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Evaluation of Mechanical and Electrical Properties of Particulate Hybrid Laminar Composite Materials

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Abstract -Metals are used in manufacturing of fibre reinforced polymer (FRP) composites which help in improving the durability and toughness of the composite.In this paper,the metals aluminium and copper,in the form of fine powder are mixed with resin. This mix is applied to fabricate a particulate hybrid laminar composite material. The Mechanical properties- tensile modulus (TM) , tensile strength (TS), flexural modulus (FS), flexural strength (FS), Inter laminar shear strength (ILSS), hardness and electrical properties-surface resistivity(SR), volume resistivity (VR) and di-electric constant are studied by using different percentages of metal powders. It is found that the mechanical properties are increased upto 15% proportion of filler addition, after that it started decreasing. Where as the electrical properties are increasing as the proportionts of filler meterials.

Keywords - Tensile strength(TS) , E-Glass fabric, Metallic fillers, ILSS, Flexural strength(FS), Mechanical properties.

I. INTRODUCTION

Mechanical, Electrical, Electromagnetic and thermal properties of composites can be enhanced by adding fillers in a matrix material. In the present scenario of composite materials they are modified with fillers to improve the properties. Based on the application various fillers are selected. The composites are the combination of matrix material and reinforcing material. Composites are used to their advantage in mechanical properties along with electrical, thermal, environmental and electromagnetic properties. Composites are more durable, corrosion resistant, nonconductive and nonmagnetic. To enhance the properties of composite fillers can be used.

An Investigation is conducted for mechanical behaviour of FRP composites (E-Glass/epoxy) with various filler materials. Various combinattions of fly ash, Al_2O_3, Mg $(OH)_2$ and hematite powder were used to fabricate composites. The mechanical attributes like hardness, impact strength (IS) and ultimate tensile strength (UTS) of composites were studied. The test data showed that composite with filler proportion of 10% by volume of $Mg(OH)_2$ revealed maximum UTS and hardness. Maximum impact strength was attained by fly ash filler composites [1]. The Fillers are the neutral constituents which are used in modification of chemical and physical properties of glass FRP composites. They help matrix polymers to reduce material costs, to improve processability, to improve product performance [2]. An Investigation was made on the incorporation of fly ash fillers in epoxy resin increased the compressive strength (CS) with an increase in fly ash filler particles [3]. The mechanical behaviour of carbon FRP composites was investigated with the inclusions of graphite filler with different proportions ranging from 5 to 30 % by weight. The results revealed that to increase in graphite particles there is an improvement in mechanical properties [4]. A Study was made on the mechanical attributes of nanosilica reinforced with epoxy resin. The mechanical behaviour and a three-point bending test is used to characterise the composites. Results proved that there is a 10-20% increase in the composite’s modulus of elasticity with 30-nm and 130-nm silica-filler incorporation. The fracture toughness showed a 25-30% enhanced toughening for both the composites [5]. The impact property of the hybrid composites was studied by fabrication through hand layup process. The materials used are E-Glass fibre, epoxy resin and hardener as matrix constituent and Cloisite 20A as a filler with varied weight proportions. The impact test results are improved with inclusion of nano clay [6]. A method was developed to enhance the strength of unidirectional (UD) composites by adding the nano particle which enhances the matrix properties. The materials used are E-glass fabric mat, epoxy resin and hardener, silica nano particles with particle size of 20nm diameter. VARTM process is followed for fabricating the composite material at 75 kPa and then post cured accordingly. The tensile properties were moderately increased. The addition of silica nano particles improved the longitudinal compressive strength (CS) dramatically [7]. An

