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Abstract

Modern technology requires materials with distinctive combination of properties that is not possible to meet the requirements by conventional metal, alloys, ceramics and polymeric materials. **Objectives**: The point of this study is to utilize and compare mechanical properties of filler (burnt coal ash remains) and uni-directional E-Glass reinforced epoxy composites. **Methods/Statistical Analysis:** The composites of different proportions by percentage of matrix (50%, 45%, 40%, 35%), reinforcement (50%, 45%, 40%, 35%), and filler (5%, 10%, 15%) by mass is developed by hand layup method and compared for their mechanical properties. **Finding**: Mechanical properties of composite material having 50% matrix, 40% E-Glass and 10% burnt coal ash filler is found to have better mechanical property compared to other proportions except for the flexural and water absorption property. Maximum strength of 129.5MPa and 137.53kJ/m2 is observed for tensile and impact performance respectively. Higher Flexural strength was observed for composite with 50% matrix, 40% E-Glass and 5% filler. Higher flexural strength, omax of 187.92MPa is observed. A higher hardness value of range 72-73 RHN is observed with increase in filler percentage. Decrease in E-glass proportion showed a decrease in flexural strength. Lower water absorption percentage was observed with increase in filler proportion. At filler percentage above 10% a drop may observed in tensile, hardness and impact due to decrease in matrix/reinforcement. **Application/Improvement:** Coal ash which is a major environmental threat can be efficiently utilised to improve mechanical property of E-Glass/Epoxy composite. These reinforced composites have budding application due to low cost, superior characteristics and improved mechanical behaviour.

Keywords: Burnt Coal Ash, Composites, E-Glass, Epoxy, Mechanical Properties

1. Introduction

Composite is the answer for constructional materials that have low density, strong, high stiffness, abrasion resistant,

impact resistance and not easily corroded. The application of polymer based composite material is expanding because of their light weight, good mechanical and tri-

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bological responses¹. In designing of composite materials scientists and engineers have indigenously combined various metals, ceramics and polymers to produce a new generation of exceptional materials. Composites materials are put in real-time application in almost all aspects of the industrial and commercial fields in aircraft, ships, common vehicles, etc. Their most attractive properties are the high strength-to-weight ratio². This work is more likely to improve E-glass fiber reinforced epoxy composite with burnt coal ash remaining as filler material. As far as the material is concerned, glass and carbon fiber reinforced composites have been equally investigated in which epoxy resin is favourable matrix material as this is easy to use and exhibit higher bonding strength³. One of the provocation in the use of glass fiber reinforced polymer (GFRP) composites for primary structures is to avoid the damage proliferation during conditions involving abrasion⁴. The coal ash burnt remains produced in forging fields are likely to be hazardous when exhibited to the outer environment.

The main problem occurs if coal ash drains and/or moves from disposal or storage sites due to air/groundwater flow⁵. The purpose of filler materials is to avoid air voids and to improve mechanical properties to certain level. Burnt coal ash remains can be used as a filler material to improve the mechanical properties as it is low cost and of smaller particle size. Burnt coal ash remains being industrial waste can be used as a filler material in polymer matrix composites because it is a mixture of oxide ceramics. It improves performance of composites both physically as well as mechanically. Particle size of a filler material plays an important role in improving the mechanical strength. As particle size of reinforcing agents decreases from macro to micro to nano-size in composite materials, dramatic enhancements in properties such as mechanical and barrier properties, flame retardency, and electrical conductivity increase⁶. The enhanced composites performance is due to optimized interfacial interaction between the matrix and filler particles and is due to the large surface area of the particles, which facilitate stress transfer to the reinforcing phase⁷.

The strength increases when fiber mass fraction increases above 30% of total composite material⁸. Previous studies have shown that filler material such as $Al_{2}O_{3}$

 $Mg(OH)_2$,SiC up to particular percentage by volume have improved mechanical properties⁹. The E-glass fiber reinforced epoxy composites filled with Al₂O₃, CaCO₃, SiO₂ and PBO filler has improved mechanical properties greatly¹⁰. Composites filled with different proportions of fly ash, aluminium oxide (Al₂O₃), magnesium hydroxide Mg(OH)₂ and hematite powder were fabricated by principle method and results showed composites impregnated by 10% volume Mg(OH)₂ manifested maximum ultimate tensile strength of 375.36MPa and hardness of 88.69BHN, maximum impact strength of 0.2846J/mm² was exhibited by Fly ash impregnated composites¹¹. In this present study improvement of mechanical properties was noticed at different proportions of filler material. This improved composite materials can employed in future applications.

2. Materials and Method

Low cost composites are gaining wider acceptance as structural material. In this study the fiber used is E-glass reinforced with Epoxy (LY556) and Hardener (HY951) with burnt coal ash remains as filler material due to its improved strength and durability factor. The main chemical components in coal ash are silica and aluminium oxide, which is immediate to pit soil (SiO₂: 60% - 70%, Al_2O_3 : 10% - 25%). Burnt coal ash remains collected from forging lab was sieved in a sieve size of 210µ, mesh no 70 (ASTM E-11-61).

