Investigations on Fly Ash Reinforced Phenolic Composite for Green Environment

Amith Kumar S J, Sabeel Ahmed K

Abstract - Fly ash is the major waste product of the coal based thermal power plants. The accumulation of fly ash in large quantities becomes a major and significant disposal problem and leads to environmental pollution. The main objective of this research is to explore the possibilities of using fly ash in the development of eco-friendly composite for green environment. Eco-friendly composite is prepared by uniform mixing of fly ash and phenolic resin in equal proportions. The significant effect of fly ash on the physical and mechanical properties of eco-friendly composite is experimentally investigated as per ASTM standards. The result reveals that the physical and mechanical properties of developed eco-friendly composite using fly ash as a major reinforcing constituent makes it a potential material for engineering structural applications.

Keywords - Fly ash, Solid waste, Sustainable development, Green environment, Eco- friendly composite

1. INTRODUCTION

Coal-based thermal power installations in India contribute about 65% of the total installed capacity for electricity generation. In terms of energy supply the contribution is even higher, as these plants meet base load requirements. In order to meet the growing energy demand of the country, coal-based thermal power generation is expected to play a dominant role in the future as well, since coal reserves in India are expected to last for more than 100 years [1]. The thermal power plants generate huge amount of fly ash as a solid waste material of coal combustion. The accumulation of fly ash in large quantities becomes a major and significant disposal problem and increases pollution [2]. Fly ash is usually disposes off in the ash ponds or in the open lands and some of these enter into atmosphere by passing through the stacks along with the flue gases. It has been proved that fly ash can be advantageously used as source of essential plant nutrients like calcium, magnesium, potassium, phosphorus, copper, zinc, manganese and iron in different agro-climatic conditions and soil types in different parts of the country using different doses. It is also boosting crop growth and yield in wheat, maize, mustard, soybean ground nut etc. Fly ash increases the yield in various crops by 20-25% with high nutritional value.

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The work carried out by several researchers on fly ash application in agriculture revealed that fly ash has some beneficial as well as undesirable effects on the fertility of soil and crop yield. Fly fiery debris is a dangerous modern waste which can be utilized as a filler material and can be utilized for engineering applications. Ashutosh et al [3] investigated the significant influence of fly ash on improved tribological behavior of the fly ash reinforced epoxy composite. Investigations carried out by Jing et al [4] revealed the enhanced longitudinal wave dissipation behaviour of fly ash reinforced polyurea composites. Giuseppina et al [5] observed that compressive strength of the innovative fly ash geopolymer - epoxy composite is significantly higher than that of the fly-ash based geopolymer. Castellanos et al [6] experimental investigation reveal that the addition of fly-ash cenospheres appears to improve the structural integrity of the tiles by reducing gaps observed in clay tiles. The highest reduction in density is observed in clay fly-ash composites of approximately 36% as compared to clay samples. However, in the present work, investigations are carried out explores the possibilities of using fly ash as a major reinforcing constituent in fire resistant phenolic resin in the development of eco- friendly composite material for green environment.

2. MATERIALS AND METHODS

2.1 Materials

Materials selected for the development and characterization of eco-friendly composites are based on their availability, cost and environmental impact corresponding to the sustainable development. Fly ash (a solid waste obtained by burning coal in thermal power plant) is supplied by M/S Cenosphere India Pvt Ltd, Kolkota – India, and phenolic resin of density 1120 kg/m3 supplied by M/S Romit Resins Pvt Ltd, Raigad- Maharastra – India, are used for the fabrication of eco-friendly composite (blend of fly ash and phenolic resin).

2.2 Fabrication of eco-friendly composite

Fig 1 shows the warm press moulding machine used for the preparation of eco-friendly composite. This technique is preferred, because the curing characteristics of phenolic resin are different than other thermosetting resins (example: epoxies).

