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Development and Analysis of Fly Ash Reinforced Aluminum Alloy Matrix Composites

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ABSTRACT: *The use of low cost materials in the reinforcement of metal matrix composites is increasing rapidly. The present study deals with development of metal matrix composites (MMC) of A356.2 alloy reinforced with locally available inexpensive fly ash (FA) particles. Fly ash particles of 2, 4, 6, 8 and 10% by weight were used to prepare the metal matrix composites by using stir casting method. Various tests such as hardness test, compression test, and tension test were performed to analyze different mechanical properties of the resultant composites. The results of the tests reveal that the hardness, compressive strength and tensile strength of the aluminum alloy increases with the increase in weight fractions of fly ash particles. The resultant composites may be used as replacements of raw aluminum due to their superior mechanical properties.*

Keywords : *Aluminum Alloy, Fly Ash, Mechanical Properties, Metal Matrix Composite*

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I. INTRODUCTION

The world is looking for the maximum possible optimization in every field nowadays. With no exception in engineering, engineers are also looking for creating the extreme best from the best. During these developments, in some way or the other,the environment is much affected. The development of low cost metal matrix composites reinforced with eco-friendly material has been one of the major innovations in the field of materials in the past few decades. Aluminum alloys reinforced with fly ash particles exhibit superior mechanical properties to unreinforced aluminum alloys and hence are candidate for engineering applications.

Particle-reinforced aluminum metal matrix composites (MMCs) containing SiC and Al_2O_3 have received great attention in the past few decades because of their improved wear resistance, reduced coefficient of thermal expansion (CTE), high elastic modulus, and improved strength compared to unreinforced aluminum alloys [1, 2]. Although they have found potential applications in weight-critical components in automobile, aerospace and defense systems [2–5], the application base of these particulate MMCs is limited by their high production cost. Recently, inexpensive aluminum alloy MMCs reinforced with fly ash, a waste by-product of coal combustion, has been engineered [6–11] to serve as a substitute for conventional particulate MMCs in several applications in order to widen the application bases of this class of MMCs. The addition of fly ash into aluminum MMCs is a value-added initiative that lowers the disposal cost of fly ash, increases energy savings by reducing the quantity of aluminum produced, and creates a healthier environment.

Aluminum- fly ash composite is metal matrix dispersion strengthened composite in which soft and ductile aluminum matrix is strengthened by hard and brittle fly ash particles. Discontinuously reinforced aluminum (DRA) based metal matrix composites are of increasing interest because of their high specific stiffness and strength, high isotropic and excellent wear resistance as well as cost effective manufacturing. DRA composites have been developed in the past two decades for various automobile, aerospace, electronic packaging and other structural applications [12]. Fly ash is a low density reinforcement which can be found abundantly as solid waste by-product during coal combustion in thermal power plants. It is also very inexpensive. It is being used in cast and wrought aluminum alloys to make aluminum-alloy–fly ash (ALFA) composites [6]. Hence, fly ash reinforced composites are more likely to overcome the cost barrier for wide spread applications. The substitution of aluminum with fly ash can decrease the need of energy intensive-aluminum, resulting in energy savings [13]. Al-fly ash composites are being widely used in various applications such as highway and runway signs, sliding tracks for windows and doors, automotive parts, industrial furniture, machine cover, frames & ducts, etc. [14]. It is reported that A356 reinforced with fly ash particles of narrow range (53-106μm) and wide size range (0.5-400 μm) resulted in increase in hardness, elastic modulus and 0.2% proof stress [8]. Progress in this area depends upon the development of metallurgy, casting and solidification, heat and surface treatments. Since there is a direct relationship between fuel consumption and vehicle weight, fuel usage and price-to performance ratio can be improved by reducing weight. Ceramic reinforced aluminum matrix composites have attracted more attention due to their combined properties such as high strength to weight ratio, high stiffness, low thermal expansion coefficient and superior dimensional stability at high temperatures as compared to the monolithic materials. Aluminum matrix composites reinforced by SiC/fly ash particles are prepared by using modified stir casting method. The stirring arrangement improves the distribution and wettability. The mechanical behavior and microstructure of Al-fly ash composites are investigated. After the investigation of the fly ash composites it has been found out that this material is suitable for automobile clutch plate.

The overall approach of the present study is to develop and fabricate something unique from the traditional metal or similar types of aluminum alloy. After completing the experimental work, the resulting composites we found were not only unique composites but they were also enhanced in physical properties. These composites can be used for vast and advanced applications with low production cost. Besides, this type of composites are much more sustainable and environment friendly than normal aluminum alloy.

