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Mechanical behaviour of E-glass fibre, fly ash, bottom ash and pond ash reinforced epoxy composites

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ABSTRACT
This article describes the development of new hybrid composites consisting of epoxy, filled with fly ash, bottom ash and pond ash particles in a fixed composition, and reinforced with e-glass fibre. The chemical composition and size of powders play a vital role to enhance the physical and mechanical properties of PMCs. The weight percentage of powders is 15%.This paper describes the technique of hand layup in order to prepare the specimen. It examines further the physical and mechanical characteristics of these composites and compares unfilled and filled PMCs samples according to ASTM standards. This study reveals that these new class hybrid composites have a hardness, tensile, impact energy, and flexural strength. Thermo gravimetric analysis shows thermal stability and degradation of the manufactured composites. Samples also discover the environmental impact of composites is placed outside for one month.
Keywords: Pond ash; Bottom ash; Fly ash; E-glass fibre; PMC

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I. INTRODUCTION

Fly ash is one of the by-products of burning of coal in a thermal power plant. Fly ash is usually taken from the chimneys of power plants, while the remaining ash, as the name suggests, comes from the bottom of the furnace, and the ash from the pond is used as a landfill to prevent ash from being released into it. When charcoal is burned, the fly ash elements produced vary significantly; however, all fly ash contains substantial quantities of silica (SiO_2), and calcium oxide [1]. A.V.Pradeep et.al [2] they made glass fiber reinforced polymer composites with fly ash in various weight percentages such as 0%, 5%, 10% and 15% using the manual layup method. They found that mechanical characteristics were improved when fly ash was reinforced by fibreglass; they suggested that fly ash 15% Wt had superior properties, as referred to in each composite we fixed 15% wt of powder. Compared to a pure matrix material, the new hybrid composite produced with E glass fibres as reinforcement offers an excellent tensile property. This composite can be used in automotive and industrial applications [3].The properties of polymer composites can be improved by varying filler / fibre material type and volume percentage. The composites properties depend on their size, shape and other physical properties. The adhesion between the matrix and the filler plays a major role in determining essential properties such as strength and toughness in all particular filled systems [4].

A 300 nm ash filling composite impregnated polymer has been found to produce better impact energy (14 J) and hardness (35 Hv) than other sources. As the practical size of the fly ash filler decreases, the interface of the polymer matrix with the solid fillers is increased [5]. Reinforce glass fibre Epoxy Composites using Fly Ash/Nano clay/Zinc oxide as hand layup method. In comparison, zinc oxide/fly ash epoxy glass was more flexural strength. Structural applications can be used with hybrid filling material dispersed in glass Fiber-reinforced composites [6]. For several electrical applications, particularly printed circuit boards, bushings, GIS spacers, ground wall insulation system and cast resin transformers, the possible use of these composites, for instance with storage devices prefers isolated material [7]. Stir casting, in situ deposition techniques, hand lay-up technique, and compo casting techniques are used to produce fly ash composites. The turbine blade industry in particular employs the hand lay-up technique for low budget turbine blades [8][9]. Particles of fly ash are usually spherical in form and size from 2 μm to 10 μm. They are mainly made from silicon dioxide (SiO_2), aluminium oxide

(Al_2O_3) and iron oxide (Fe_2O_3) [10]. Development of epoxy-reinforced, multi-phase hybrid composites filled with rice husk particulate matter. His study revealed that filler addition [11] improves hardness, tensile modulus, impact energy, and erosion resistance of these new class hybrid composites. The effect of replacing different percentages of fly ash with compact particles on thermal conduct and compounds was investigated. The study shows that, due to the free or physically binding water removal, the obtained fly ash-based geo-polymer shows a mass loss of 20 percent in the 25–300oC temperature range [12]. Therefore, this study aims to examine the effects of powder particles on physical, mechanical and thermal properties of the fixed weight percentage in e-glass fibre composite.

II. EXPERIMENTAL DETAILS

2.1. Materials

The epoxy resin (LY 556) is used as the matrix material in this work. Epoxy is chosen mainly due to its excellent thermal and dimensional stability. It is chosen to use epoxy resin and the appropriate hardener (HY 951) and e-glass fiber mat. Fly ash, bottom ash and pond ash are used as filler, as this is an industrial waste of a low density of 2.35 – 2.50 gm/cc. The Ash powders are collected from the Thermal Power Plant of RINL Visakhapatnam Steel Plant, Visakhapatnam, India. The obtained ash powders were taken in separate crucibles and put into the muffle furnace for 4 hours at 900^0C for removal of moisture and unwanted matter. Sieve analysis is done for the powders in the sieve shaker for 20 minutes. After Sieve analysis, BSS 350 mesh size powder is chosen for all experiments.

