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SYNTHESIS OF AL-FLY ASH COMPOSITE BY STIR CASTING TECHNIQUE

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ABSTRACT

In this paper stir casting technique has been used to process Al-fly ash composite. This paper also includes problems encountered during the processing of Al-fly ash composite. To process Al-fly ash composite, fly ash particles less than 90 μm size were added 8 weight percentage of aluminum(>99% pure) in molten aluminum and mixed using mechanical stirrer. Fly ash addition not only makes aluminium harder, stronger, stiffer and more wear resistant but also saves energy consumption and helps in cutting down green house emissions by utilizing almost freely available fly ash which is a waste of thermal power plant and problematic to dispose off. But sometimes agglomeration of ash particles and porosity occurs readily during the composite manufacturing, leading to inferior mechanical properties of composite.

Keywords: *Stir casting technique, Fly ash, Agglomeration and Porosity*

1. Introduction

The aluminum metal matrix composites are produced either by casting route or by powder metallurgy. The former has the advantages of producing the composites as lower cost of production and possibility of producing larger components. However, the inherent difficulties of casting route are non wettability of ceramic particles by liquid aluminum [1], segregation of particles, higher porosity level and extensive inter-facial reaction due to higher processing temperature. Stir Casting is the simplest and the most cost effective method of liquid state fabrication. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional metal forming technologies. Aluminium-fly ash composite is metal matrix dispersion strengthen composite in which soft and ductile aluminium matrix is strengthen by hard and brittle fly ash particles. DRA composites have been developed in the past two decades for various automobile, aerospace, electronic packaging and other structural applications [2]. Now much more emphasis is given to develop lighter material using low cost reinforcements. 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 furnaces and thermal power plants has been successfully dispersed into cast and wrought aluminum alloys to make aluminum-alloy–fly-ash (ALFA) composites [3].There are two types of fly ash, namely precipitator (solid particle) and cenosphere (hollow particle). Incorporation of fly ash particles improves the wear resistance, damping properties, hardness, strength and stiffness and reduces the density of Aluminium [4]. The substitution of aluminum with fly ash can decrease the need of energy intensive-aluminum, resulting in energy savings. Aluminum-fly ash composite will also require reduced energy for remelting during recycling since fly ash will not melt only aluminum fraction will have to be melted. Aluminium requirement can effectively be reduced by replacing it with Al-fly ash composite. Al-Fly ash composites are being widely used in various applications such as automotive parts, industrial furniture, machine cover, highway signs, frames & ducts, etc.

2. Processing of Al-Fly Ash Composite

Relatively low cost stir casting technique is evaluated for use in the processing of Al-Fly Ash composite.[5] Stir Casting is a liquid state method of composite manufacturing, in which a dispersed phase is mixed with a molten matrix metal by means of mechanical stirrer.

2.1 Stirring setup description

The biggest challenge was setup that should be economic and able to mix light ash particles into dense molten aluminium effectively. The essence of Set-up is in three main components, viz; structure, motor, and impeller-shaft assembly. Fig.1 shows photograph of setup placed on the furnace ready to work.

i. Structure: The whole structure was made of 1.5 inch angles which were accurately cut & then welded together.
ii. Motor: A single phase 0.5 HP DC motor with maximum 700 rpm is used. To control the speed of motor and jerk free start a regulator of 600 watt is connected.
iii. Impeller assembly: The impeller used for the purpose of mixing fly ash into aluminium is shown in Fig. 2. The fly ash particles being very light are difficult to uniformly mix into molten aluminium. For uniform dispersion impeller must be capable of producing enough vortexes to effectively pull the lighter fly ash into the melt [3]. Keeping this fact in mind impeller was designed. The design of impeller was based on propeller design. Impeller is having three curved blades cut from 4 mm thick MS plate, varying in width from top to bottom, welded in spiral way on the mild steel hub. These angled blades create propelling action by pulling surrounding matter radially and force it to flow out axially with high enough vortex which leads to better mixing. The impeller hub was internally threaded at bottom to fix with the shaft and the top end of shaft was coupled to the motor shaft.