II. EXPERIMENTAL PROCEDURE

The matrix material was melted and preheated reinforcement material was mixed with it using stir casting method. The mixture was then poured in a mold for uniform solidification. The methodology has been showed in step by step below.

2.1 Materials Used

For experimental investigation, aluminum alloy A356.2 was used as the matrix material whose chemical composition is listed in Table 1 [15]. A356.2 is an alloy with good casting properties. The alloying elements silicon and magnesium leads to high strength and hardness. The components made with A356.2 alloy are ideal for applications which require good thermal properties but low weight. It can be easily cast and main advantage of this material is that preheating is not required before casting or testing.

Table I: Chemical Composition of A356.2

Constituent	Al	Si	Fe	Mn	Mg	Zn	Ti	Cu	Other
Wt.%	91.3-93.5	6.5-7.5	.12	.05	.30-.45	.05	.20	.10	Remainder

Class C fly ash as designated in ASTM C618 standards was used as filler material which was obtained from the Barapukuria Coal Power Plant, Bangladesh. The particle size ranged from 50-100 μm.Class C fly ash normally comes from coals which may produce an ash with higher lime content generally more than 15%, often as high as 30%. Elevated CaO may give Class C fly ash unique self-hardening characteristics [16].

2.2 Stir Casting

At first, sand molds were made two days before the casting as shown in Fig. 1(a). Initially, A356.2 Al alloy was weighed and charged into the crucible and heated to about 750ºC till the entire alloy in the crucible was melted. The reinforcement particle fly ash was weighed and preheated to 600℃ before incorporation into the melt. This was done to facilitate removal of any residual moisture as well as to improve wettability. The stirrer made up of stainless steel was lowered into the melt slowly to stir the molten metal. The preheated fly ash particles in 2% by weight were added into the molten metal at a constant rate. The stirring process was continued for 2 minutes, even after the completion of particle feeding as shown in Fig. 1(b).The mixture was poured into the mold and was allowed to cool down to room temperature. By repeating the same procedure the other compositions were prepared with mixing fly ash 4, 6, 8 and 10% by weight respectively. When the mold was cool, it was broken and the composites were taken out as shown in Fig. 2.

Figure 1 (a) Preparation of Mold (b) Mixing A356.2 and Fly Ash

Figure 2 (a) Pouring Molten Metal into the Mold (b) Cast A356.2/FA Composites

2.3 Specimen Preparation

Different types of machining operations were carried out to make different types of test specimen.

- First of all, facing was done on the raw cast composite work pieces.
- Then turning was carried out to obtain cylinder shaped work pieces.
- Grinding was done to cut away a part of the cylinders to make specimen for the compression test and hardness test.
- Turning and taper turning was done to obtain desired specimens for tension test.

2.4 Experimental Specimen Analysis

Five specimens were made for each experiment:

- Specimen 1 : A356.2/FA (2 wt.%) matrix composite
- Specimen 2 : A356.2/FA (4 wt.%) matrix composite
- Specimen 3 : A356.2/FA (6 wt.%) matrix composite
- Specimen 4 : A356.2/FA (8 wt.%) matrix composite
- Specimen 5 : A356.2/FA (10 wt.%) matrix composite

2.5 Testing for Mechanical Properties

To determine different characteristic changes in the mechanical properties of the specimens, different tests namely, hardness test, tension test, elongation test, compression test were carried out.The tension tests were conducted on these specimens according to ASTM E8 standards at room temperature. Diameters and gage lengths of the specimens were 12.5 mm and 50 mm respectively. A hydraulic universal testing machine (Time Group Inc., China) was used for the tension test. The compression tests were conducted as per ASTM E9 standards.The diameter of the specimens were20 mm and lengths were 60 mm. The hardness was measured using a Brinell Hardness Tester which had a ball of 5 mm diameter. A load of 500 kg was applied for a period of 30 seconds in accordance with the ASTM E10 standards.

III. RESULTS AND DISCUSSION

After collecting all the data, graphs were plotted and also mechanical properties of the composites were compared with that of pure alloy.