The fabrication of composite was done using simple hand layup method by volume 300mm x 300mm x 3.2mm. E-Glass sheet is initially cut to 300mm x 300mm size as shown in Figure 1. A ceramic tile is placed, above which a thin plastic coated with wax as releasing agent was laid. Epoxy along with burnt coal ash remains was sandwiched between E-Glass fiber sheets as per different proportions. Table 1 is the proportions employed for fabrication of composites. Number of layers required for fabrication of composite is calculated as shown in Table 2. Figure 2 shows the final product that is been fabricated.

The fabricated composite is allowed to cure for a day and is post cured at 85°C for 6hrs. All the materials where dried under sun to remove excess moisture until a constant weight is reached. Now the fabricated materials are machined using computer numerical controlled (CNC)



Figure 1. E-glass sheet cut into 300mm x 300mm.



Figure 2. End product after fabrication.

machining as per ASTM standards for tensile test as shown in Figure 3 (ASTM D638) under displacement load in universal testing machine (UTM, INSTRON 3333) with resolution of piston movement of 0.01mm. Figure 4 shows tensile specimen dimension as per ASTM D638. Figure 5 shows flexural specimen dimension as per ASTM D790. Machined flexural specimen shown in Figure 6 is tested in INSTRON 3333. Figure 7 shows machined Impact specimen (Charpy) (ASTM E23). Figure 8 shows the impact specimen dimension. Hardness test is conducted as per standards (ASTM E10-00) and water absorption capacity (ASTM D570) for different composition is conducted for



Figure 3. Tensile specimen as per ASTM D638.



Figure 4. Tensile specimen dimensions(mm).



Figure 5. Flexural specimen dimensions (mm).



Figure 6. Flexural specimen as per ASTM D790.



Figure 7. Impact specimen as per ASTM E23.



Figure 8. Impact specimen dimensions (mm).



Figure 9. Specimen immersed in distilled water.



Figure 10. Water absorption specimen dimensions (mm).

Composite Composition No.	Matrix Composition (%)	Reinforcement Composition (%)	Filler Composition (%)
1	45	50	5
2	40	50	10
3	35	50	15
4	50	45	5
5	50	40	10
6	50	35	15

 Table 1.
 Proportions of materials utilised for fabrication

When, mass fraction of matrix	0.45	
When, mass fraction of fiber	0.5	
Mass fraction of filler	0.05	
Density of composite ($\rho_{composite}$)	Density of epoxy × (Mass Percentage of epoxy) + Density of fiber× (Mass percentage of E-Glass fiber) + Density of filler× (Mass percentage of filler)	
When volume of composite	300mm x 300mm x 3.2mm = 288cc	
Mass of composite	='X' gms	
Therefore mass of fibers	0.5 x 'X' gms ='Y' gms	
Let mass of one fiber layer	'Y ₁ ' grams	
Total mass of fiber layer	(Y/Y_1) grams ='Z' layers	
Total mass of epoxy matrix	0.45 x Density of the composite	
Total mass of coal ash filler	0.05 x Density of composite	

Table 2. Number of layers of fiber required for fabrication of composite

24Hrs as shown in Figure 9 and is measured using the Formula (2). Figure 10 shows the water absorption specimen dimension.

Water absorption capacity= Final weight – Initial weight (2)

3. Results and Discussion

In this study, the tensile, flexural test, impact test, hardness test and water absorption test was carried out on E-glass/epoxy composites to study the effect of burnt coal ash remains as filler material with varying composite proportions. In this section experimental results obtained for tensile, bending, impact and hardness tests are widely discussed. The results were analysed by plotting bar graphs for materials that having different proportions of matrix, reinforcement and filler.

3.1 Tensile test

The results revealed in the Figure 11 manifest that tensile strength for composite increased with increasing filler proportion. Tensile strength of 74.57MPa, 92.8MPa, 104.5MPa, 115.89MPa, 129.54MPa and 91.92MPa was observed for 1st, 2nd, 3rd, 4th, 5th and 6th composition respectively. Maximum tensile strength observed was 129.54MPa and further dropped suddenly due to brit-



Figure 11. Tensile characteristics graph.

tle fracture. The failure of specimen is observed due to cracks propagating in a direction perpendicular to the external load. In 1st, 2nd and 3rdcomposition with constant fiber mass proportion by 50% exhibited an increase with increase in filler material. This is because as the filler increased, it resulted in more uniform distribution of epoxy reducing the localised shrinkage.

Increase in tensile strength with increase of fly ash may be attributed to hollowness of fly ash¹². The hollowness of fly ash particles increases the material capacity to increase the material capacity to increase energy¹³. A reduction in tensile strength is observed in 6th composition having 15% filler, this may be due to fly ash content up to 15% massfraction in the composite damages matrix continuity, less volume of fiber and more void formation in the composite⁹. It is clear that mass fraction of fibers and filler show a major contribution in exhibiting high tensile strength.

3.2 Flexural Test

Three point bending test was carried out as per ASTM D790 and Figure 12 shows that flexural property improved with addition of filler material to certain limit and a dip

has been observed. The maximum flexural strength observed was 187.92MPa.