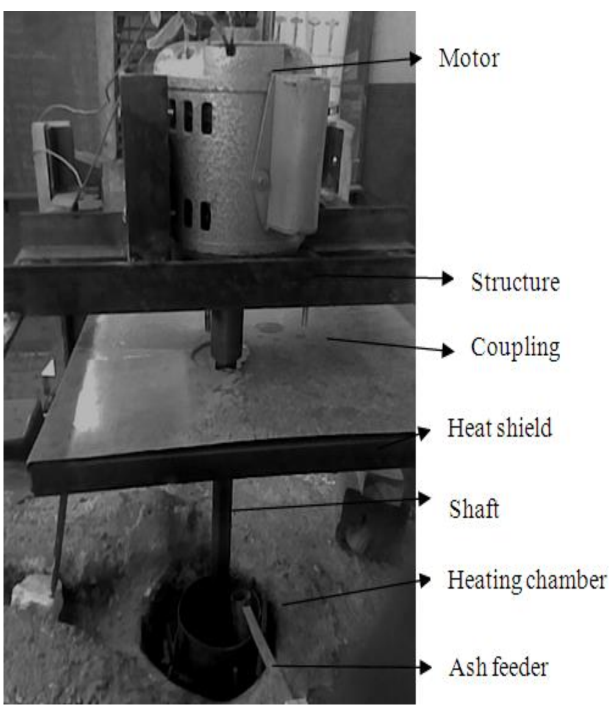


Fig. 1 Setup Placed on Furnace Heating Chamber

Fig. 2 Impeller

2.2 Procedure of producing Al-Fly Ash composite

Two kg of pure aluminium put into crucible for composite synthesis. After melting, stirrer dipped into molten aluminium and started rotating gradually with the help of speed regulator. The maximum speed of impeller was 600 rpm [6]. 8 wt % fly ash i.e.160 gm was preheated at 100℃ about two hours before mixing. At the time of formation of vortex created by stirrer, preheated fly-ash particles were added with the help of an ash feeder into the molten at the rate of 3.2 gm/min. Then the melt was poured into the sand moulds of different sized cavities. After solidification the cuboids of the composite were ready for testing. Mixing of ash into molten aluminium is shown in Fig. 3

2.2.1 Possible chemical reactions

Thermodynamic analysis indicates that there is the possibility of chemical reactions between aluminum melt and fly ash particles. These particles contain alumina, silica, and iron oxide, which during solidification, processing of aluminum–fly ash composites or during holding of such composites at temperatures above the melting temperature of aluminum, are likely to undergo chemical reaction.

The possible chemical reactions between molten aluminum and fly ash are as follows:

$$2\,Al(l) + 3/2\,SiO_2(s) = 3/2\,Si(s) + Al_2O_3(s) \quad (930 \text{ to } 1683K) \qquad (1)$$

$$2\,Al\,(l) + Fe_2O_3(s) = 2\,Fe(s) + Al_2O_3(s)$$
(930 to 1033K) (2)

At the temperature of about 850°C silica and ferrite reduces in their elements, i.e., Si (silicon) and Fe (iron) while oxidizing aluminium into Al_2O_3 (alumina) according to equation (1) and (2), which is extremely hard and brittle. Presence of 11.73% oxygen is due to these oxides. Progress of the chemical reactions between the aluminum and fly ash particles can be studied using differential thermal analysis (DTA). The microstructure of the resulting samples was observed through scanning electron microscopy (SEM). The change in the chemical composition of aluminum matrix due to the chemical reactions can be examined by energy- dispersive X-ray (EDX) analysis. [7]