(a) (b) (c)

Figure 1: Heat-treated Powders of (a) Fly ash (b) Bottom ash (c) Pond ash

2.2 Chemical composition of powders

The chemical composition of the Powders has been obtained with the help of X-ray fluorescence (XRF) spectroscopy setup. The XRF was done in RINL Visakhapatnam steel plant central QATD lab.XRF was conducted on a Rigaku ZSX Primus 2 machine, which is a 2017 model that is made in Japan. The device has an X-Ray tube which operates at 4kw.

2.3 Density of Powder

The principle of the ASTM C188 test method is used to determine the Density of powders. A unique flask, the Le Chatelier flask, is used to facilitate the volume measurement. The measurement of the displaced volume of a liquid (Kerosene) by the addition of a powder specimen. The Density can be calculated by using the mass of powder.

2.4 Fabrication of Composite:

E-glass fibre mats are reinforced by epoxy resin and fly ash, bottom ash and pond ash (15 wt.%) are added as filler material for preparing the composites, with no filler material considered to be the base material.E- Glass fibre has a modulus of about 80GPa, Tensile strength 2000MPa,and possesses a density of 2.58g/cm^3, respectively. The epoxy is mixed with a hardener in the ratio of 10:1 at room temperature, in a glass beaker with the help of a glass rod, stirring done for 10 minutes until a homogeneous mixture of hardener and epoxy is made. 15 wt% of powder reinforcements of Fly ash, bottom ash, pond ash powders are added to this mixture and four different combinations are prepared for four different composites. The E-glass fibre has a cross-section of 200x200mm. The glass fibre reinforced epoxy composite is made with a thickness of 5mm. The fabrication is done using a hand layup technique, in which a plastic sheet is placed on a work table and then prepared matrix mixture is applied; after that, a layer of glass fibre mat is placed over it. Continuous applying and placing of E- glass fibre mat layers are done, which as a result, forms a pile of fibres of 5mm thickness, which is compressed with a roller to avoid the formation of defects such as porosity in it. The prepared composite sheet is left for curing for 24 hr, which finally forms the required Composite. Similarly, all the four composites, i.e., with powder reinforcements and pure E-glass fibre epoxy composite, are fabricated. After curing, the sheet is cut into as per the standards of the samples for experimentation purposes.

2.5 Density of Composite:

By using the following equation, the theoretical density of composite material can be obtained. Each composite sample under this study consists of three components-fibre, matrix and particulate filler-and is used to obtain the average value of the density by using three number of specimens of the same composition. The theoretical density in weight fraction of the composite sample can be obtained in the following equation 1.

$$\rho_{ct} = \frac{1}{(w_{f/\rho_f}) + (w_{m/\rho_m}) + (w_{p/\rho_p})} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where ρ and W represent the Density and weight fraction, respectively. The suffix m, f, and ct stand for the matrix, fibre, and the composite specimen, respectively. The suffix 'p' indicates the particulate filler material. However, the actual density ρ_{ce} of the composite specimen can be determined experimentally by the Archimedes principle. The volume fraction of voids (V_v) in the composite samples is calculated by using the following equation 2:

$$v_v = \frac{\rho_{ct-}\,\rho_{ce}}{\rho_{ct}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

2.6 Mechanical Test

2.6.1 Hardness

The Rockwell hardness test is used to measure composite hardness. It uses a direct reading device based on the differential depth measurement principle. The test is conducted by slowly elevating the specimens against the indenter until a fixed load of 10 kg is applied. The heavy load is then applied via a loaded lever system. After the dial point rests, the heavy load is removed and still works with the minor load. On the dial gauge the Rockwell hardness number is read by M with a 1/2 tonne Ball indenter with an applied load of 60Kgf.

2.6.2 Tensile strength

The tensile testing was done on INSTRON 8801. The cross-head speed was 2.0mm/min. The specimens were subjected to a controlled tension until they failed. The elongation up to the breaking point, the load taken by the samples until the end of breaking and the ultimate tensile stress were calculated by the machine.

2.6.3 Flexural strength

The flexural test of the prepared composite specimens was also done on a universal testing machine (model: Instron 8801) by changing the jaws; The cross-head speed was 2.0mm/min. The flexural load is taken by the specimens before breaking, and thus the flexural stress at that maximum flexural load was calculated. Flexural strength in terms of MPa is determined using the equation

$$F = \frac{3PL}{2wt^2}$$

Where, P = Load applied on center of specimen (N), L = Span length of specimen (m),
w = Width of specimen (m), t = Thickness of specimen (m).

2.6.4 Impact Strength

The pendulum impact testing machine measures the notch impact strength of the material by shattering the V-notched specimen with a pendulum hammer. The testing conditions may be regarded as ideal. The samples are clamped in a simple support beam. The respective values of impact energy of different specimens are recorded directly from the dial indicator. The test is repeated three times for each sample to obtain the average value of impact strength.