Fig 1. Warm press moulding test setup

The mould consists of two M.S Plates of size (380 × 380) mm. Mould surfaces were coated with silicon grease and then wraped with aluminium foil to ensure easy removal of composite after curing. Eco-friendly composite is made by the ratio 50:50 by weight. The mixture was then thoroughly packed in the inner cavity of the mould cavity which was kept on the lower mould plate. After packing the blend, the two mould plates were firmly clamped and then heated. The core was cured at 140 -150 0C for 15 minutes in between the MS mould plates followed by room temperature curing for at least 24 hours. Provision is also made in the mould to allow the hot gases to escape during the process of curing. Fig 2 shows the Eco-friendly composite fabricated for present investigation.

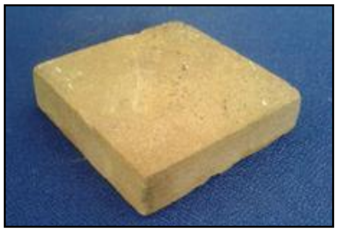


Fig 2. Eco-friendly composite

2.3 Density measurement

The density of the eco-friendly composite was measured in accordance with ASTM C271. The coupons of (300×300×12.5) mm were weighed to an accuracy of 0.1 mg and the density was then calculated using the Equation 1.

$$\rho_{composite} = \frac{1000000m}{v} \quad (1)$$

Where, ρ composite is the density of composite in kg/m3, m is the mass of the composite in grams and v is the volume of the composite in mm3.

2.4 Resin burnout test

Resin burn-out test was conducted as per ASTM D2584 to determine the reinforcement (fiber or filler) volume fraction in polymeric composite materials. In this method, eco-friendly composite coupon was burnt in a muffle furnace at 565°C so as to completely burn the resin matrix. The residue of reinforcement was cleaned to remove the ashes, dried and then weighed. The reinforcement volume fraction (Vf) was calculated using Equation 2 and the matrix volume fraction (Vm) using Equation 3.

$$V_f = \frac{\frac{m_f}{\rho_f}}{\frac{m_f}{\rho_f} + \frac{m_m}{\rho_m}} \quad (2)$$

$$V_m = 1 - V_f \quad (3)$$

Where m_f and m_m are the mass fraction of the reinforcement and the matrix respectively and ρ_f and ρ_m are the density of the reinforcement and the matrix respectively.

2.5 Evaluation of mechanical properties

Mechanical tests such as tension and compression were carried out at room temperature under low strain rate using computer interfaced Instron 3382 universal testing machine with capacities of 100 kN using the data acquisition software Instron's Series IX™/s.

2.5.1 Tension test

Tensile properties of eco-friendly composite were determined as per ASTM D 638. A dog bone shaped eco-friendly composite coupon was cut from the composite panel. The coupon was loaded to failure under uni-axial tension loading at the displacement rate of 0.5 mm/min. Poisson's ratio was determined by mounting two element strain gauge rosette at the centre of the gauge length in longitudinal and transverse direction.

2.5.2 Compression test

Compression properties of eco-friendly composite were determined as per ASTM C 365. Eco-friendly composite coupons were casted in a cylindrical mould with diameter 30 mm and height 60 mm. The coupon was loaded to failure at a constant displacement rate of 0.5 mm/min. Strain induced in the coupon was monitored by two element strain gauge rosette mounted on the coupon at its mid height.

3. RESULTS AND DISCUSSION

3.1 Density measurement

Density of eco-friendly composite solely depends on the volume fractions of the constituent materials i.e fly ash and phenolic resin. Density of eco-friendly composite is evaluated to be 671.14 kg/m3, which is less than the density of water (<1000 kg/m3). It is buoyant composite material because of less density.

3.2 Resin burnout test result

Resin burnout test reveal that, eco-friendly composite are thermally stable up to 4500C. Beyond that temperature, phenolic resin starts to decompose upon the rise in temperature up to 565°C. The fly ash from eco-friendly composite residue left after resin burnout test were washed, dried and weighed to an accuracy of 0.001g to monitor the mass changes, to determine the volume fraction of fly ash. By using equation 2 and 3, the volume fraction of fly ash was found to be 70 % and that of phenolic resin is 30%.