Fig. 3 Ash Mixing

3. Problems encountered during Processing of Al-Fly Ash Composite

3.1 Porosity

Surfaces were examined as full of gas holes as shown in Fig. 4 even small holes were observed deep inside. Primary reason is absorbing gases from the air during casting and other may be low wettability, inefficient stirring. Wettability can be improved by surface treatment of particles in an acidic solution under ultrasonic vibration for 5-10 min., filtered and dried in an oven. Even, presence of 0.35-0.40% magnesium enhances wettability [1]. Stirrer was designed to rotate in one direction only. An additional reverse rotation and slight up and down movement of stirrer would offer better mixing. Liquid aluminum actively dissolves hydrogen; dissolved hydrogen evolves as porosity during the solidification of aluminum. So, it needs to be degassed. Degassing is done either by purging of aluminium with nitrogen or inert gases like argon, using ultrasonic vibrations or using degassing fluxes composed of chlorine and fluorine containing salts (0.2-0.3 wt. % of aluminium).

3.2 Agglomeration

The biggest problem faced during synthesis of ash composite was agglomeration tendency and low wettability of fine ash particles that leads to non uniform dispersion of particles. It is known fact that better the dispersion of reinforcement particles better and more uniform properties of composite

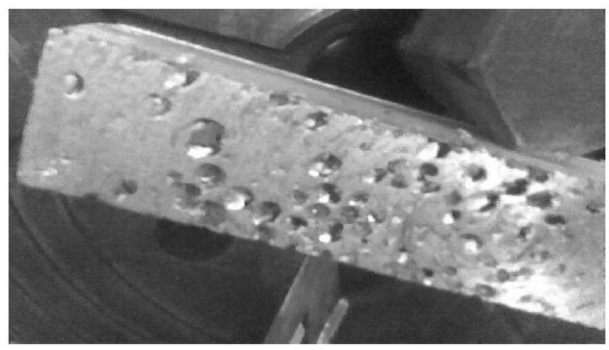


Fig. 4 Gas Holes in Composite

4. Micro structural study

Studies focused on the micro structural changes occurring between as cast specimen of pure aluminium and stir cast Al-fly ash composite (8 wt.%). Studies were performed with ZEISS EVO Series Scanning Electron Microscope EVO 50.

