Mechanical Characterization & TOPSIS Ranking of Glass Fiber Reinforced particulate filled Epoxy based Hybrid Composites

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ABSTRACT

In this Research article, Epoxy (E) based composites reinforced with E-Glass fiber (G.F) and filled with two different micro fillers saw wood dust(S.W.D) and cattle bone powder(C.B.P) were fabricated by manual hand layup technique with appropriate compositions of raw materials. After fabrication of composites, to investigate the mechanical properties like Tensile Strength (T.S), Tensile Modulus (T.M), Flexural Strength (F.S), Inter Laminar Shear Strength (ILSS), Impact Strength (I.S), Hardness (H) of composites with and without fillers they are cut in to specimens as per ASTM Standards. The tests were conducted on those specimens for mechanical characterization and results were tabulated. The possible reasons for increase/decrease in the mechanical characterization are explained and finally the TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) is implemented to measure the proximity to the ideal solution.

KEY WORDS- Epoxy (E), E-Glass Fiber (G.F), Saw Wood Dust (S.W.D), Cattle Bone Powder (C.B.P), Mechanical characterization.

1. INTRODUCTION

Due to several physical limitations like low resistance to impact on loading, low stiffness of polymers, they do not have required mechanical strength for application in various fields. To overcome this problem the reinforcement should be done in to the polymer with high strength fibers (Rufai & Lawal, 2015). The synthetic or manmade fibers like Glass, carbon and Kevlar fibers are provided as reinforcement to get high strength to weight ratio and high strength as compared to conventional materials or mono materials. But due to high initial cost, adverse effect on environment the usage of synthetic fibers is decreasing (Prakash Tudu, 2009). To reduce the usage of synthetic fibers natural fibers should be used in place of synthetic fibers as reinforcement otherwise combination of synthetic and natural fibers are used as reinforcement in polymers to reduce the usage of synthetic fibers. For various industrial applications and fundamental research the interest in usage of natural fiber as reinforcement in polymer composites is rapidly growing (Deepa, 2011). These natural fibers/fillers are biodegradable, recyclable, renewable and cheap (Gulbarga and Burli, 2013; Kasama and Nitinat, 2009; Joshi Drzal, 2004; Roe and Ansell, 1985; Zadorecki and Michell, 1989). Due to high hardness, non-toxic, good acoustic resistance and hard wearing quality saw wood dust is potential material for the development of new composites which are used in automotive industry. In structural applications like door panels, window parts, decking, fencing, outdoor furniture, roofline products, furnishing, packaging etc. for automotive industry and building industries wood filled composites are used (Markarian, 2002; Pritchard, 2004; Joshi, 2004; Rozman, 2000; Gachter and Muller,1990; Canche-Escamilla, Rodriguez-Laviada, Cauich-Cupul, Mendizabal, Puig and Herrera-Franco, 2002; Coutinho, 1997; Balasuriya, 2002; Raj, Kokta, 1989; Netravali and Chabba, 2003). Due to high stiffness and strength, Low density, and low price wood fillers are used in composites (Bledzki, 1998; Dalava, 1985; Park and Balatinecz, 1996; Nogellova, 1998).The tensile strength and tensile modulus were increased when Silane treated wood flour is added to poly propylene (Ichazo, Albano, González, Perera and Candal, 2001). (Agunsoye, 2013) studied the effect of cow bone powder as filler in polyethylene and found that addition of cow bone powder to polyethylene improved the strength and wear properties. (Isiaka, 2013) investigated that the reinforcement of fine cow bone powder in polyester leads to improve the strength and coarse cow bone powder leads to improve the toughness. By keeping this in view the investigation carried out to fabricate an epoxy based hybrid composite reinforced with glass fiber and filled with saw wood dust/cattle bone powder for enhancement of the mechanical properties. TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) is implemented to measure the proximity to the ideal solution as per procedure detailed (Suresh, 2016].