2.7 Scanning Electron Microscope (SEM) Analysis:

The surface morphology of the specimens is examined by the SEM JEOL SEM – JSM 6610LV. Scanning Electron Microscope analysis was carried out to assess the morphology of all Powders, fabricated Composite, and Tensile fractured surfaces of the composites.

2.8 Thermo gravimetric analysis (TGA)

Thermo gravimetric analysis has been used to investigate the thermal stability and degradation of the composites manufactured. The investigation was done at a heating rate of 10 ° C / min and under the nitrogen atmosphere by SETSYS Evolution TA Instruments machine from the ambient temperature at 700 ° C.

III. RESULT AND DISCUSSION:

3.1 Powder Characterization:

3.1.1 Chemical composition of powders:

The chemical composition of the samples has been obtained with the help an X-ray fluorescence (XRF) setup (model Rigakuzsx primus 2). The result of the XRF study is presented in Table 1.

Table 1: The chemical composition of Fly ash, bottom ash and pond ash

S.No.	Compound	Fly Ash (%)	Bottom Ash (%)	Pond Ash (%)
1	Na_2O	0.064	0.061	0.098
2	MgO	0.44	0.37	0.39
3	Al_2O_3	26.2	25.2	25.2
4	SiO_2	60.1	62.2	60.2
5	P_2O_5	0.73	0.75	0.35
6	SO_3	0.48	0.92	0.21
7	K_2O	1.43	1.58	1.07
8	CaO	1.28	1.22	0.60
9	TiO_2	1.80	1.79	1.83
10	Fe_2O_3	6.46	4.78	8.65

3.1.2 Density of powders

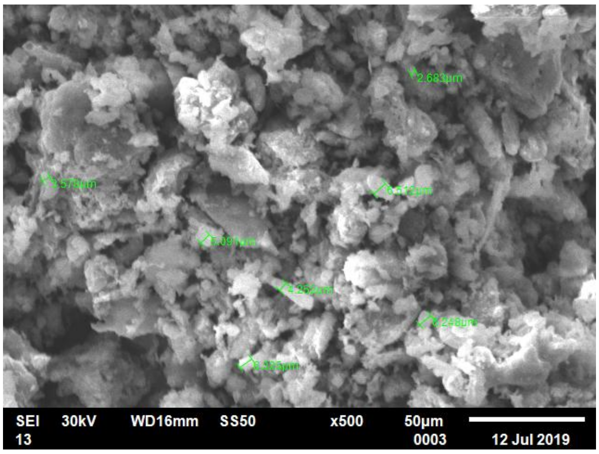
The Density of powders is measured with the help of Le Chatelier flak. Initially, Kerosene poured in the Flask up to the zero marks, The fixed quantity of powder (64 grams) is poured in the Flask and Place the stopper on the Flask, powder takes time to settle down. The volume rise is observed in the Flask. The constant temperature bath should be maintained at a temperature such that its temperature variation between the initial and final readings within the Flask does not vary by more than 0.2°C.The measurement of the displaced volume of a liquid (Kerosene) by the addition of a powder specimen. The Density can be calculated by using the mass per unit Volume.

Table2: density of powders

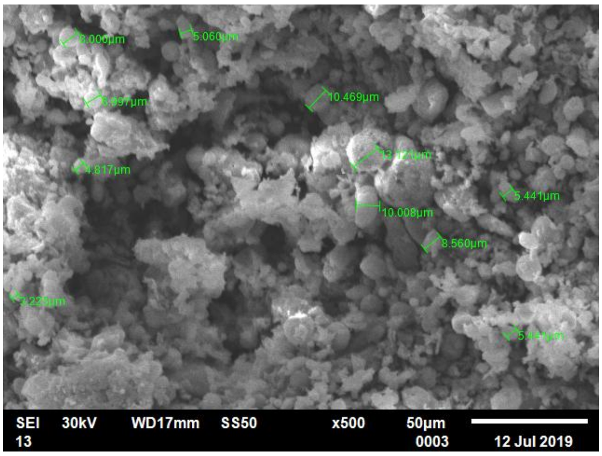
S.no.	Name of powder	density(gm/cc)
1	Fly ash	2.35
2	Bottom ash	2.40
3	Pond ash	2.50

3.1.3 Metallographic studies of powder

JEOL SEM – JSM 6610LV was used to study the morphology of the fly ash, bottom ash, Pond ash particles. Examinations under the scanning electron microscope showed that the samples have the usual all powders morphology and were composed of mostly small, spherical particles. Figure. 2 show the SEM micrograph of the cenospheres particle. It can be noticed that the all Powder samples consists of almost regular spherical particles ranging from 2 µm to 13 µm in diameter was measured in the Figure. 2.