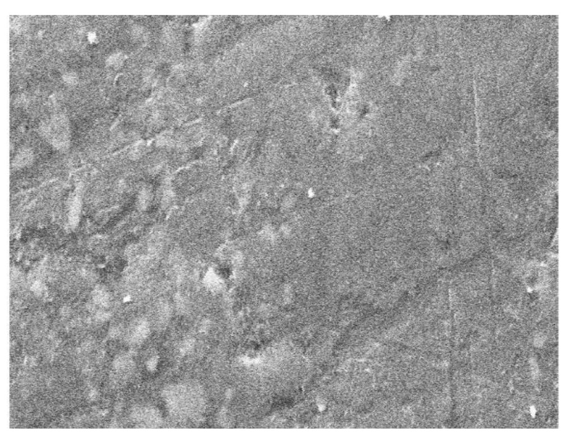


Fig. 5 SEM Micrograph of Pure Al

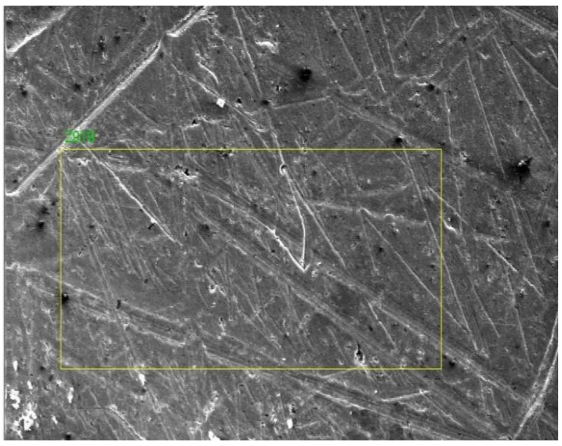


Fig. 6 SEM Micrograph of Al-Fly Ash Composite

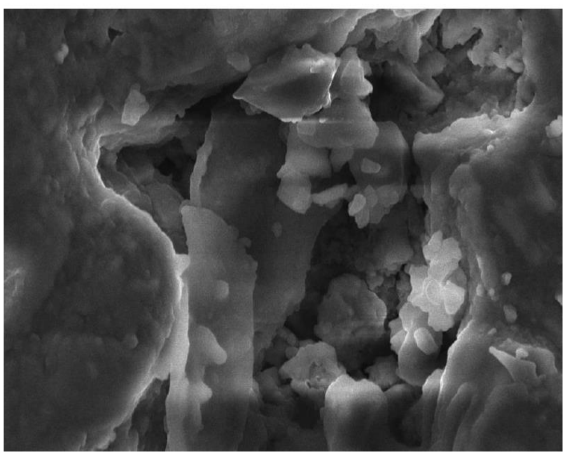


Fig.7 SEM Micrograph of Al-Fly Ash Composite (4kx)

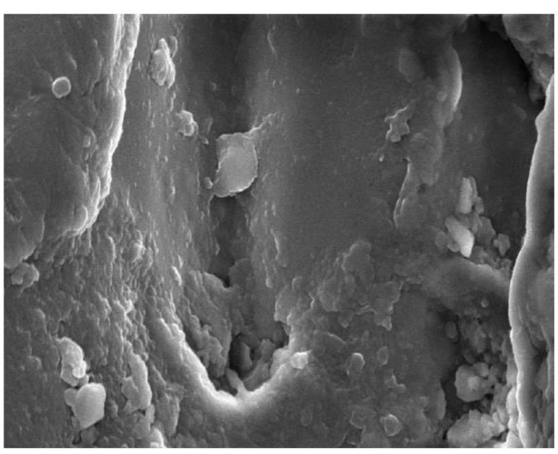


Fig.8 SEM Micrograph of Al- Fly Ash (5kx)

Fig. 5 is SEM micrograph of pure aluminium showing continuous phase of Aluminium. Fig. 6 is the result of low magnification at 500× showing the distribution of fly ash particles in aluminium matrix while Fig. 7 and Fig. 8 are highly magnified with magnification 4000× and 5000× respectively.. The dispersion of ash particles is not uniform because of agglomeration of particles took place that is clear in magnified micrographs in Fig. 7 and Fig. 8.

4.1 Quantitative Analysis

Studies were conducted with ZEISS EVO Series Scanning Electron Microscope EVO 50 equipped with Energy Dispersive X-ray spectroscopy and Argon flash spectroscope. Quantitative analysis with EDX is done for ash composite and fly ash.

An EDX analysis shows that major content in the fly ash are Al2O3, SiO2 and mullite. The chemical composition of as received fly ash particles, in weight percent, is 61.59 O, 12.19 Al, 14.75 Si, 4.43 Fe, 1.84 Ti, and 1.80 Ca. EDX spectrum of fly ash is given in Fig. 9.

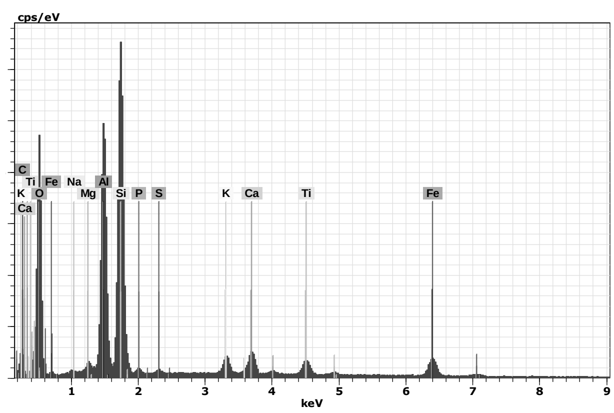
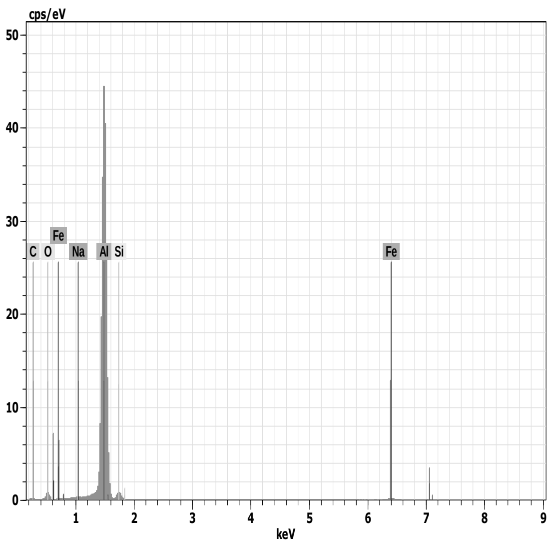