2. DETAILS OF EXPERIMENT

Materials Required: A low viscosity epoxy resin (Araldite GY 257) and Hardener (AD 140) were used as the matrix system and E-Glass Fiber of weight 360gms/m2 is used as reinforcement .Epoxy resin, hardener & E-Glass fibers were supplied by kotson engineering corporation private limited, Guntur. Saw wood dust particles and bone powder of size 70µm were used as fillers. Saw wood dust of Balasha teak wood is collected from Sudheer timber depo, Vuyyuru. Bone powder in the form of raw bone meal is collected from VB industries, Kondapalli. Saw wood dust and bone powder are cured in a woven at a temperature of 105^0C to remove the moisture content and then they are sent to ball milling to get the fine powder of size 70µm to 80µm.

Fabrication of composite without filler material: A mold of size $320X320X3mm^3$ is prepared and PVA which acts as a releasing agent was coated at the work side of the mold for easy removal of composite. First, Eight layers of E-Glass fiber of size $320X320mm^2$ are weighed and assumed to 60 wt% of glass fiber and remaining 40 wt% is for the mixture of epoxy resin and hardener. They were mixed with the help of mechanical stirrer in a ratio of 10:4.5 by weight. The mixture of resin and hardener were applied to the work surface of mold with the help of a brush after the application of PVA. One layer of E-Glass fiber is placed in the mold and it is coated with the resin and hardener mixture and rolled with mild steel roller to remove the entrapped air bubbles and for uniform spreading of the resin and another layer of E-Glass fiber is placed on the first layer in the mold. Finally it is cured at room temperature for 72 Hrs.

Fabrication of Hybrid composites (Reinforced with E-Glass fiber and filled with Saw Wood Dust/Cattle Bone Powder): A mold of size $320X320X3mm^3$ is prepared and mansion white wax is applied to the work surface of the mold for easy removal of prepared composite. Eight layers of E-Glass fiber of size $320X320mm^2$ are weighed and assumed to 60% Weight fraction,35 wt% of Resin and hardener are weighed in-proportionate to Glass fiber in the ratio of 10:4.5 by weight remaining 5 wt% of fillers such as S.W.D/C.B.P are weighed. The fillers are added to the resin and mechanical stirring was done by using stirrer for 30 minutes to get the uniform mixture of epoxy resin and filler after that hardener is added to the epoxy resin and filler mixture. The same procedure of fabrication of composite without fillers is followed to prepare the composite with the fillers. In the same manner we have to prepare the composites with the composition of 60 wt% glass fiber 30 wt% Epoxy resin and hardener mixture and 10 wt % S.W.D/C.B.P.

The Designation and compositions of composites are shown in Table.1.

Table.1. Designation and Composition of Composites Raffi 1

Designation of Composites (D)	Composition
C1	60 wt% E +40 wt% G.F
C2	60 wt% E +35 wt% G.F +5 wt% S.W.D
C3	60 wt% E +30 wt% G.F +10 wt% S.W.D
C4	60 wt% E +35 wt% G.F +5 wt% C.B.P
C5	60 wt% E +30 wt% G.F +10 wt% C.B.P

Specimen preparation: The fabricated composite slabs (C1, C2, C3, and C4 & C5) were taken from the mold and as per ASTM Standards they were cut in to specimens of correct dimensions for mechanical characterization. To cut the specimens various engineering work shop tools and power hacksaw were used.

Table.2. Details of type of test and ASTM Standards_Raffi 1

TEST TYPE	ASTM Standard
Tensile Strength & Tensile Modulus	ASTM-D-638-III
Flexural Strength & ILSS	ASTM-D-790:2003
Impact Strength	ASTM-D-256
Hardness	ASTM-D-2240:2003

Material Test Details:

Tensile strength and Tensile Modulus: To determine the tensile strength As per ASTM-D-638-III Standard dog bone shape specimens are used. The specimens are loaded in FIE 40, UTN-40 Machine. From the slope of the linear portion of the stress strain curve the tensile modulus can be determined.

Flexural and Inter laminar shear strength*:* The short beam shear test is performed to determine the ILSS and flexural strength as per ASTM-D-790:2003 Standard. On UTE-60T universal testing machine the test is conducted.

ILSS equation is: $ILSS= \frac{3P}{4bd}$

Flexural Strength: $F.S = \frac{3PL}{2bd2}$

Impact strength: By using IZOD Impact testing machine (Krystal Elmec model : K1-300,Range :168J) Impact tests were done on the specimens as per ASTM-D-256 standard by shattering the specimen with a pendulum hammer of impact tester and the value of impact energy of specimens are directly recorded from the dial indicator .

