Effect of Fly Ash Content and Particle Size on Physical Properties of Polyester-Based Composites

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***Abstract—* In this investigation a class of polymer composites consisting of polyester as a matrix material with a micro-size fly ash as a filler material is developed. A set of composite specimens with filler content ranging upto 30 wt. % has been fabricated using simple hand lay-up technique. Sets of composites are prepared for two different particle sizes i.e. 75 microns and 150 microns. The effect of filler content and particle size on different physical properties of the prepared sample is studied. The various physical property evaluated are density, void content and water absorption behavior. From the experimental results, it is found that inclusion of fly ash increases the density of the composites. Voids increases with filler content. Water absorption for filled composites is higher than unfilled once.**
***Keywords—*Epoxy, fly ash, density, void content, water absorption rate.**

I. INTRODUCTION

In a thermal power plant, huge amount of fly ash is collected in an electrostatic precipitator when the combustion of coal took place. The coal combustion process generates the fused particles which are carried forward in flue gases and precipitated as solid spherical particles [1]. The management of generated fly ash is always a great concern all over the world as its disposal requires large area. Disposal of fly ash in open land area give rise to land, water and air pollution. In past, fly ash is very limited utilized mainly for civil purpose that is for landfill, production of bricks and cement. Later, the scope of using fly ash widen up with increase in use to road embankment, bricks for lightweight construction and in cement industries. It is also been used as filler for development of polymer composites at low-cost. Fly ash mainly consist of combinations of ceramics like silicon oxide, aluminium oxide and ferrous oxide in major quantities and magnesium oxide, phosphorous oxide and many other oxides in little quantities. Having a ceramic nature, it is expected that inclusion of fly ash may enhance the mechanical and thermal properties of the material. Fly ash filled polymer composites can be used in applications like in automobile, aerospace, transport and construction for load bearing application [2-5].

Over the past several years, extensive research has been carried out on fly ash reinforced polymer composites. Sroka et al. [6] investigated the effect silanization of fly ash on mechanical and thermal properties of the epoxy-based composites. They reported to achive enhancement in different mechanical and thermal properties of the material with the inclusion of fly ash in epoxy matrix. Further, they found that salinization enhances the mechanical and thermal properties of the material even more. Bachtrong et al. [7] reported the effect of fly ash content on dielectric properties of the epoxy/fly ash composites. They also modified the surface of fly ash 2 % steric acid and 2 % silane noticed the variation in dielectric properties of the material. From the analysis, they found that samples with fly ash modified by SA 2 % and silane GF80 2 % has significantly improved insulating properties compared to the non-modified fly ash samples. Similarly, the treated fly ash samples produce higher dielectric constant and loss compared to the untreated fly ash samples. Ping et al. [8] investigated mechanical properties of epoxy/fly ash composites. They evaluated the flexural and impact behaviour of the material as a function of filler content. From the experimentation, they found that with increasing weight fraction of fly ash, the impact and flexural strengths and the flexural modulus of EP composite samples increased, and reached the highest values when the weight fraction of fly ash reached 15 wt%. The mechanical characteristics of the composites however deteriorated with further increasing of fly ash content. For the EP composites reinforced with different size grading ratio of fly ash, the larger proportion of small fly ash particles, the better mechanical properties of the EP composites. Patra et al. [9] worked on evaluating the mechanical and thermal properties of the epoxy/fly ash composites. In their analysis, they found that, ultimate tensile strength and percentage elongation is maximum for sample with 30 wt. % fly ash, whereas hardness is maximum for composites with 40 wt. % fly ash. They carried out the TGA and DSC analysis of 40% fly ash epoxy composite in order to find out the thermal stability of the composite. They found that the specimen is getting decomposed in three stages and in the first stage up to 100°C there is around 2% due to moisture loss, in the second stage and third stage there is around 5% and 3.2% mass loss respectively. The peak degradation is taking place at two temperatures initially at around 300 ºC and completed within 500°C the material lose is 55%. The glass transition temperature of pure epoxy was observed at 140.4 °C which is shifted to a higher temperature at around 190°C with the inclusion of fly ash in epoxy matrix. Sim et al. [10] also evaluated the mechanical properties of epoxy/fly ash composites. They fabricated composites up to 50 vol % of fly ash for two different particle size of fly ash. While studying the mechanical properties, they found that the tensile strength increased as the amount of fly ash increased, up to a critical point. On the other hand, they found that the compressive strength of the composite increased continuously as the amount of fly ash increased. In addition, they reported that due to the pores present in the fly ash particles larger than 50 µm, the mechanical properties of the composite containing less than 90 um fly ash was reduced. Hollow-shaped large fillers such as fly ash cause significant decreases in strength, due to the thinner and weaker walls of the particles. They concluded that composites with smaller particle size fly ashes showed significant improvement in mechanical properties.