Fig. 9 EDX Spectrum for Fly Ash

The quantitative analysis is done to find out elemental changes occurring due to processing of pure aluminium to fabricate composite. Elemental identification of pure aluminium was conducted with Argon flash spectroscope and the contents are:

	Al	Si	Fe	Cu	Mn	Mg	Zn	Cr
Ave	99.4	0.170	0.262	0.0331	0.0093	0.0120	0.0060	0.0019
	Ni	Ti	Be	Ca	Li	Pb	Sn	Sr
Ave	< 0.0050	0.0210	< 0.0001	0.0041	0.0002	0.0028	< 0.0100	0.0003
	V	Na	Bi	Zr	B	Ga	Cd	Co
Ave	0.0162	0.0024	< 0.0050	0.0045	0.0007	0.0173	< 0.0010	< 0.0030

The ash composite tested with EDX and the resulting spectrum and content table are as:



El	AN	Series	norm. C [wt.%]	Atom. C [at.%]	Error [%]
C	6	K-series	5.09	10.07	1.1
O	8	K-series	11.73	17.42	2.1
Na	11	K-series	1.00	1.03	0.1
Al	13	K-series	77.82	68.52	4.4
Si	14	K-series	2.63	2.23	0.2
Fe	26	K-series	1.72	0.73	0.1
		Total:	100.00	100.00	

Fig. 10 EDX Spectrum for Al-fly Ash Composite

The mixing of fly ash through stir casting results reduction in aluminium percentage from 99.4% to 77.82% and increment in silicon and iron content from 0.17% and 0.262% to 2.63% and 1.72% respectively. An additional amount of oxygen 11.73% appeared in the composite is due to ash and reduction oxidation reaction taking place between phases of ash and aluminium. So, the oxygen is present in the form of oxides of which majorly having alumina, silica and hematite due to reaction occurring between ash and pure aluminium above melting point.

4.2 Mechanical Properties

Studies dedicated to evaluate changes in mechanical properties of aluminium by adding fly ash. Addition of fly ash improves hardness, stiffness and strength while reducing density, ductility and toughness. These changes can be measured through different mechanical tests.

4.2.1 Impact test:

The Charpy impact test is used which is also known as the Charpy v-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness.

Table 1: Energy Absorbed up to Fracture

Material	Energy absorbed
Pure Al	40
Al-Fly ash composite	6

Fig. 11 Fractured ends of Pure Al

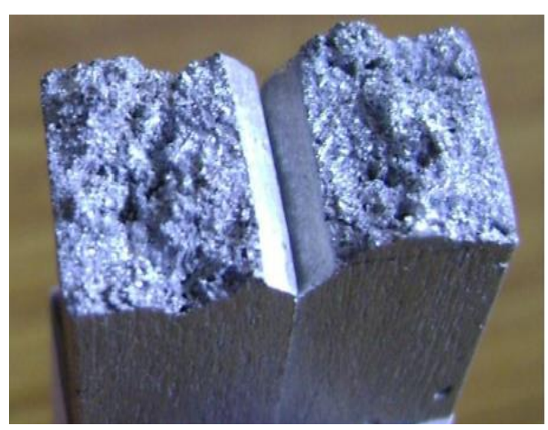


Fig. 12 Fractured ends of Al-Fly ash Composite

4.2.2 Hardness test

The Vickers hardness test method is used for hardness measurement. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. The load applied on pure aluminium and ash composite is 300 gm. The results are as follows:

