Synthesis and comparison of mechanical behavior of fly ash-epoxy and silica fumes-epoxy composite

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Abstract Present day innovation requires materials with a typical combination of properties that are not possible by conventional metal, alloys, ceramics and polymeric materials. Particulate reinforcements for polymers are selected with the dual objective of improving composite properties and save on the total cost of the system. The point of this study is to utilize and compare the mechanical properties of filler (fly ash and silica fumes) reinforced epoxy composites. The composites of different proportions by percentage of matrix(100%), fillers(5%,10% and 15%) volume are developed using hand lay-up process are tested for tensile and compression, according to ASTM Standards. From these mechanical properties, the flexural analysis of these composites is simulated. And which are characterized by Scanning electron microscopy for the fracture surface study, which reveals the brittle fracture, this also conforms from the Finite element analysis (FEA). And the overall mechanical properties of the fly ash reinforced polymer composites were found to have better than silica fumes reinforced composites.

Keywords: Fly-ash/epoxy composite, silica fumes/epoxy composites, hand lay-up, mechanical testing, FEA.

1. Introduction

Modern technology requires materials with a distinct combination of properties that are not possible to meet the requirements by metals, alloys, ceramics and polymeric materials. Particle reinforcements for polymers are selected with a dual objective of improving composite properties and saving on the total cost of the system.
Fly-ash is rich constituents of aluminosilicate obtained from coal plants and its disposal is a reason for high ecological care. Cenospheres of different sizes can be obtained from fly-ash using advanced grading methods. These are empty micro-sphere particles with low density and effort are made to develop valued products from the Cenospheres [1-5]. A possible application of fly-ash Cenospheres is the lightweight filler in polymer matrices, and can enhance the strength, so they are good from a technical and economic perspective [6]. The analysis of energy dispersive X-ray spectroscopy and X-ray diffraction spectroscopy have shown that fly-ash is a mixture of SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, and several metallic oxides, and its microstructure is very complex [7–11]. Silica fumes are By-products of the production of silicon metal and the ferrosilicon alloys having silicon contents of 75% or more contain 85~95% non-crystalline silica. It is usually particles of a gray-color, somewhat similar to Portland cement or some fly-ashes[12, 13]. Epoxy resins are widely used in various technical and structural applications such as electrical industries, commercial, railway and military industries. In order to improve their performance and to reduce costs, different fillers are introduced into the Resins during processing [14]. Most commonly used fillers in epoxy resins include inorganic [15,16], organic [17,18] and ceramic [19,20]. It has been recognized that the properties of epoxy composite materials can be modified by the properties of the fillers, including the size, shape, volume fraction in the resin and as well as the modification of the filling surfaces by treating with different solutions.

The present study is to utilize and compare the mechanical properties of filler (fly ash and silica fumes) reinforced epoxy composites as there is a very few literature found on comparative studies on these fillers. The composites of different proportions by percentage of matrix (100%), fillers (5%,10% and 15%) volume are developed using hand lay-up process are tested for tensile and compression, according to ASTM Standards. From the mechanical properties the flexural analysis of these composites is simulated. And which are characterized by Scanning electron microscopy for the fracture surface study, which reveals the brittle fracture, this also conforms from the Finite element analysis (FEA). And the overall mechanical properties of the fly ash reinforced composites were found to have better than silica fumes reinforced composites.

2. Materials, methods and testing

Required amount of epoxy and fly-ash/silica fumes (5%,10%,and 15%) were mixed properly in a glass container with the help of mechanical stirrer. The mixture was mixed for 5 min to form a homogenized mixture. Then the mixture was poured into the mold made up of steel bit, the sizes of the mold were 250×25×4 mm$^3$ and 250×25×15 mm$^3$. The OHP sheet was kept beneath(before pouring the viscous mixture) so that the composite material wouldn’t stick to the bottom. The castings are left to cure at room temperature for about 24 hours, after which the sample was removed,which are shown in figure 1 (a) and (b) and are tested for tensile and compression according to ASTM standard using Simadzu AGX plus 100 KN (Japan) UTM which is shown in figure 1 (c) and (d)
3. Numerical simulation