(a)



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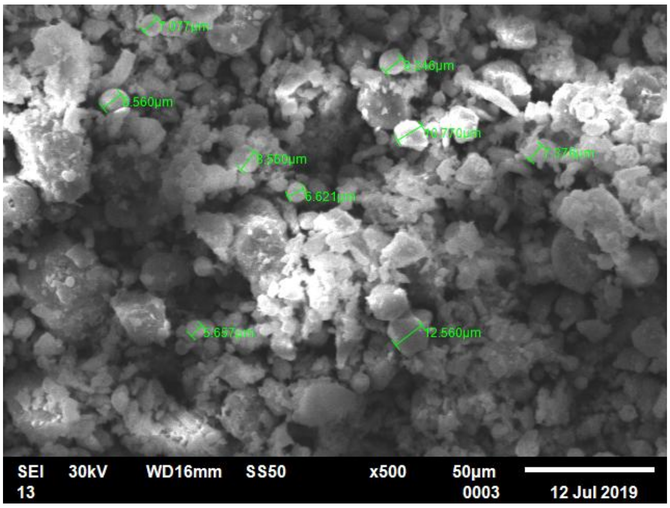


(c)

Figure 2: SEM micrographs of powder particles: (a) Fly ash (b) Bottom ash and (c) Pond ash

3.2 Composite Characterization:

3.2.1 Density of Composite:

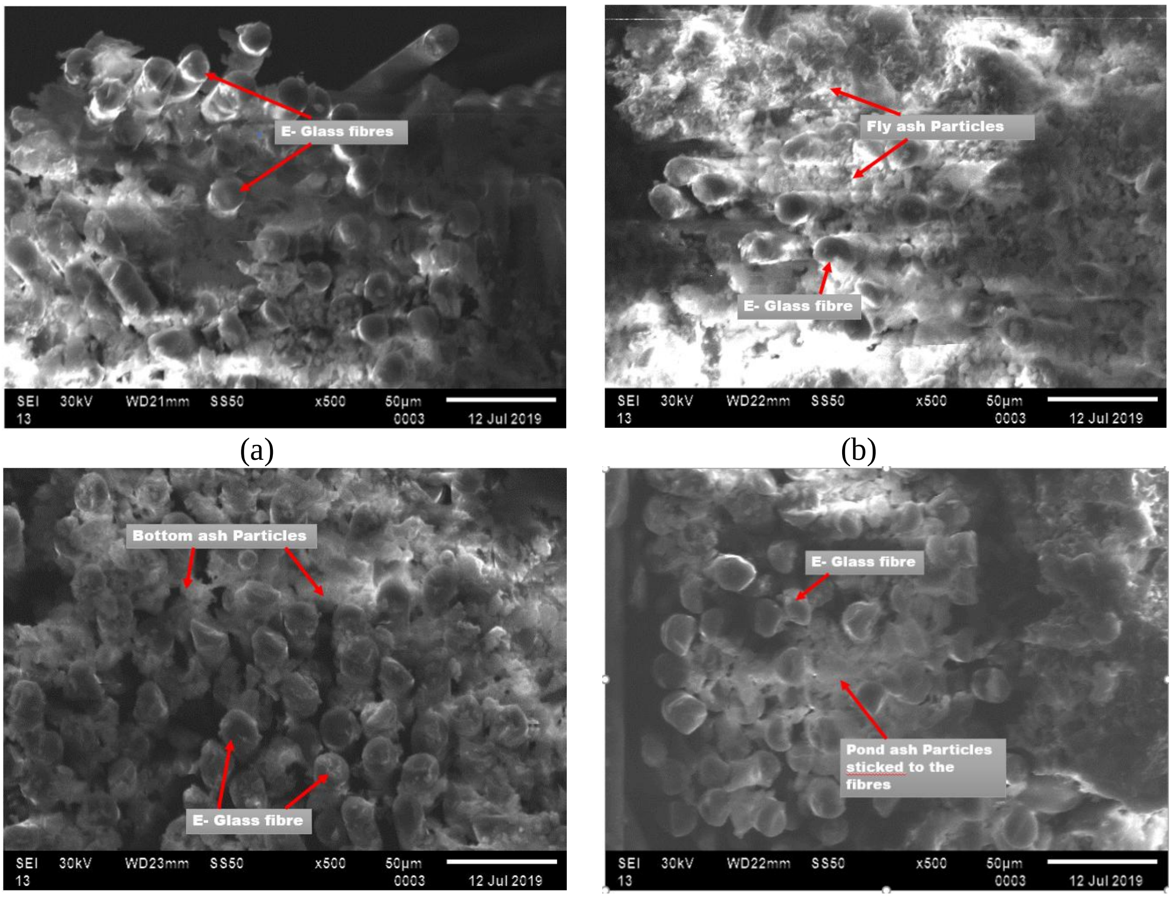
The theoretical and measured densities, along with the corresponding volume fraction of voids, are presented in Table3. The theoretical Density calculated by using Equation (1) and Experimental Density is calculated by the Archimedes principle. The void fraction is calculated by Equation (2). The measured Density of all Composite's values is very similar, but a void fraction is more in base material followed by Fly ash, Pond ash, and Bottom ash. It can be understood that a good composite should have fewer voids. Both bottom ash and pond ash shows lower void fraction. Higher void contents usually mean lower fatigue resistance and a greater tendency to water penetration and weathering[13]. The presence of voids is unavoidable in Composite because it's a hand-lay-up technique.