Table 2: Hardness Comparison

Material	Vickers Test
Pure Al	Depth = 17.62 μm D1 = 121.15 μm D2 = 125.55 μm HV = 34.5
Al-Fly ash composite	Depth = 15.79 μm D1 = 110.57 μm D2 = 110.55 μm HV = 45.5

4.2.3 Density

Density is measured by Archimedes principle and it was found as follows:

Table 3: Density Comparison

Material	Density
Pure Al	2.710 gm/cm^3
Al-Fly ash composite	2.532 gm/cm^3

Table-3 reveals that weight of aluminium was reduced by 6.58% due to addition of fly ash.

4.2.4 Tensile tests

Tensile properties often are measured during the development of new materials, so that different materials can be compared. The tensile test is a good predictor of how the part will react under real life loading. Table 1.4 gives values obtained through tensile test while Fig. 13 and Fig. 14 are giving stress strain behavior of both the materials.

Table 4: Tensile Properties

Properties	Pure Aluminium	Al-Fly ash composite
Yield strength	3.01 kg/mm^2	04.96 kg/mm^2
Ultimate Tensile strength	5.33 kg/mm^2	12.57 kg/mm^2
% Elongation	14.05	05.17
E- Modulus	48.02 kN/mm^2	155.87 kN/mm^2

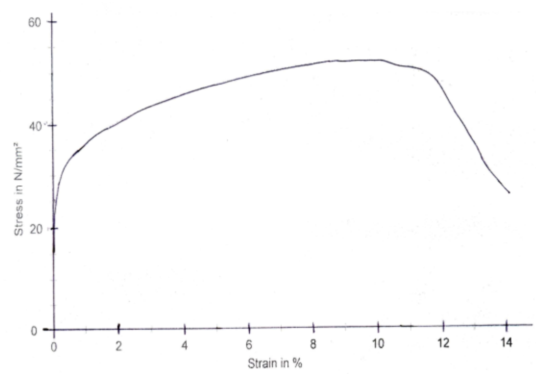


Fig. 13 Stress-Strain Curve for Pure Aluminium

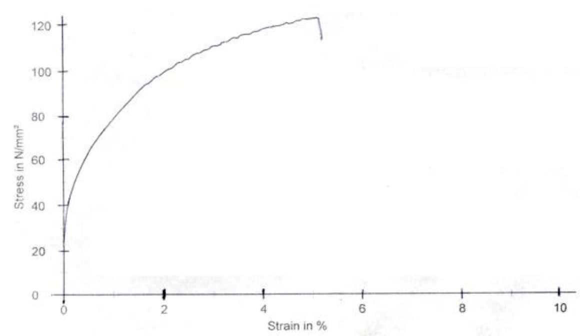


Fig. 14 Stress-strain Curve for Ash Composite

5. Conclusion

The mixing of fly ash results a complete transformation in mechanical properties of aluminium. Mechanical properties like hardness, specific strength and wear resistance are increased and on the contrary toughness, ductility, density and shrinkage are reduced. This reduces the generation of green house gases as they are produced during the bauxite processing and alumina reduction. Molten alluminium has affinity to hydrogen. Hydrogen is absorbed by alluminium creating porosity. Therefore to avoid this porosity it is necessary that melt should be supplied with some degassing agents. The Chemical reactions between aluminum and fly ash particle occur at temperature of 700°C to 850°C. Al-Fly ash composite is a conductive material and can be processed by unconventional machining like EDM & ECM. Surface treatment of fly ash particle is necessary to increase specific surface absorption area to be properly wet by aluminium for good dispersion with minimum agglomeration and porosity otherwise it starts segregating chunks of aluminium by covering it.

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