The flexural analysis of the fly-ash epoxy and silica-fume epoxy composites are as follows. The composite plate modeled as 3D deformable solid element and support roller and loading part are created as Rigid discrete element in part module. The material properties used for modeling of composite are listed in the table 1. The composite plate modeled as 3D deformable solid element and loading part are created as Rigid discrete element in part module. The material properties used for modeling of composite are listed in the table 1. The parts assembled view is as shown in figure 2a. And are meshed using C3D8R element which is shown in figure 2b. Boundary conditions are applied as similar to the physical flexural testing. Job is created and submitted for simulation and bending results are analyzed.

| Material          | Density (g/m$^3$) | Young's modulus (GPa) | Poisson’s ratio |
|-------------------|-------------------|-----------------------|-----------------|
| Matrix epoxy      | 2000              | 3.2                   | 0.29            |
| Fly-ash           | 1300              | 98                    | 0.21            |
| Silica fume       | 1350              | 73                    | 0.16            |
| Fly-ash composite*| 1210              | 12.68                 | 0.28            |
| Silica fume composite* | 1250          | 10.18                 | 0.27            |
4. Results and discussion

The SEM images of the fly-ash and silica fumes are shown in figure 3. Which shows spherical shape for the fly-ash and for silica fumes it was irregular shape.

![Figure 3. Scanning electron microscopy of a) fly-ash and b) silica fumes particles](image)

![Figure 4. Graphs for fly-ash epoxy composite (FE) a) tensile b) compression](image)

From the figure 4. It can be seen that, 10% volume composite has a better property for tensile as well compression strength concern. As the volume % of fly ash increases above 10% the strength of the composite decreases. This is also revealed from the microstructure figure 7 that, for 10% Fly-ash epoxy composite, the distribution of fly-ash was uniform. Whereas for 15% the fly-ash particles accumulated in one place.
Figure 5. Graphs for silica fume epoxy composite(SE) a) tensile b) compression

The tensile graph shows that 15% volume composite has a better property than 5% and 10%. As the volume % of silica fumes increases, the strength of the composite increase also ductility decreases. The compression graph shows that 10% volume composite has a better property than 5% and 15%. Because, as the volume % of silica fumes increases above 10%, the strength of the composite decreases.

Mechanical properties of composite material having 100% matrix, 10% fly ash and 10% silica fume filler is found to have better mechanical property compared to other proportions which can be revealed from the figure 4 and 5. Maximum strength of 32MPa for fly ash epoxy composite tensile testing and 15MPa for silica fumes epoxy composite. 110MPa for fly ash-epoxy composite compression testing and 104MPa for silica fume compression testing. The overall result of Fly ash epoxy composite was found to have better properties than silica fumes epoxy composite. At filler percentage above 10%, a drop may observe in tensile and compression due to improper distribution of particles decrease in matrix.

From the numerical simulation of fly-ash epoxy and silica fumes epoxy composites, it can be seen that the plate cracked initially opposite side of the load applied further it propagates towards the loading side which can be is clearly observed in figure 6.

Figure 6. Flexural simulation of a) Fly-ash and b) Silica fumes epoxy composites
From the microstructure of the fractured surfaces, it reveals that pure brittle fractures on all the specimens of FE and SE composites. And reinforcement distribution in the epoxy was uniform till 10% where upon increasing the reinforcement % above 10 there is particles amalgamation was happening which can be seen clearly from the figure 7(c).

5. Conclusion
Polymer matrix composite was successfully prepared by using fly ash and silica fumes. The tensile strength and the compression stress were found to be 32MPa and 110MPa for fly ash composite and 15 MPa and 104 MPa for silica fumes composite.

The fly ash epoxy composite had higher strength than silica fumes epoxy composite. Hence, it is effective to use fly ash for the composite, since it is an environmental threat. And also fly ash is more abundantly available and less costly than silica fumes

SEM and FE analysis reveals the brittle fracture of the fly ash and silica fume composites.

6. References
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