Hardness: As per ASTM-D-2240:2003 The Specimens Are Tested for micro hardness by shore hardness tester (SHR-Gold, standard block 50shore D).

Topsis: To measure the proximity to the Ideal solution the TOPSIS Technique is implemented. In this TOPSIS the selected alternative should have the shortest distance from the positive ideal solution and farthest distance from negative ideal solution. As per the procedure of TOPSIS steps are determined in Results and Discussion.

3. RESULTS AND DISCUSSION

Table.3, shows the Experimental results of mechanical properties of composites prepared.

Table.3. Mechanical Properties of Fabricated Composites

Composite Designation	Mechanical Properties					
	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Impact Strength (J)	Hardness (Hs)	ILSS (GPa)
C1	223.11	8.118	203.27	4	86.66	5.959
C2	175.71	9.562	214.43	3.6	89	6.542
C3	159.91	5.688	189.58	4	85.66	7.84
C4	213.81	10.61	213.2	4	84.66	7.082
C5	205.76	7.338	192.26	3.2	91	5.641

Tensile Strength: From the Table.3 & Graph for type of composite VS tensile strength the hybrid composite filled with 5 wt% C.B.P exhibited maximum tensile strength of 213.2MPa compared to other filler composites and less than the unfilled composites. This may be due to strong interface adhesion between filler glass fiber and polymer.

The tensile strength of the unfilled composites is 223.11MPa, which is more compared to particulate filled composites. The decrease in tensile strength of particulate filled composites compared with the unfilled composites is Due to the presence of pores at the interface between matrix and particles and the interfacing adhesion may be too weak and due to irregular shaped particulates which results in stress concentration in the matrix base.

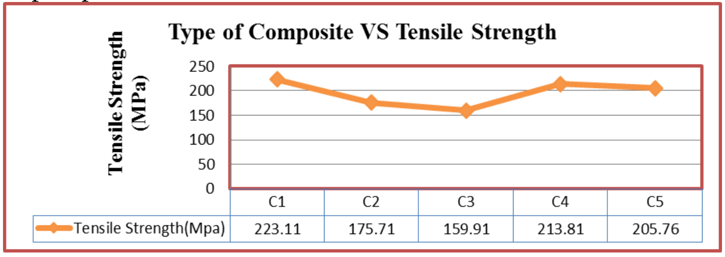

Figure.1. Graph for Type of Composite Vs Tensile Strength

Tensile Modulus: Table.3, shows the Experiments results of tensile modulus. From the Table.3, and the graph of Tensile Modulus it is observed that the composites filled with 5wt % C.B.P Exhibited maximum tensile modulus of 10.610 GPa, with the increase in addition of filler tensile modulus will be increased, this may be due to deformability of the matrix, filler particle size and restriction of the mobility.

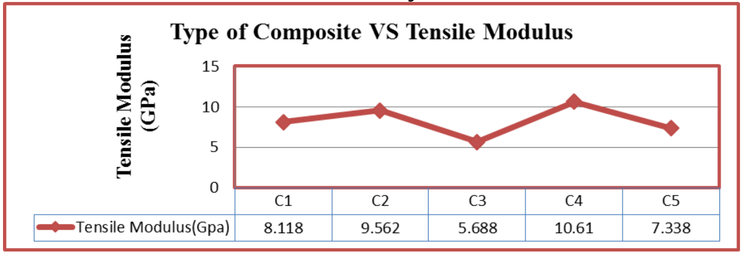

Figure.2. Graph for Type of Composite Vs Tensile Modulus

Flexural Strength and ILSS: From the Table-III and its graph of Flexural Strength, it is observed that 5 wt% S.W.D Modified epoxy composites exhibited more flexural strength of 214.43Mpa. May be due to good adhesive strength of the matrix compared to other fillers. With the increase in filler content the flexural strength of the composites decreases. This might be due to the poor dispersion of micro sized particulates.