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investigation which was done on the glass FRP composites modified with fillers (calcium carbonate and aluminium oxide) as varying weight proportions (5% and 10%). These were manufactured through hand layup process. The epoxy resin is used with with corresponding hardener. The results show that there is a decrease in TS and FS with the inclusion of filler material. However, there is a significant improvement in IS and hardness was observed [8]. Fabrication of the FRP composites by using epoxy and polyester resin with aluminium oxide and silicon carbide in different proportions was done. It is observed that composites made of epoxy resins show better strength compared to composites made of polyester resin. Silicon carbide has revealed a very good stiffness whereas the shrinkage is reduced by adding fillers in the composites [9]. The effect of metallic powders added to the FRP composites was investigated to emphasize the electromagnetic shielding effectiveness (EMSE). The materials used in this investigation are carbon fibre, LR20 epoxy resin with corresponding LH281 hardener and metallic fillers (aluminium and copper). The results show that there is a slight improvement in SE when two metal meshes are used. Overall, it appears that the principal of adding metallic fillers to carbon fibre laminates is a potential alternative to the current aluminium mesh approach of improving the EM shielding properties of FRP composites [10].

II. MATERIALS AND METHODS

A. *Materials*

In current study two types of materials are used to prepare composite laminates, they are direct raw materials and indirect raw materials. Direct raw materials include resin, hardener, E-Glass fabric, fillers, etc. Indirect raw materials include emery paper, molds, acetone, wax polish, etc. Matrix material used in this investigation is Epofine 1555 which is an epoxy based resin along hardener Fine Hard 5200, and reinforcing material as E-Glass fabric (13mil). Aluminium and copper powders are used as filler materials with particle size of 44 microns and 45 microns respectively. Aluminium powder has colour- silver gray, boiling point- 2467^0 C, melting point – 660 ^{0} C, density – 2.702 g/cm^3. Copper has colour – Reddish brown, boiling point - 2567^0 C, melting point – 1083.4 ^{0} C, density – 8.94 g/cm^3.

B. *Fabrication*

Fabrication method used in this investigation is hand layup process with matched die mold. Matched die mold is selected because it is easy to remove the composite laminates from the mold. Firstly the mold is scrubed with emery paper of 200 grade and 400 grade to remove left out resin from the mold, then it is wiped with acetone to confirm that there are no dust particles left on the surface of the mold. Otherwise it might damage the composite laminates.

E—Glass fabric of one meter in length is taken and weighed without resin, the weight of the fabric mat is 436 grams. Based on the weight of the fabric, weight of the required quantity of resin is calculated in 60:40 ratio i.e., 60 % fabric and 40 % of resin. By calculation, the quantity of resin is 317 grams. The resin and hardener are mixed in the ration of 100:27. Firstly the resin is taken in a beaker. As the resin is of high viscosity it is heated up to 45^0C in a heating mandrel to reduce the viscosity. Then the hardener is added to the resin and stirred well. The mixture of the resin and the hardener is prepared as calculated. The mixture then applied to fabric mat evenly throughout the mat and leaving it for couple of hours, to allow the resin to impregnate into the fabric. Subsequently, the fabric mat to which the resin mixture is applied is cut into small mats (layers) using a template (tile) of the required dimensions. Wax Polish is applied to the mold which acts as a release agent. Now, the layers are then placed on the mold cavity layer-by-layer, without dust particles and air bubbles. Here composite laminates are fabricated with different dimensions for various tests.

The orientation is maintained at 0^0, 90^0 to carry longitudinal and transverse (lateral) loading. After the layup is done, the mold is then closed and tightened with C-clamps, nuts and bolts. The mold is then kept in oven for curing process. The curing cycle for the resin is 120^0 C for three hours and 160^0 C for the next three hours. After the curing process is done, the mold is cooled to room temperature. Now, the laminate is detached from the mold by opening the C-clamps, nuts and bolts. Laminate obtained is trimmed by machine.