3.1 Hardness

Hardness is the measurements of how resistant solid matter is to various kinds of permanent shape change when a compressive load is applied or deformation.The standard BHN no. for A356.2 alloy is 75 [15].The hardness of different composite material has a great impact on its mechanical properties. In our experimental work piece, it has been found that the hardness of different work pieces is increased due to the increased percentage of fly ash in aluminum alloy.From Fig. 3, it can be noted that the hardness of the composites increase with the increase in weight fraction of the fly ash particles.

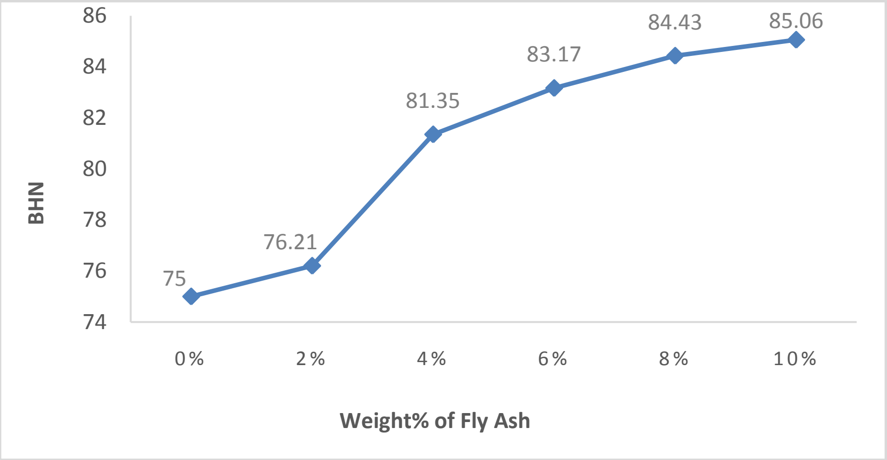

Figure 3 Variation of Hardness with Weight Fraction of Fly Ash

Tensile Strength

In the present study, it has been found that the tensile strength is increased due to the increased percentage of fly ash in the aluminum alloy.Standard casted aluminum alloy A356.2 has a good tensile property. It has been found that standard tensile strength of aluminum A-356.2 is almost 278 MPa [17]. Fig. 4 shows the variation of tensile strength of the composites with the different weight fractions of fly ash particles. It can be noted that the tensile strength increases with the increase in the weight percentage of fly ash. This is because the fly ash particles act as barriers to the dislocations when taking up the load applied. The hard fly ash particles obstruct the advancing dislocation front, thereby strengthening the matrix. The observed improvement in tensile strength of the composite is attributed to the fact that the filler fly ash possess higher strength.

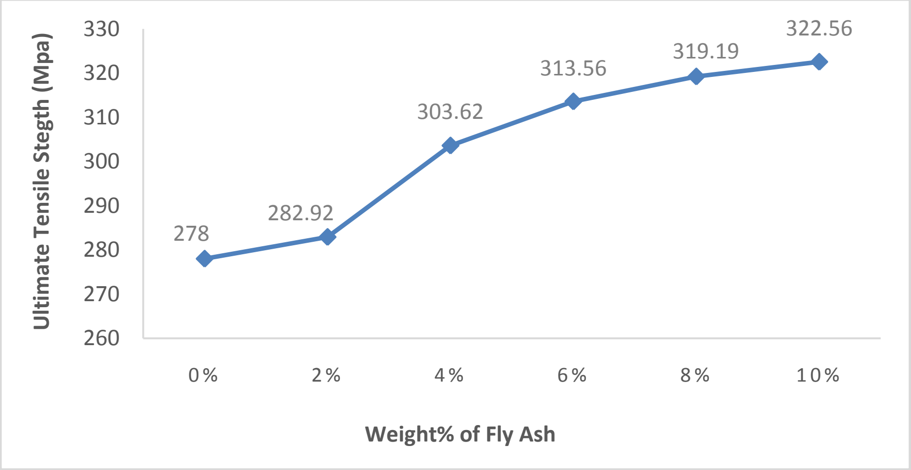

Figure 4 Variation of Tensile Strength with Weight Fraction of Fly Ash

3.2 Compressive Strength

Compressive property defines how much compressive force a work piece can sustain without damage the work piece. It has been found that, compressive strength of aluminum alloy A-356.2 is around 250 MPa [18].It can be observed from Fig.5 that the compressive strength increased with an increase in the weight percentage of fly ash particles. This is due to the hardening of the base alloy by fly ash particles.