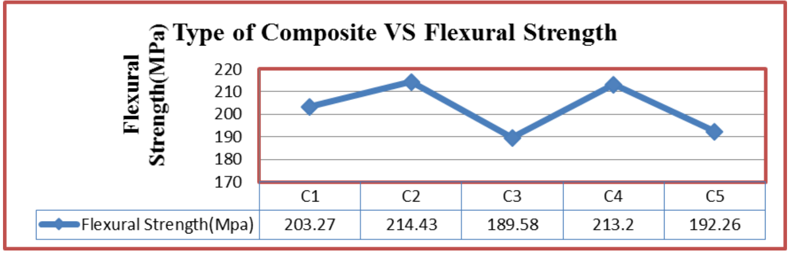

Figure.3. Graph for Type of Composite Vs Flexural Strength

From the Table.3, and its Graph of ILSS, it is observed that, the composite filled with 10 wt % S.W.D exhibited maximum ILSS of 7.84014 GPa. The reduction in ILSS of the rest of the composites is due to the presence of Voids in the Epoxy matrix.

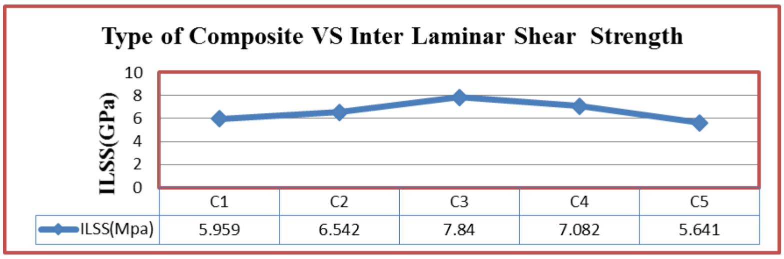

Figure.4. Graph for Type of Composite Vs ILSS

Impact Strength: From the Table.3 and the graph of impact strength, it is observed that the maximum impact strength is 4J and it is for the pure composites, composite with 10 wt% S.W.D and composite with 5 wt% C.B.P. The decrease in impact strength is due to decrease in energy absorbing capacity with filler addition, the decrease in energy absorbing capacity in composite is due to the reason that the mobility of polymer chain is constrained by the filler content which reduces the ability to deform freely and makes the material less ductile.

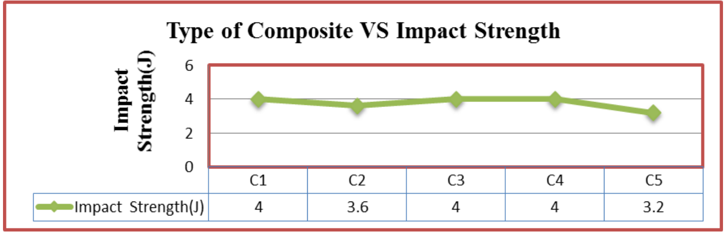

Figure.5. Graph for Type of Composite Vs Impact Strength

Hardness: It is observed from the Table.3, that with the addition of filler shore hardness was increased. This is because during the compressive loading in hardness test the reinforcement phase (i.e. filler and glass fiber) and matrix phase are pressed together tightly in such a way that the interface can transfer pressure more effectively which results in enhancement of hardness.

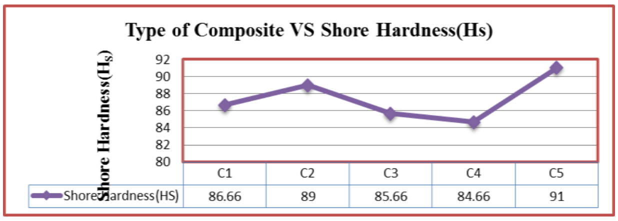

Figure.6. Graph for Type of Composite Vs Hardness

TOPSIS Results: In this methodology, all the composite materials Designated from C1 to C5 are compared based on the TIOPSIS method and ranking has been done. The decision matrix, normalization matrix, weight normalized matrix, ideal positive and ideal negative solution, separation measure relative closeness value and ranking are tabulated as follows.