The above process is repeated for preparation of laminates of 5%, 10%, 15%, 20% and 25% fillers. The fillers (aluminium and copper) are mixed in the equal proportions. Fillers are added to resin before hardener is mixed in it. Fillers are taken as 5%, 10%, 15%, 20% and 25% by weight of matrix material

C. *Specimen Preparation*

Prepared E-Glass FRP laminate and particulate hybrid laminar composites (E-Glass FRP composite laminates filled with various proportions of filler materials) are taken and then are made into coupons for various tests according to ASTM standards. The test coupons were made by cutting the laminates using diamond tipped cutting machine.

III. TESTING

In this investigation three properties were evaluated, they are

A. Testing of Mechanical properties

Different mechanical properties are tested such as TS, TM, FS, FM, ILSS, hardness. Universal testing machine is used to perform various tests such as tensile test, flexural test

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and ILSS test. A Barcol impresser (Hardness testing equipment) is used to test the hardness of the laminates.

1) *Tensile strength and tensile modulus*: Six identical coupons of each proportion of filler were prepared for tensile test. This test is performed as per ASTM D3039 using the UTM. Test coupons are of dimensions with 250 mm length, 25 mm width and 2.5 mm thickness. The coupons were loaded between manually variable grips of a 100kN UTM with an extensometer. Six coupons of each proportion of filler are tested.

2) *Flexural strength and flexural modulus:* Test coupons of required dimensions are prepared as per ASTM D790. This is performed on 100kN UTM with a fixture for flexural test, at distance of 80 mm which is span length of supports. The span length is 80 mm because 16xt= 16x5=80, here t represents thickness, and 2 mm/min is the cross head speed. Three point bend test method is used in this test. Six test coupons of each proportion of filler are prepared and tested.

3) *Inter laminar shear strength:* The main aim of this test is to check the bonding strength of fabric and resin. It is the reason of failure and a exclusive characteristic of composite. In this test, load applied is perpendicular to the coupon, as the load reaches the maximum layers tend to break one-by-one. This is performed on a three point bending fixture of the UTM. The test is done according to ASTM D2344. The span length of the fixture is 20 mm (4xt=4x5=20 mm, where t represents thickness) and 1mm/min is cross head speed.

4) Hardness: Hardness is measured on the laminates prepared prior to cutting of specimens. Barcol impresser is used to determine the hardness, which is only for composite materials. This test distinguishes the indentation hardness of materials through the depth of penetration of an indenter, loaded on a material coupon and compared to the penetration in a reference material. It is measured on a scale from 0 to 100 with the general range varying between 50B and 90B. This test is performed according to ASTM D2583

B. Testing of physical properties

1) Density of the laminates: Density of laminate is determined using the Archimedes's principle. Three samples from each laminate of different filler proportions were used to check the density. Firstly, the weight of each coupon is measured in air, and then the sample is kept in distilled water to remove the air entrapped. The weight of the sample, then measured with distilled water. This is repeated for all the samples. The difference of the measured values gives the density of the composite.

2) Resin content and fibre content: Three samples were chosen to check the resin and fibre content in the laminate. Firstly, the weight of the sample in air is taken, and the weight of empty crucible is measured. The weighed sample is taken in the crucible and kept in the furnace at 600^0 C for 1 hour. Through this, the resin in the sample gets evaporated and then only fibre will be remained. The weight of the crucible is measured and the difference in the measured values gives the fibre content and resin content.

C. Testing of electrical properties.

These properties are used to evaluate the effect of conductive fillers in composite materials.

1) Dielectric constant: Di-electric constant of composites were measured at ambient temperature by a dielectric analyser. In this investigation, electrical characteristics such as capacitance, resistance were recorded. The composite laminates of different filler proportions were kept between two electrodes. The measurements were recorded at frequencies ranging from 1 kHz to 10 kHz.

2) Surface resistivity and Volume resistivity: Measurements of surface resistivity and volume resistivity are required only when either a conductive coating is applied or conductive fillers are added to the insulating material. Surface resistivity is determined as the electrical resistance of the surface of an insulating material. It is measured from electrode to electrode along the surface of the composite laminate. Volume resistivity is determined as the electrical resistance through a cube of insulating material. This test is carried out as per ASTM D257. A mega Ohm meter is used to measure the surface resistivity and volume resistivity of composite laminates.