3.3 Eco-friendly composite under tension

Tensile stress-strain behaviour of three identical coupons of eco-friendly composite (70% volume fraction of fly ash) is shown in Fig 3. The stress increases linearly with strain upon loading until failure. The tensile modulus was determined from the slope of the linear region of the stress–strain plots. The maximum tensile strength and tensile modulus of eco-friendly composite was found to be 6.25 MPa and 1.86 GPa respectively. Further, the Poisons ratio was found to be 0.24. Low strain-to-failure of the coupon is an indication of the brittle nature of the material. Typical failure of a coupon under tension in brittle mode is shown in Fig 4. Tensile fractured surface of coupons observed under scanning electron microscope at two different regions of the fractured zone is shown in Figs 5 (a) and (b). Under tensile loading, isolated interfacial micro-cracks in composite were generated, that increases in its number with the increase in the load and finally coalesces into a catastrophic macro- crack leading to the failure of the eco-friendly composite coupon.

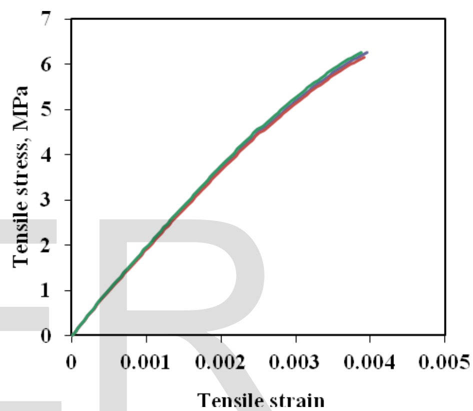


Fig 3 Tensile Stress-strain plots of eco-friendly composite

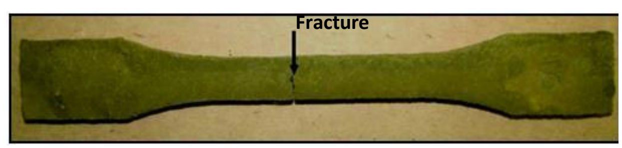
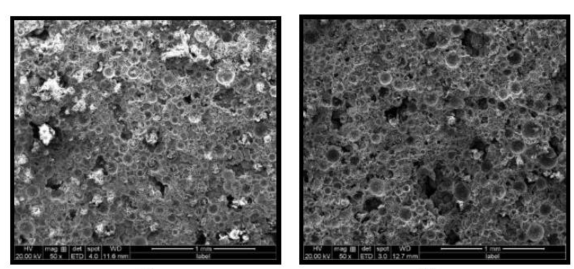


Fig 4. Mode of fracture of eco-friendly composite under tension



(a) (b)

Fig 5. SEM of fractured eco-friendly composite under tensile loading

3.4 Eco-friendly composite under compression

Fig 6 shows the compressive stress-strain behaviour of three identical coupons of eco-friendly composite having 70% volume fraction of fly ash. The eco-friendly composite coupons showed a distinctive compressive response by exhibiting three distinct regions namely; linear elastic region where stress is proportional to the strain, plateau region where the stress is nearly constant and the region of steep increase in stress for small increase in strain. The nature of the curve in the plateau region of composite coupon exhibits its strain hardening characteristic. The energy absorption capacity of the composite is significantly influenced by the stress-strain behavior and density of the composite. Area under the linear region of the stress-strain plot represents the energy required for the onset of crack in the composite, whereas the area under plateau region represents the energy required for the propagation of cracks in the composite leading to progressive collapse of the eco-friendly composite. The absorption of energy is terminated at the end of the plateau region at which the eco-friendly composite is completely crushed. The stress at the fly ash / phenolic interface may cause compressive or shear failure in the matrix and/or fly ash. The compression stress at yield was found to be 7.09 MPa which is found to be greater than the compressive strength of clay brick (3.5 MPa) [7] and Portland cement brick (2.2 – 4.4 MPa) [8]. Further, the compression modulus of eco-friendly composite determined from the slope of the linear region of its stress– strain plots was found to be 1.326 GPa. A typical mode of failure of eco-friendly composite under compression is shown in Fig 7.