Flexural strength of 69.93MPa, 123.06MPa, 184.45MPa, 187.92MPa, 171.33MPa and 75.5MPa was observed in 1st, 2nd, 3rd, 4th, 5th and 6th composition respectively. When the reinforcement was maintained constant and matrix along with filler was increased an improvement in tensile and flexural property was observed. This is because higher content of filler resulted in stronger fibermatrix interface, when fiber percentage was high when compared to matrix, composite exhibited higher flexural property. Here the cracks where initially observed in the matrix and cracks later propagated towards fiber causing it likely to fail. When matrix was kept constant with increase in reinforcement percentage a decrease in flexural strength with increase in filler occurred due to lower fiber percentage to maintain a stronger matrix-fiber interface. With constant matrix and increased filler proportion decrease in flexural strength was observed because of increased brittle nature of composite with decrease in fiber content¹⁴. A lower flexural strength of 75.5MPa is observed in 6th composition with 15% filler. This may be due to filler-matrix agglomeration resulting in improper wetting of fiber.



Figure 12. Flexural characteristics graph.

3.3 Impact Test

Figure 13 shows the impact strength exhibited by the composite. Impact strength of 82.2kJ/m^2 , 97.6kJ/m^2 , 129.94kJ/m^2 , 107.6kJ/m^2 , 131.57kJ/m^2 and 80.2kJ/m^2 was observed in 1st, 2nd, 3rd, 4th, 5th and 6th composition respectively. It is noticed that composite filled by 10% filler mass exhibited high impact strength when compared with other

filled composites. This is due to that improved bonding strength between filler, matrix, fiber and flexibility of the interface molecular chain resulting in absorbs and disperses the more energy, and prevents the cracks initiator effectively. But there was reduction in impact resistance as the coal ash content increases which might be because of formation of additional voids and this void increases the crack propagation⁹.



Figure 13. Tensile characteristics graph.

3.4 Hardness Test

Hardness test was conducted using Rockwell hardness test method using ball indenter of 1/16 inches diameter. Figure 14 shows maximum hardness value observed is 72RHN for 2nd composition and 73RHN for 5th composition i.e., 10% of filler composition has shown higher value of hardness when compared to other filler percentages. Hardness value of 64RHN, 72RHN, 60RHN, 61RHN, 73RHN and 65RHN was observed for 1st, 2nd, 3rd, 4th, 5th and 6th composition. Hardness of the material found to fluctuate due to composition of particulates with the base matrix. Increase in filler up to 10% with constant reinforcement showed higher hardness value due to the resistance offered against the indentation by the composite. At 15% filler, due to lower epoxy percentage resulted in weaker bonding allowing the indenter to penetrate easily through the composite. When matrix composition was kept constant with varying fiber and filler concentration, an increase upto 10% filler is noticed. With further addition of filler a decrease in hardness value is noticed. This may be due to the epoxy-filler agglomeration resulting in improper wetting of fiber, lower fiber percentage failing to offer resistance against indentation.

3.5 Water Absorption Test

The fabricated composite is immersed in distilled water for duration of 24hrs as per ASTM D590 .The specimen is weighed initially and at the end of 24hrs of immersion for calculating water absorption. From Figure 15 it is lucid that water absorption reduced by increase in filler materials. This is because high content of filler has impaired diffusion of water through the matrix as it as clogged the pores and voids inhibiting water diffusion. Due to lower surface voids and pores at higher filler percentage chance of water diffusing through the composite is minimal.

Observing Figure 11, composite with constant reinforcement percentage showed lower water absorption with increase in filler. With matrix as constant i.e., 50% a drop in water absorption is observed, but lower drop than the specimen composition with constant reinforcement matrix is manifested. Higher percentage of epoxy resulted in stronger water affinity towards the specimen because of the polar hydroxyl (-OH) groups created by the epoxyamine reactions might be intensified by unreacted amine groups and hydroxyl-ether units as a consequence of etherification reactions. The hydrogen bonds between the water molecules and the polar hydroxyl groups of the



Figure 14. Hardness characteristics graph.



Figure 15. Water absorption characteristics graph.

network will disrupt the inter chain hydrogen bonding altering the molecular structure¹⁵.

4. Conclusions

From the experiments, it is lucid that coal ash remains utilised as filler have improved mechanical performance of E-Glass/Epoxy composites. Increased filler composition exhibited higher tensile and flexural performance at constant reinforcement percentages. As the epoxy reduced, chances of matrix agglomeration reduces and with increase in coal ash filler resulted in uniform distribution of epoxy enhancing matrix-fiber interface.

Increase in tensile, flexural, hardness and impact behaviour is observed with increase in filler up to certain proportions and with further increase in filler content a decrease was observed due to filler agglomeration causing improper wetting of fiber. Decrease in fiber percentage resulted in increased brittle nature of the composite showing reduction in flexural strength. Fillers clogged the gaps between the fibers inhibiting the penetration of water resulting in lower absorption of water. Fillers play a major role in strength performance, matrix of the composite resulting uniform distribution of load throughout the composite. Coal as filler due to its improved mechanical performance can be efficiently utilized in building up structural and non-structural materials.

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