IV. RESULTS AND DISCUSSIONS

The results obtained from this investigation are interpreted in the form of bar graphs. Mechanical properties, physical properties and electrical properties of particulate hybrid laminar composite materials depends on fiber orientation, void content, effective fiber distribution, type, quality and quantity.

A. Mechanical properties

1) *Tensile strength and tensile modulus*: The TS of composites mainly relies on strength and modulus of the fibres, chemical stability of resin, interaction of matrix and reinforcement. The results obtained are presented in Fig.1, it is observed that when compared with composites without filler materials and particulate hybrid laminar composite with 15% filler exhibited maximum TS of 363.5 MPa, laminate with 25% filler proportions has less TS of 281 MPa.

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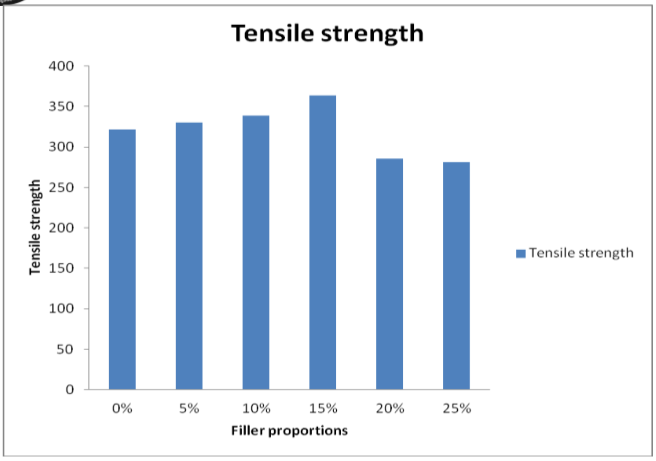