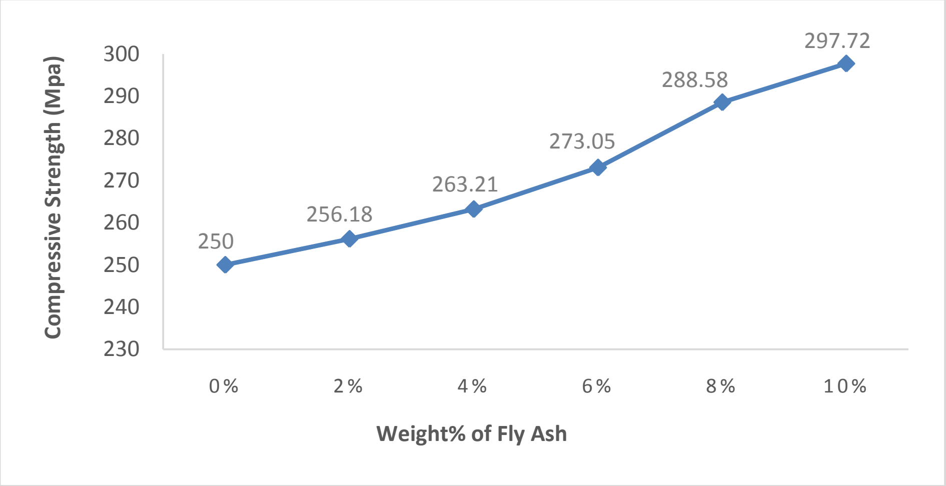

Figure 5 Variation of Compressive Strength with Fraction of Fly Ash

3.3 Ductility

Elongation of a work piece defines how much length increases in a work piece during tension. It has been found that due to increase in percentage of fly ash in aluminum alloy, ductility decreases. And due to decrease of ductility, elongation percentage of different specimen decreases. Standard aluminum alloy A356.2 has elongation percentage around 6 [15]. Fig. 6 shows that the ductility of the composites decreased with the increase in weight fraction of the fly ash. This is due to the hardness of the fly ash particles or clustering of the particles. The various factors including particle size, weight percent of reinforcement affect the percent elongation of the composites even in defect free composites.

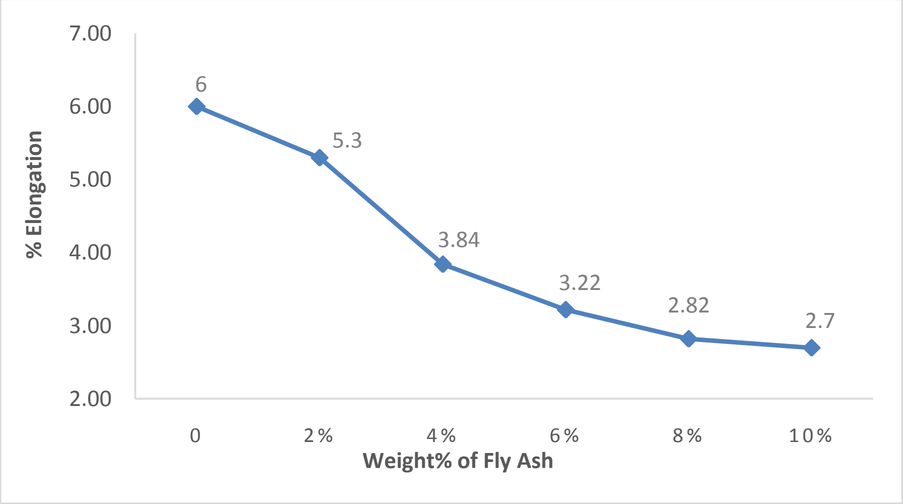

Figure 6 Variation of Elongation with Weight Fraction of Fly Ash

IV. CONCLUSION

Fly ash particles were successfully incorporated in A356.2 alloy by using stir casting techniques. The hardness of A356.2/FA composites increases with increase in fly ash contents. The ultimate strength increases with increase in fly ash content. The compressive strength of A356.2/FA composites also increases with the increase in fly ash content. The elongation decrease with the increase in fly content. Fly ash, an industrial waste can be successfully used as a reinforcing material to produce Metal Matrix Composites (MMCs) components in aluminum matrix. Thus the use of fly ash for the production of composites can turn industrial waste into industrial wealth and inevitably solve the problem of storage and disposal of fly ash. Incorporation of fly ash particles in aluminum matrix can lead to the production of low cost aluminum composites with improved hardness and strength. These composites can find application where lightweight materials are required with good stiffness and strength.

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