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Against this background, an attempt has been made in this research work to develop micro-sized fly ash-based epoxy composites using simple hand lay-up technique and to study their physical behavior under controlled laboratory conditions.

II. MATERIALS AND METHODS

A. *Material considered*

Unsaturated isophthalic polyester supplied by Ciba-Geigy India Ltd. is taken as the matrix materials in the present investigation. Polyester is a category of polymer which contains the ester functional group in their main chain. The term unsaturated polyester resin is generally referred to the unsaturated (means containing chemical double bonds) resins formed by the reaction of dibasic organic acids and polyhydric alcohols. Polyester resin is also known as a thermosetting plastic, which implies the plastic sets at high temperatures. Polyester resin composites are cost effective because they require minimal setup costs and the physical properties can be tailored to specific applications.

Fly ash is a by-product of coal combustion in thermal power plant. It consists of very fine particles of burned coal and comes out from boiler along with flue gases. In updated thermal power plant, this fly ash is separated from the flue gases with the help of filtering equipment or precipitator so that only flue gases may come out from the chimney. The collected fly ash consists of particles of varying sizes. From those, particles of 75 microns size and 150 microns size are separated with the help of sieve. These are used for fabrication of two different sets of composites. Fly ash mainly consist of silicon dioxide, aluminium oxide and calcium oxide together with some other minerals. The exact composition depends upon the source and composition of coal. The fly ash is used in present investigation is of class F type. The filler used as fly ash obtained from Rourkela steel plant, Odisha, India. The fly ash was a spherical or non-uniform shape. The density of the fly ash is 2.2 g/cm^3.

B. *Composite Fabrication*

In the present investigation, micr-sized fly ash polyester composite is fabricated using simple hand lay-up technique. The fabrication of composite using hand lay-up method involves following steps:

1. The room temperature curing polyester and corresponding hardener methyl ethyl ketone peroxide (MEKP) are mixed in which hardener is added 2 % by weight as recommended.
2. Micro-sized fly ash will then added to the polyester-hardener combination and mixed thoroughly by hand stirring.
3. Before pouring the polyester/filler mixture in the mould, a silicon spray is done over the mould so that it will be easy to remove the composite after curing. The uniformly mixed dough is then slowly poured into the mould so as to get the specimens as per ASTM standard for the entire characterization test.
4. The cast is than cured for 8 hours before it was removed from the mould. In this process exothermic reaction between the matrix and hardener occur which hardened the composite body in this specified duration.

Composites were fabricated with different weight fraction of filler ranging from 0 wt. filler i.e. neat polyester to 30 wt. % filler. Two categories of composites are fabricated with particle size 75 microns and 150 microns respectively. The composite fabricated under the investigation is given in table1

C. *Physical Characterization*

The experimental density (ρce) of composites under study is determined by using Archimedes principle using distilled water as a medium (ASTM D 792-91). The theoretical density (ρct) of composite materials in terms of weight fractions of different constituents can easily be obtained using rule of mixture model. The volume fraction of voids in the composites is calculated using measure and calculated density. Water absorption test were carried out to analyze the behaviour of composite in the presence of water affected environments. The test is performed as per ASTM D 570.

