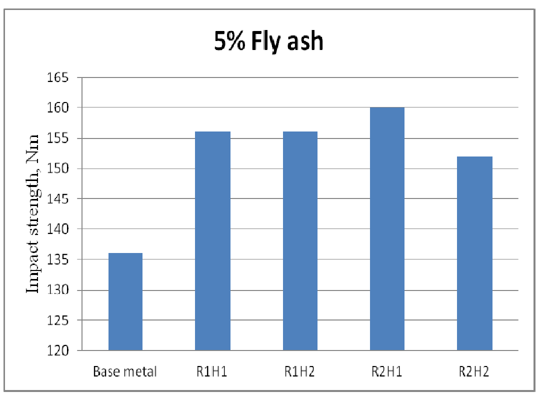

Fig. 1.2 Charpy Impact test

R1H1	Stirring speed 500 rpm and stirring height 30mm.
R2H1	Stirring speed 300 rpm and stirring height 30mm.
R1H2	Stirring speed 500 rpm and stirring height 60mm.
R2H2	Stirring speed 300 rpm and stirring height 60mm.

Figure shows the increase in the impact strength of cast AMC as compared to unreinforced. The impact strength is highest at R2H1 i.e. at 300 rpm speed and at 30mm height of blade. The increase in the impact strength shows the better mixing and bonding of fly ash particles with matrix i.e. with Aluminium.

B. FE-SEM/EDS

To evaluate the microscopic characteristics FE-SEM/EDS was performed on the cast samples. It was performed on SEM/EDS machine of model JEOL, JSM-6610 LV, from Indian Institute of Technology (IIT) Ropar.

Element	Weight %
Al	43.14
C	32.60
O	21.28
Zr	1.41
Si	1.14
MgO	0.44

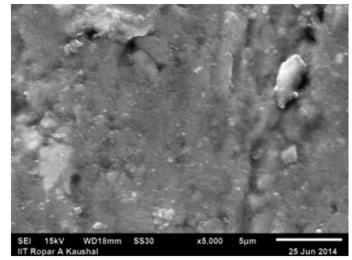

Fig. 1.2 SEM/EDS 5000X at 5% fly ash, with 500 rpm and 30mm height of stirrer blade

The major constituents of fly ash are Silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), Fe_2O_3 and minor constituents of fly ash are Cao. Mg, Ca etc.The SEM/EDS test shown in the figure indicates the mixing of fly ash into matrix. In figure, there is formation of Si

Element	Weight%
O	36.66
C	35.14
Si	12.55
Al	12.36
MgO	1.93
Zr	1.02
Na	0.33

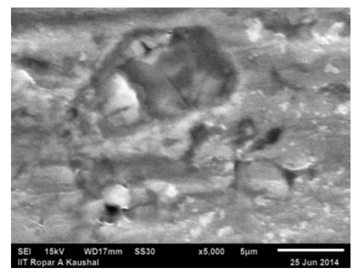

Fig. 1.3 SEM/EDS 5000X at 5% fly ash, with 300 rpm and 60mm height of stirrer blade

It indicates that there is a chemical reaction took place between fly ash and matrix material. According to P.K. ROHATGI and R.Q. GUO, during the chemical reaction between aluminium and fly ash, there is formation of metallic element which is Si.

In figure 1.3, there is formation of MgO or $MgAl_2O_4$ by following reaction;

$$2Al + 2SiO_2 + Mg \rightarrow MgAl_2O_4 + 2\ Si$$

The formation of MgO depends upon the content of Mg in present in the aluminium alloy.

C.Hardness test

To measure the hardness of the prepared AMC samples, hardness test was performed on Vicker hardness tester; model VM 50 of capacity 50 kgf with diamond indenter. The hardness values are shown in the table:

TABLE IV VARIATION OF HARDNESS WITH RESPECT TO SPEED AND HEIGHT

SAMPLE No.	PARAMETERS	HARDNESS (HV)
Al-6063	-------	60
1	5%R1H1	63.4
2	5%R1H2	72.2
3	5%R2H1	70.2
4	5%R2H2	72.4

D. Comparison of hardness with different process parameters

The variability in the value of hardness indicates that there is influence of stirring process parameters (Speed and Height) on the mechanical properties of the cast samples. The figure1.4 contains a bar chart drawn between harness of cast samples and parameters taken.

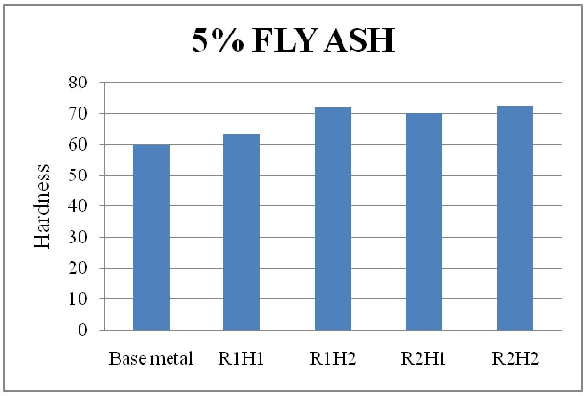

Fig. 1.4: Hardness at different process parameters with 5% fly ash

From the graph, it is clear that the hardness of cast AMC is increased as compared to unreinforced base metal. The variation in the value of hardness shows the influence of process parameters on the mechanical properties of the cast samples. Because the AMC was prepared with same wt% of fly ash that was 5%. The increase in the hardness is due to the presence of hard fly ash particles which offers more resistance to plastic deformation which leads to increase in the hardness of composites. From the results, it is clear that with variable speeds of 300rpm and 500rpm and at common stirring height of 60mm, the hardness value is maximum. It shows the influence of height of the stirring blade. Because the particles of fly ash are lighter than matrix and they tend to float on the surface, with high stirrer placement there is better mixing of floating fly ash with matrix which results in increase in the hardness of the AMC.

VIII. CONCLUSION

From the analysis, it is concluded that there are improvements in the mechanical properties of the cast AMC with addition fly ash as compared to unreinforced base metal. The following parameters showed optimum results under the given set of conditions:

- At stirring speed of 300rpm and stirrer height of 30mm, maximum impact strength was achieved among the tests conducted.
- The hardness was maximum at 60mm height of the stirring blade at both stirring speeds.

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