Fig. 1 Tensile Strength of Laminates

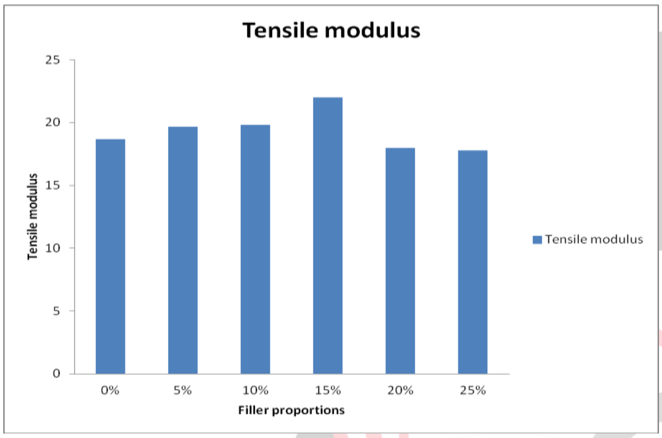

Fig. 2 Tensile Modulus of Laminates

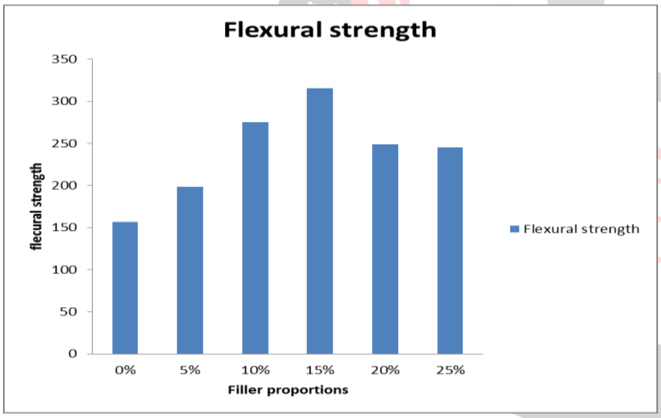

Fig.3 Flexural Strength of Laminates

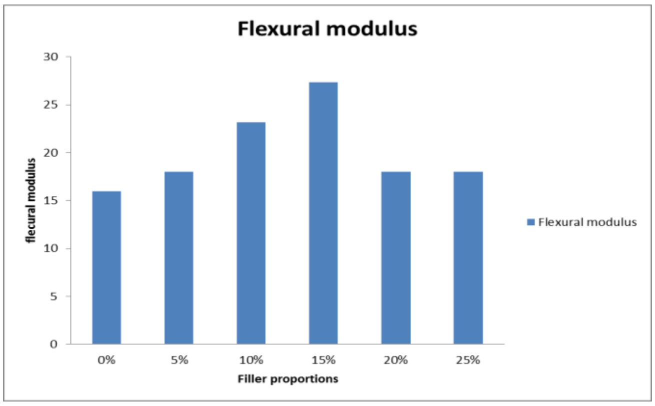

Fig. 4 Flexural Modulus of Laminates

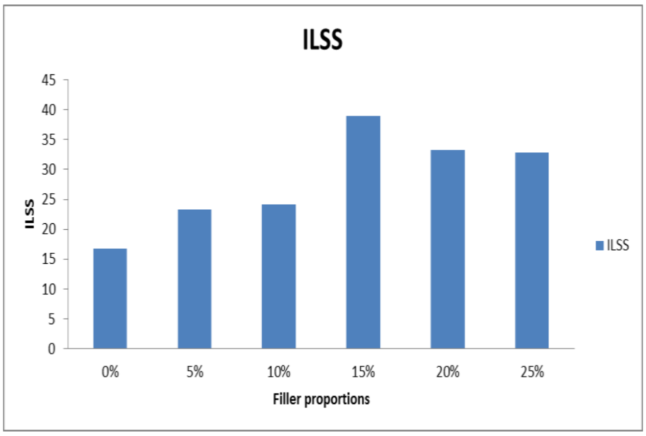

Fig. 5 inter laminar shear strength of laminates

The results of TM are shown in Fig.2, tensile modulus of composites with fillers and without filler materials are compared. It is observed as particulate hybrid laminar composite with 15% filler has maximum TM 22GPa where as 25% filler has a minimum value of 17.8 GPa.

2) *Flexural strength and flexural modulus*: From the results of flexural test which is presented in Fig.3 it can be observed that composite of 15% of filler material gives more FS of 315.5 MPa when compared with composite without filler material which has a FS of 157 MPa. The increase in flexural strength is almost twice the strength before adding filler material. FM also exhibits the same behavior as tensile modulus i.e., adding 15% of filler material gives the more flexural modulus of 27.33 GPa than compared to composites without filler material. Comparison is presented in Fig.4.

3) *Inter Laminar Shear strength (ILSS):* Results obtained in this test are presented in Fig.5 which has 0% of filler material to 25% of filler material. 15% of filler material exhibits more ILSS of 39.028 MPa and composite without filler material exhibits less ILSS i.e., 16.71 MPa.

4) *Hardness*: Hardness for Hardness for E-Glass/Epoxy Laminate (control laminate) is 50-53. Hardness for 5% of E-Glass/Epoxy Laminate (5 % filler (2.5% Al and 2.5% Cu)) is 50-54Hardness for 5% of E-Glass/Epoxy Laminate (10 % filler (5% Al and 5% Cu)) is 55-58 Hardness for 15% of E-Glass/Epoxy Laminate (15 % filler (7.5% Al and 7.5% Cu)) is 54-61.Hardness for 20% of E-Glass/Epoxy Laminate (20 % filler (10% Al and 10% Cu)) is 58-60 Hardness for 25% of E-Glass/Epoxy Laminate (25 % filler (12.5% Al and 12.5% Cu)) is 60-62. Hardness values mentioned above indicate that, as the filler proportions increases hardness also increases. This is due to metallic fillers which are added in the composite laminates.