Step-1:

Table.4. Decision Matrix (D) Of Fabricated Composites

Composite Designation	Decision Matrix(D)					
	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Impact Strength (J)	Hardness (Hs)	ILSS (GPa)
C1	223.11	8.118	203.27	4	86.66	5.959
C2	175.71	9.562	214.43	3.6	89	6.542
C3	159.91	5.688	189.58	4	85.66	7.84
C4	213.81	10.61	213.2	4	84.66	7.082
C5	205.76	7.338	192.26	3.2	91	5.641

Step-2:

Table.5. Normalized Matrix

Composite Designation	Normalized Matrix(N)					
	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Impact Strength (J)	Hardness (Hs)	ILSS (GPa)
C1	0.50618629	0.4301894	0.4482299	0.4740454	0.443293	0.400168
C2	0.398646377	0.5067099	0.4728388	0.4266409	0.455262	0.439319
C3	0.362799739	0.3014187	0.4180421	0.4740454	0.438177	0.526484
C4	0.485086687	0.5622456	0.4701265	0.4740454	0.433062	0.475582
C5	0.466823052	0.3888556	0.4239518	0.3792363	0.465493	0.378813

Step-3:

Table.6. Weight Normalized Matrix (W)

Composite Designation	Weight Normalized Matrix(W)					
	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Impact Strength (J)	Hardness (Hs)	ILSS (GPa)
C1	0.0843643	0.07169823	0.074704990	0.079007	0.073882	0.06669
C2	0.0664410	0.08445165	0.078806469	0.071106	0.075877	0.07321
C3	0.0604666	0.05023645	0.069673695	0.079007	0.073029	0.08774
C4	0.0808477	0.09370760	0.078354424	0.079007	0.072177	0.07926
C5	0.0778038	0.0648092	0.070658638	0.063206	0.077582	0.06313

Step-4:

Table.7. Best & Worst Solutions

Ideal Solution	Best & Worst Solutions					
	Tensile Strength	Tensile Modulus	Flexural Strength	Impact Strength	Hardness	ILSS
Positive Ideal Solution (A_b)	0.084364	0.093708	0.078806	0.079008	0.077582	0.087747
Negative Ideal Solution (A_w)	0.060467	0.050236	0.069674	0.063206	0.072177	0.063136

Step-5:

Table.8. Separation Measures of Attributes

Composite Designation	Separation Measures Of Attributes	
	S^*	S^-
C1	0.030953738	0.036363244
C2	0.026139721	0.038309275
C3	0.050645657	0.029259844
C4	0.010665264	0.053761489
C5	0.042426096	0.023305205

Step-6 & 7:

Table.9. Relative Closeness & Composite Ranking

Composite Designation	Relative closeness & Composite Ranking	
	$C1^*$	R
C1	0.459820642	3RD
C2	0.405587716	4TH
C3	0.633819409	2ND
C4	0.165540926	5TH
C5	0.645447375	1ST

Ranking of the composite by TOPSIS as follows:

- Rank 1 for the composite Designated by C5
- Rank 2 for the composite Designated by C3
- Rank 3 for the composite Designated by C1
- Rank 4 for the composite Designated by C2
- Rank 5 for the composite Designated by C1

4. CONCLUSIONS

The following conclusions can be drawn based on the research in this paper:

- By a simple hand layup process fabrication of epoxy based composites reinforced with glass fiber & particulate fillers like S.W.D & C.B.P is done.
- Effect of fillers on mechanical characterization (Tensile Strength, Tensile Modulus, Flexural Strength, ILSS, Impact Strength, Hardness) is observed from the obtained results
- TOPSIS was successfully employed to find the ranking of the composite based on the mechanical properties

From the test results it is observed that the Tensile Strength of the pure composite without fillers is (223.11MPa) more compared to the other composites which are filled with micro fillers (S.W.D and C.B.P),The Tensile Modulus is maximum for the composites filled with 5 wt% C.B.P and it is 10.610 GPa, The Flexural Strength is (214.43 MPa) maximum for the composite which is filled with 5 wt% S.W.D, The ILSS is (7.84014GPa) maximum for the composite filled with 10 wt% S.W.D, The Impact Strength is (4J) maximum for the composites without fillers and with 10 wt% S.W.D / 5 wt% C.B.P, The Hardness of the composite filled with 10 wt% C.B.P is ($91H_S$) maximum compared to rest of the composites.

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