Table 3: density and Void Fraction of Prepared composites

Sample name	Theoretical Density (gm/cc)	Measured Density (gm/cc)	Void Fraction (%)
Base Material	1.81	1.67	7.73
Fly Ash Composite	1.82	1.73	4.94
Bottom Ash Composite	1.77	1.70	3.95
Pond Ash Composite	1.79	1.71	4.46

3.2.2 Scanning Electron Microscopy of Composite

The SEM morphology of all four Composite, as shown in figure 3. The bonding between the particle and the matrix, dispersion of the particulates were observed in a Scanning Electron Microscope (SEM). The uniform distribution of all power particles in Composite is observed.



(a) (b) (c) (d)

Figure 3: SEM image of as-fabricated Hybrid PMCs (a) Base (b) Fly ash (c) Bottom ash and (d) Pond ash.

3.3 Mechanical Properties:

3.3.1 Hardness:

Figure 4 shows the measured hardness values of all four composites. The hardness is considerably affected by the addition of powder particles. Compared to fly ash and base composite, the composite of the bottom ash and the pond ash shows higher hardness. This increase in hardness with the incorporation of the filler can be explained as follows: a compressive load is operated during a hardness test. Thus, the solid filling phase and matrix phase are pressed together and tightened. The interface can thus more efficiently transfer pressure, even if the interfacial bond strength may be insufficient. This leads to an increase in hardness. Similar change in property has been reported in previous works for fly ash, alumina and SiC particles filled in polymer composites [14][15][16].

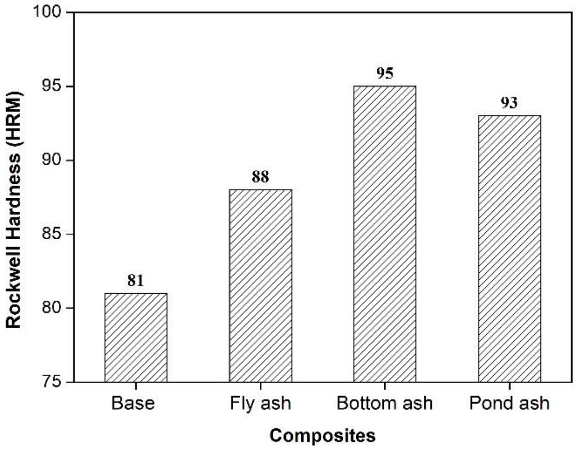


Figure 4:Bar chart shows the comparison of the hardness of the composites

3.3.2 Tensile Strength:

The Tensile stress versus Tensile strain and Ultimate tensile strengths of E-glass epoxy composites filled with all three powders and without powder (Base) is shown in Figure 5 and Figure 6. It is found that there is an increase in tensile strength with Bottom ash composite and followed by Fly ash, Pond ash, and Base. Base composite has a strength of 214.82 MPa intension, and this value Increases to 233.3 MPa, 240.23 MPa and 257 MPa In Fly ash, Pond ash, and Bottom ash with the addition of 15 wt.% respectively. A review of previous research suggests that the composite glass fibre typically reduces the deformation of the resin matrix and reduces the tensile strain [17][18].