TABLE I
POLYESTER COMPOSITES FILLED WITH FLY ASH

Composition			
Category I		**Category II**	
Set A1	Polyester + 5 wt. % Fly ash (75 microns)	Set B1	Polyester + 5 wt. % Fly ash (150 microns)
Set A2	Polyester + 10 wt. % Fly ash (75 microns)	Set B2	Polyester + 10 wt. % Fly ash (150 microns)
Set A3	Polyester + 15 wt. % Fly ash (75 microns)	Set B3	Polyester + 15 wt. % Fly ash (150 microns)
Set A4	Polyester + 20 wt. % Fly ash (75 microns)	Set B4	Polyester + 20 wt. % Fly ash (150 microns)
Set A5	Polyester + 25 wt. % Fly ash (75 microns)	Set B5	Polyester + 25 wt. % Fly ash (150 microns)
Set A6	Polyester + 30 wt. % Fly ash (75 microns)	Set B6	Polyester + 30 wt. % Fly ash (150 microns)

III. RESULTS AND DISCUSSION

A. *Desnity and void contents*

The measured density obtained from Archimedes method and the theoretical density obtained from rule of mixture model of polyester-based composites are presented in figure 1. From the figure it can be seen that the density of composite increases with increase in filler content. The increasing trend observed is for densities obtained from measured values as well as theoretical values. The trend obtained is obvious because fly ash used in present work are having higher density as compared to polyester resin. Density of neat polyester is 1.12 g/cm^3. The maximum density value under category I is 1.275 g/cm^3 for set A6 composites which is 13.84 % higher than neat polyester. Again, the maximum density value under category II is 1.266 g/cm^3 for set B6 composites which is 13.03 %. Also, theoretically calculated density values are higher as compared to the measured values. It is because, while calculating the density, it has been assumed that the composites are free from voids, but actually, fabrication of composites gives rise to a certain number of voids within the composite body. It can further be observed that densities of category II composites are lower as compared to the density of category I composite for corresponding sets. It is because of the presence of a greater number of voids in category II composites as compared to the category I composites.

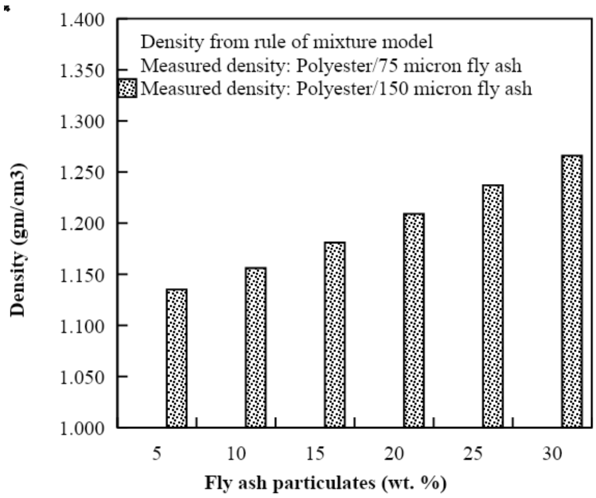

Fig. 1 Measured and calculated density of polyester filled with different particle size of fly ash

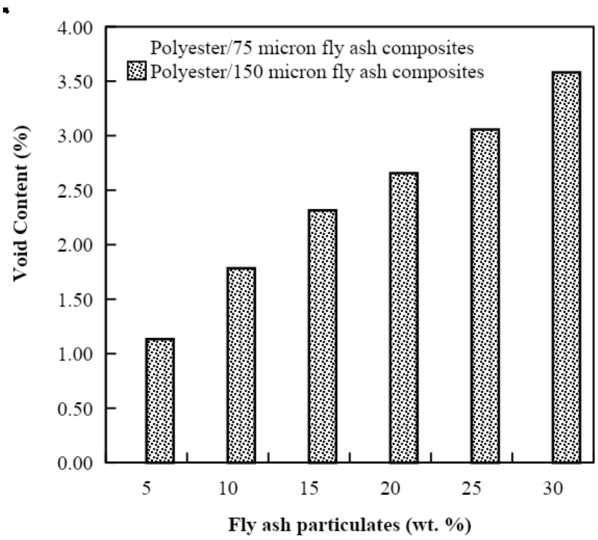

Fig. 2 Void content generated in polyester composites filled with different particle size of fly ash

The number of voids presents in different sets of composites are presented in figure 2. The void fraction is calculated with the help of measured density and theoretical density. From the figure it is clear that composites fabricated with smaller size particles give rise to a smaller number of voids as compared to the composites prepared with larger size particles. This is the main reason that density of category II is less than the density of category I for same filler content.