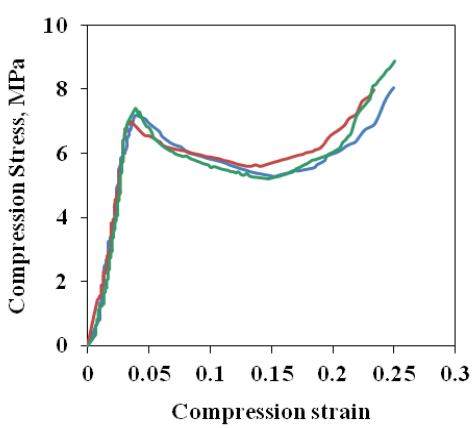


Fig 6 Compressive Stress-strain plots of eco-friendly composite

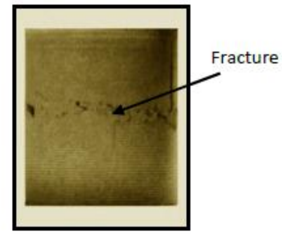


Fig 7 Compressive mode of fracture of eco-friendly composite

It was observed that, high volume fraction of fly ash in eco-friendly composite resulted in a thin layer of phenolic matrix at the interface of the fly ash. This leads to decreased compression strength and modulus of eco-friendly composite. Flatwise compression test coupons will be subjected to severe crushing ensuing in the separation of eco-friendly composite fragments from the coupon. Failure modes of eco-friendly composite observed under scanning electron microscope at different magnification levels are shown in Fig 8. SEM images reveal that, interfacial bonding failure between the phenolic matrix and fly ash, and crushing of fly ash are the predominant modes of failure of eco-friendly composite. These failure modes resulting in extensive formation of debris as can be seen from the micrographs.

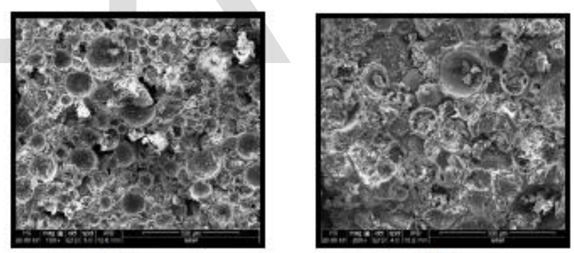


Fig 8 SEM of fractured coupons under compression loading

4. CONCLUSION

Eco-friendly composites are developed using fly ash as the major reinforcing constituent. The developed composites are tested for physical and mechanical properties as per ASTM standards. Based on the results obtained from the experiments, the following important conclusion are drawn,

1. Density of eco-friendly composite (fly ash reinforced phenolic resin) is about 671.14 kg/m3, which is less than the density of water (<1000 kg/m^3). It is a buoyant composite material because of less density.

2. Resin burnout test reveal that, eco-friendly composite thermally stable up to 4500C, beyond which the phenolic resin deteriorate.

3. The tensile strength and tensile modulus of eco-friendly composite are found to be 6.25 MPa and 1.86 GPa respectively.

4. The compressive strength of eco-friendly composite was found to be 7.09 MPa which is greater than the compressive strength of clay brick (3.5 MPa) and Portland cement brick (2.2 – 4.4 MPa). This potential of eco-friendly composite makes it possible to use as an alternative to clay brick and Portland cement brick.

5. The fly ash / phenolic resin based Eco-friendly composite promises its application in weight critical structures, decks, bulkheads, bricks and can also be used as an alternative to wood. Environmental pollution can be controlled to a greater extent by making use fly ash (a solid waste from thermal power plant) as a major constituent in the development of eco-friendly composite for structural applications.

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