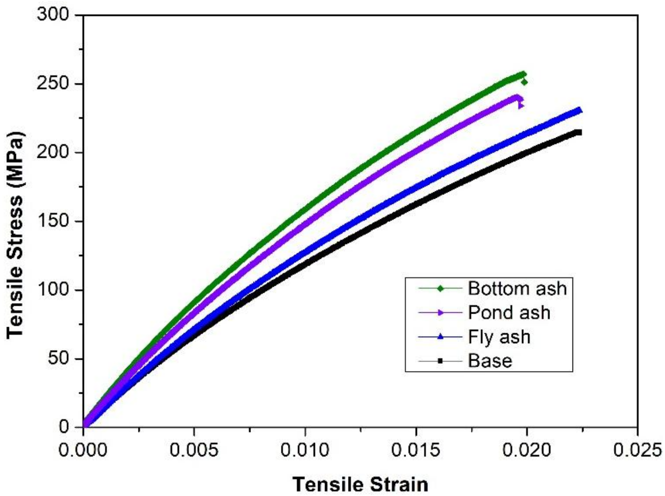


Figure 5:Stress-Strain curve of Base and particles (Powders) reinforced PMCs

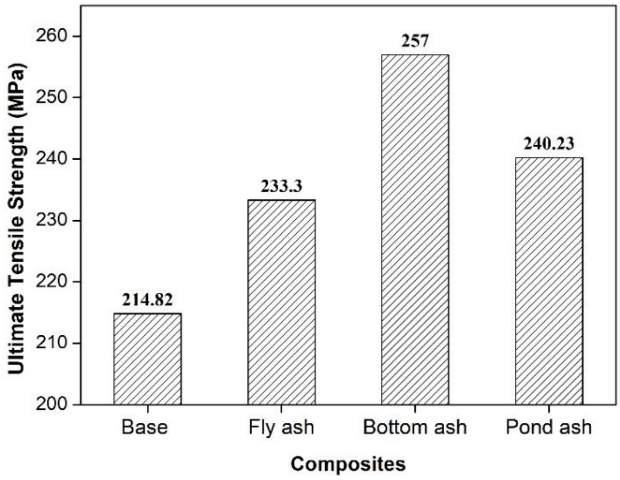
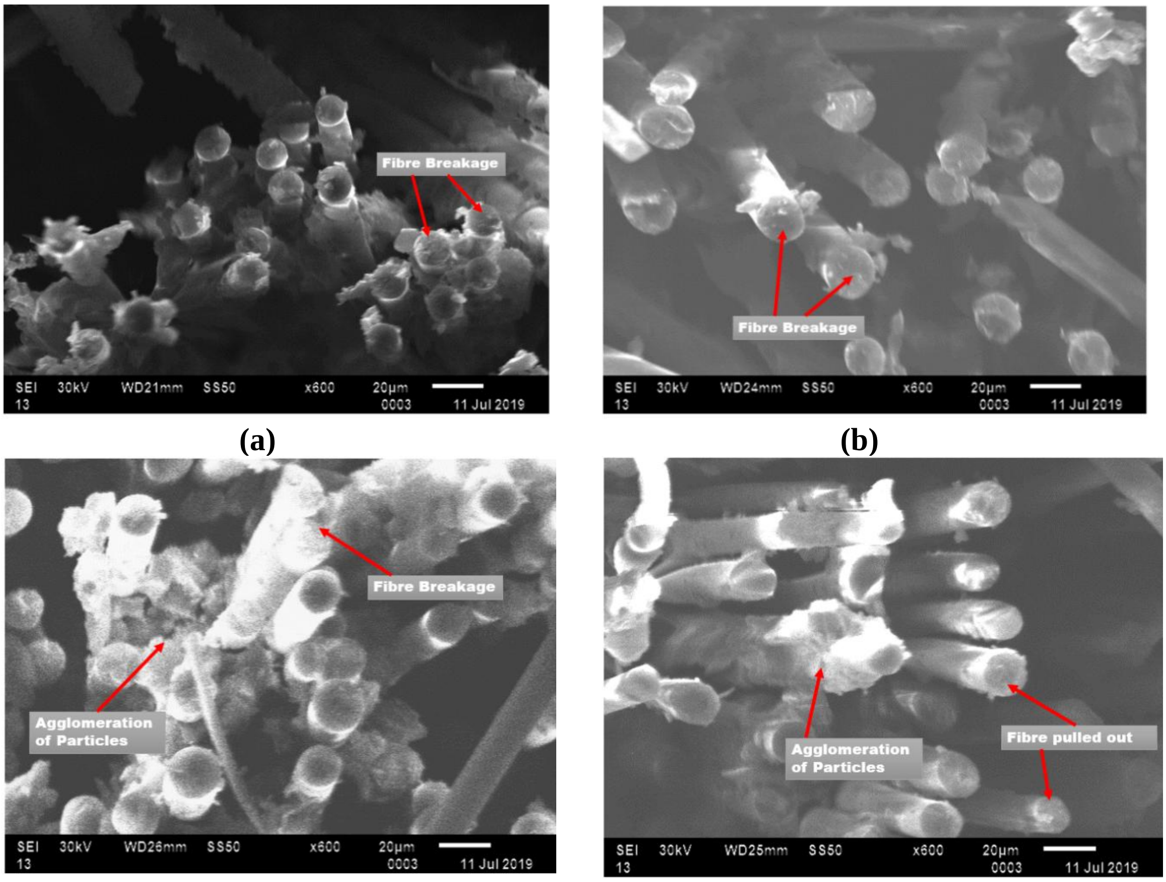


Figure 6: Bar chart shows the comparison between Flexural strengths of the composites.

3.3.3 Scanning Electron Microscopy of tensile fractured composites:

In Figure 7(a), after tensile test, in a base specimen, matrix de-bonding occurs, and fibres get pulled out, and clearly, it shows the fibre breakage, the Figure 7(b) shows the uneven distribution Fly ash particles in the matrix and Fibre get brake is observed, Figure 7(c) shows the Uniform distribution of bottom ash powder the breakage occurred along with the power and Fibre, and Figure 7(d), shows the agglomeration of Pond ash particles in the matrix. The rupture occurred along with the Fibre and powder.