B. Tensile Strength

Weight of all sets of specimens is measured in dried condition, then specimens are dipped into distilled water for a span of seven days. After every 24 hour, weights of the composites are measured again. The various data obtained under are shown in the figure 3 for category I composites and in figure 4 for category II composites. The percentage of water absorption by composite specimen is recorded and from these values it is observed that as the content of fly ash increases, water absorption percentage increases. The maximum water absorption percentage is recorded for composite with maximum filler loading i.e., set A6 and set B6. These values recorded to 1.22 % and 1.34 % respectively for category I and category II composites. It is observed that, water absorption rate for category II composites i.e. composites prepared with larger particles size fly ash is higher as compared to category I composites i.e. composites prepared with smaller size fly ash particles.

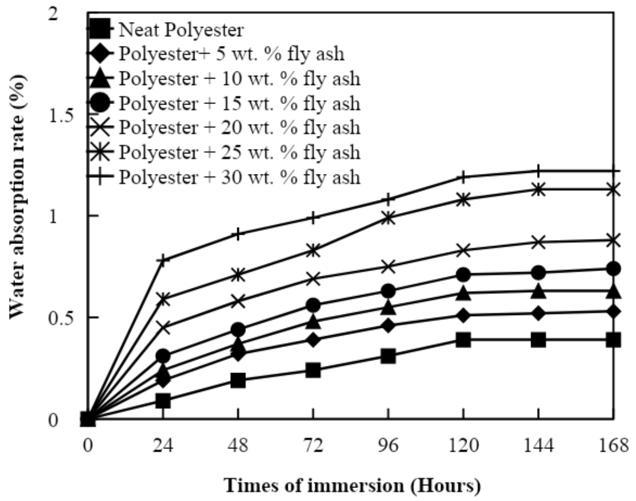

Fig. 3 Water absorption rate of polyester composites filled with fly ash of 75 microns particle size

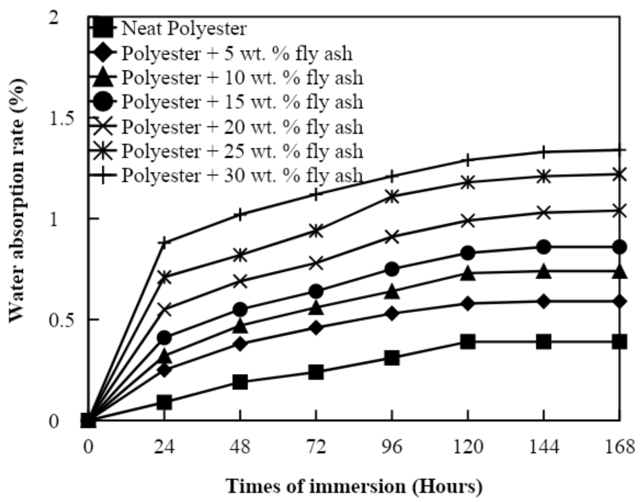

Fig. 3 Water absorption rate of polyester composites filled with fly ash of 150 microns particle size

Water absorption rate depends upon the void content as well. For category I composites, voids generated are more and hence water absorption rate is high. The results show that with higher filler content has a greater diffusion coefficient, due to the fact that absorption of water is higher, as a result of a higher content of voids. The formation of micro-cracks at the interface region, induced during the process of fabrication, can increase the diffusion transport of water via them. Furthermore, a capillarity mechanism becomes active, water molecules flow through the interface of filler and matrix, leading to greater water absorption.

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IV. CONCLUSIONS

This experimental investigation on fly ash filled polyester composites has led to the following specific conclusions:

1. Successful fabrication of polyester matrix composites reinforced with fly ash is possible by simple hand-lay-up technique.
2. The density of the fabricated composites increases with increase in weight fraction of the filler content. Category I composites shows higher density as compared to category II composites for same content of filler.
3. Voids generated during the fabrication of composites increases with increase in filler content. Further, composite prepared with larger particle size has higher void content as compared to composites prepared with smaller particle size composites.
4. The water absorption rate increases with increase in filler content and duration of immersion of composite body inside the water. Composite with high void content shows higher water absorption i.e. category II composites has higher water intake for given filler content and time.

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