B. Physical properties

1) *Density of the laminates:* Density of the laminate is unknown as we do not know the mass occupied by the volume of the fibre. The density of the laminate can be calculated by Archimedes principle. The table 1 shows the average values of the density of the laminates.

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Table 1 Density of composite laminates

Filler proportions	0 %	5%	10 %	15 %	20 %	25 %
Density	1.66	1.72	1.71	1.77	1.78	1.76

2) *Resin and fibre content:* The resin content and fibre content of the composite laminate can be obtained by calculating the amount of fibre remained after burnout of resin in the furnace. The table 2 provides the average values of resin and fibre content of the composites. As the resin was applied in calculated quantities i.e., 60:40 ratio. Some amount of resin is reduced as per calculations. This is due to squeezing of resin, resin wasted on the walls of the beaker.

Table 2 Resin and fibre content of composite laminates

Filler proportions	0 %	5%	10%	15%	20%	25%
Resin content	30.13	29.50	29.78	30.75	31.21	30.58
Fibre content	69.87	70.5	70.22	69.25	68.79	69.25

C. Electrical properties

1) *Di-electric constant*: Di-electric constant of composite laminate without filler and particulate hybrid laminar composite materials are presented in table 3. Filler proportions of 0%, 5%, 10% and 15% are only considered because composites of filler proportions up to 15% have better mechanical properties than 20% and 25%. Increase in Dielectric constant indicates that composite laminates with filler can be used as insulator material.

Table 3 Di-electric constant of composite laminates

Filler proportions	Dielectric constant
0%	3.50
5%	3.678
10%	4.044
15%	4.81

2) *Surface Resistivity and Volume Resistivity*: Surface resistivity and volume resistivity of particulate hybrid laminar composite materials are shown in the table 4. In case of volume resistivity, composite laminate with 5% filler proportion i.e., 25.34 X 10^{12} exhibit more resistivity than that of other laminates, where laminate with 15% filler proportion have least resistivity. In case of surface resistivity, composite laminates with 10% filler proportion i.e., 15.71 X 10^{13} has a highest resistivity than that of remaining laminates. The reason is due to the amount of increase in conductive fillers in insulating matrix.

Table 4 Surface resistivity and Volume resistivity of composite laminates

	0 %	5%	10%	15%
Volume resistivity	11.024 X 10^{12}	25.34 X 10^{12}	21.74 X 10^{12}	38.58 X 10^{11}
Surface resistivity	25.09 X 10^{12}	78.91 X 10^{12}	15.71 X 10^{13}	15 X 10^{13}

V. CONCLUSIONS

Mechanical and electrical properties of particulate hybrid laminar composite materials are tested. The effects of filler materials on tensile properties of E-Glass/Epoxy Epofine 1555/FH5200 are, As the filler proportions in the laminate increases the TS and TM of the coupons were also increasing which is only up to 15 % fillers. Tensile properties of laminates with filler proportions above 15 % tend to decrease. The maximum TS among the laminates with various filler proportions is 365.5 MPa. Similarly, as in the case of tensile properties the same trend is fololloweed by flexural properties. Flexural strength and flexural modulus at 15 % filler proportion is 315 MPa and 27.33 respectively. In case of ILSS, the strength is gradually increasing with respect to filler proportions and there is drop in ILSS in the laminates with filler proportions above 15 %. ILSS of 15% filler proportion laminate is 39.028 MPa. As per investigation done in this work, it is concluded that from the mechanical properties, aluminium and copper fillers can be used up to 15 % by weight. In case of electrical properties, there is an improvement in Dielectric constant with increase in filler proportions. As the fillers are conductive particles, surface resistivity of laminate is high at 10% filler proportion and volume resistivity is more at 5% filler proportion.

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