(a) **(b)**

(c) **(d)**

Figure 7: SEM image of as-fabricated Hybrid PMCs After Tensile Test (a) Base (b) Fly ash (c) Bottom ash and (d) Pond ash.

3.3.4 Flexural strength:

Figure 8 shows the flexural strengths of the composites obtained experimentally from bend tests. It is observed that the flexural strength of the Composite is increased with Both Pond ash and Bottom ash Composite. Because of fewer voids observed in Pond ash and Bottom ash composite, as shown in table3.Similar observations have been found earlier by previous researchers for red mud and alumina filled glass-epoxy composites[14].

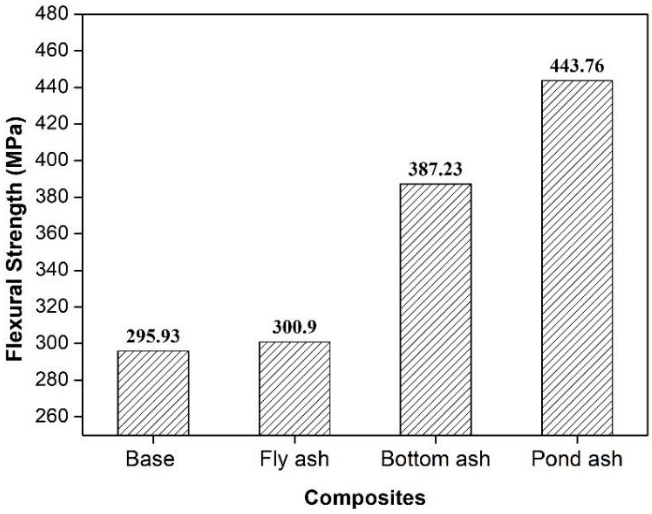


Figure 8: Bar chart shows the comparison of Flexural strengths of the composites.

3.3.5 Impact Strength:

The recorded impact energy values of different composites during the impact test are presented in Figure 9. It shows that the resistance to impact loading of E-glass epoxy composites improves with the addition of powder particles. However, this improvement is not very significant. It is seen that the resistance to impact loading of E-glass epoxy (Base) Composite shows 11.33 and with the addition of powder particles show 13.33, 20, 27.33 of Fly ash, bottom ash, Pond ash composites.

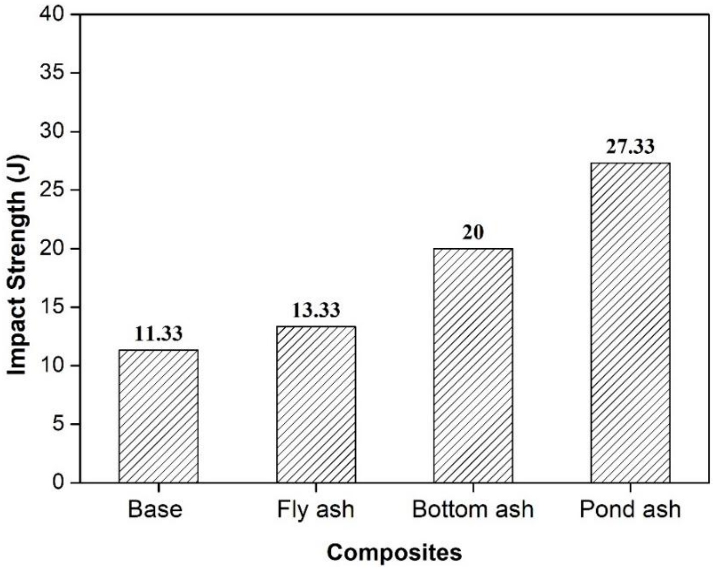


Figure 9: Bar chart shows the comparison of the Impact Strength of the composites.

3.4 Thermogravimetric analysis (TG-DTA) :

As the temperature increases, the weight of the composites decreases. Thermal degradation is higher at high temperatures. Differential thermal analysis (DTA) is a programmed change of temperature. The temperature should be the same until the thermal event occurs, such as melting, decomposition or change in the crystal structure. In figure 10 shows that all composites suffered in less than 500 ^{0}C. More thermal events occurred in pond ash and fly ash composites followed by bottom ash and base composites. In figure 11can be seen in graphs that thermal stability of the composite increases with reinforcement. Base material starts losing weight at low temperature as compared to the other three composites. Base material has shown maximum weight loss over the experimental temperature range. So, it is evident that thermal stability increases with reinforcement of fly ash, bottom ash and pond ash. All four composites, bottom ash, start losing weight at higher temperatures and weight loss in bottom ash composite is least among all composites. So, it can be concluded that bottom ash composites show the best thermal stability over other composites.

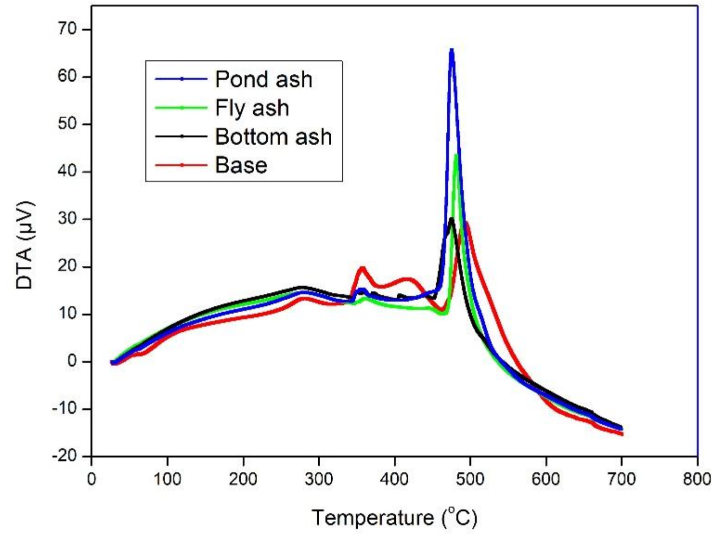


Figure 10:DTA curves of E-glass epoxy composites at hating rate 10°C/min

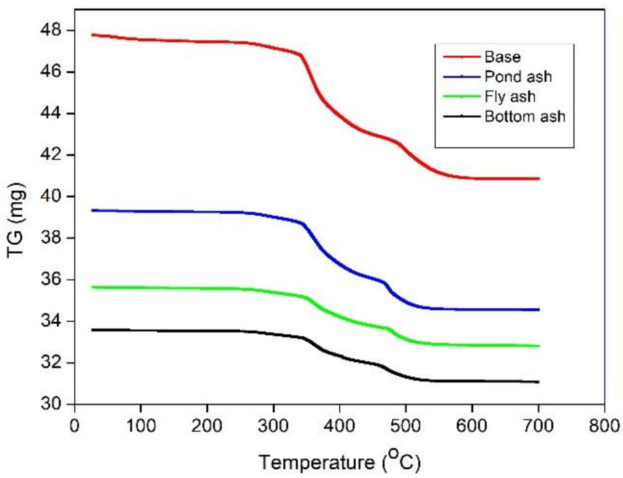


Figure 11:TG curves of E-glass epoxy composites at hating rate 10°C/min

3.5 Environmental effect on composites:

The result of ultraviolet radiations, humidity, sunlight on the composite samples is observed.

In hot , dry climates, most weathering processes are significantly slower than in hot , wet climates. The presence of high humidity in polymers is tending to increase photo damage, especially at higher temperatures. In comparison with an inert atmosphere, the thermal stability of the majority of polymers diminishes in the air by the oxygen presence. Oxygen chemically interacts with polymers and forms reactive intermediate species that accelerate degradation. During this procedure, two samples are taken of each of the Base, fly ash, bottom ash and pond ash composites and placed in an open air in which direct sunlight falls on each of the samples. Samples are placed under sunlight for approximately one month so that sample changes are observed. The loss of weight and appearance and colour of the samples is noted. Composite weight loss, as shown in Table 4.

Table 4: weight loss of composites in an open atmosphere

S.No.	Composite Sample	Initial wt.(gm)	Final wt.(gm)	Wt. loss(gm)
1	Base	32.9343	32.5765	0.3578
2	Fly ash	33.8238	33.5217	0.3021
3	Bottom ash	31.5343	31.2387	0.2956
4	Pond ash	34.8344	34.5612	0.2732

IV. CONCLUSIONS:

1. The industrial waste fly ash, bottom ash, and pond ashcan be used as particulate reinforcement in the epoxy matrix, to prepare composites by hand layup technique.
2. It has been noticed that with the addition of reinforcements, the Density of the composites decreases.
3. It has been found out that the mechanical properties of the composites such as Rockwell hardness, tensile strength, flexural strength, impact strength and compression strength increase with the addition of Fly ash, bottom ash, and pond ash.
4. The result shows that better improvement was observed in bottom ash and Pond ash particulate reinforced epoxy composite in mechanical tests.
5. The morphology of fractured surfaces is examined by using SEM after tensile testing. From this study, it has been concluded that the homogeneity in the distribution of particles and good interfacial bonding is responsible for higher mechanical properties.
6. From the thermo gravimetric analysis, it is evident that the thermal stability of the composite increases with the addition of Powder particulates.
7. It has been observed that there is a significant effect of environmental factors such as ultraviolet radiations, sunlight and moisture on the composites. Weight of the composites is slightly decreased, and a slight change in color is also observed.

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