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Evaluation of Mechanical Properties of Epoxy Based Hybrid Composites & MCDM Technique for Composite Selection

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ABSTRACT

Fiber reinforced polymer composites has been used in a variety of application because of their many advantages such as relatively low cost of production, easy to fabricate and superior strength compare to neat polymer resins. Reinforcement in polymer is either synthetic or natural. Synthetic fiber such as glass, carbon etc. has high specific strength but their fields of application are limited due to higher cost of production. Recently there is an increased interest in natural filler based composites due to their many advantages. In this connection an investigation has been carried out to make better utilization of coal powder/coal fly ash /Bagasse ash as filler material along with glass fiber as reinforcement for preparation of epoxy based hybrid composites.

The objective of the present research work is to study the mechanical properties of glass fiber reinforced epoxy based hybrid composites. The effect of fiber loading and filler material on mechanical properties like tensile strength, tensile modulus, flexural strength, ILSS, hardness and Impact Strength of composites is studied. A multi-criteria decision making approach called TOPSIS is also used to select the best alternative from a set of alternatives based on different attributes (mechanical properties).

KEYWORDS: *Fiber Reinforced polymers, Tensile Strength, Flexural Strength, ILSS, TOPSIS*

I. INTRODUCTION

In The Field Of Material Science Engineering, Development Of New Composite Materials (Or) Modification Of Existing Composite Is The Real Challenge For Most Of The Researchers. Polymer Matrix Composites Have Good Potential To Replace The Traditional Metallic Materials Because Of Their Advantages Like Easy Processing, Productivity, and Cost Reduction Etc. Over Conventional Materials. Among The Thermosetting Polymers Epoxy Resins Are The Most Widely Used For High Performance Applications Because Of Their Excellent Mechanical And Thermal Properties High Chemical And Corrosion Resistance Low Shrink On Curing And The Ability To Be Processed Under A Variety Of Conditions [1] .To Develop New Class Of Polymer Structural Materials Polymer Matrix Modification Is One Of The Approaches. The Properties Of Polymers Are Modified By Using Carbon Fiber And Glass Fibers As Reinforcements [2]. Glass Fiber Reinforced Epoxy Composites Give

The Attractive Combination Of Physical And Mechanical Properties Which Cannot Be Obtained By Monolithic Materials [3,4].Mechanical Properties Of Fiber Reinforced Composites Depends On Type Of Fiber, Quantity, Fiber Distribution And Orientation And Void Content. Besides This The Nature Of The Interfacial Bonds And The Mechanism Of Load Transfer Of The Interphase Also Play An Important Role [5]. It Is Observed From Literature That There Is A Significant Improvement On Mechanical Properties Of Epoxy Based Composites With The Addition Of Micro Fillers, Which Acts As Additional Reinforcing Components And Enhances Their Mechanical Properties And Also Reduces The Processing Cost Significantly. The Properties Of These Composites Depend Upon The Type, Size And Weight Percentage Of The Filler Material Used [6, 7]. The Mechanical Characterization And Comparison Of Mechanical Properties Of E-Glass Reinforced Epoxy Based Hybrid Composites With Equal Weight % Of Fillers (Modifiers) Like Bagasse Ash/Coal Powder/Coal Fly Ash Has Not Been Studied Hence In This Paper E-Glass Reinforced Particulate (Modifiers Or Fillers) Filled Epoxy Based Hybrid Composites Are Prepared And Their Mechanical Properties Are Studied With the addition of 5wt% ,10wt% of Fillers. There Will Be Some Improvement In Mechanical Properties If Modifiers Are Added To Epoxy.

TOPSIS is a multiple criteria method to identify solutions from a finite set of alternatives based upon simultaneous minimization of distance from an ideal point and maximization of distance from a nadir point. TOPSIS has been applied to a number of applications many researchers. Singh et al. [8] studied the selection of material for bicycle chain in Indian scenario using MADM Approach. They concluded that both MADM and TOPSIS methods User friendly for the ranking of the parameters. Huang et al. [9] studied the multi-criteria decision making and uncertainty analysis for materials selection in environmentally conscious design. It was reported that TOPSIS method demonstrates a reasonable performance in obtaining a solution; and entropy method presents designers' or decision makers' preference on cost or environmental impact and effectively demonstrates the uncertainties of their weights. Khorshid et al. [10] studied the selection of an optimal refinement condition to achieve maximum tensile properties of Al-15%Mg2Si composite based on TOPSIS method and observed that the TOPSIS method is considered to be a suitable approach in solving material selection problem when precise performance ratings are available. Ghaseminejad et al. [11] used data envelopment analysis and TOPSIS method for solving flexible bay structure layout, and found that this method is useful for creating, initial layout, generating initial layout alternatives and evaluating them. Chakladar and Chakraborty [12] studied the combined TOPSIS-AHP-method-based approach for non-traditional machining processes selection and also include the design and development of a TOPSISAHP- method-based expert system that can automate the decision-making process with the help of a graphical user interface and visual aids. Shahroudi and Rouydel [13] studied a multi-criteria decision making approach (ANP TOPSIS) to evaluate suppliers in Iran's auto industry. Lin et al. [14] studied on customer-driven product design process using AHP and TOPSIS approaches and results shows that the proposed approach is capable of helping designers to systematically consider relevant design information and effectively determine the key design objectives and optimal conceptual alternatives. Isiklar and Buyukozkan [15] studied a multi-criteria decision making (MCDM) approach to assess the mobile phone options in respect to the users preferences order by using TOPSIS method.

II. MATERIALS AND METHODS

Materials required

Bagasse ash, coal powder and coal fly ash particles are used as modifiers. Bagasse fiber and Bagasse ash are collected from KCP sugars and Industries Corporation Limited, Vuyyuru. Coal power and coal fly ash are collected from NTTPS, Vijayawada. Collected fly ash, coal powder and Bagasse ash are cured in a woven at a temp of 105 °C for removal of moisture and then sieved to an average size of 70-80 µm. The epoxy resin Araldite (LY-556), hardener (HY-951) and E-Glass fiber for reinforcement is supplied by kotson engineering corporation, Guntur.

Fabrication of composite without filler material

The fiber piles were cut to size from the glass fiber cloth. The appropriate numbers of fiber plies were taken: eight for each composite. Then the fibers were weighed and accordingly the resin and hardeners were weighed. Epoxy and hardener were mixed by using stirrer in a bowl. Care was taken to avoid formation of bubbles. Because the air bubbles were trapped in matrix may result failure in the material. The subsequent fabrication

Table 2.1. Composite constituents & weight percentages

Designation	Composition
C1	50 wt % Epoxy Resin + 50 wt % Glass Fiber
C2	45 wt % Epoxy Resin + 50 wt % Glass Fiber + 5 wt % Coal Powder
C3	40 wt % Epoxy Resin + 50 wt % Glass Fiber + 10 wt % Coal Powder
C4	45 wt % Epoxy Resin + 50 wt % Glass Fiber + 5 wt % Coal Fly Ash
C5	40 wt % Epoxy Resin + 50 wt % Glass Fiber + 10 wt % Coal Fly Ash
C6	45 wt % Epoxy Resin + 50 wt % Glass Fiber + 5 wt % Bagasse Ash
C7	40 wt % Epoxy Resin + 50 wt % Glass Fiber + 10 wt % Bagasse Ash

process consisted of first putting a releasing film on the mould surface. Next a polymer coating was applied on the sheets. Then fiber ply of one kind was put and proper rolling was done. Then resin was again applied, next to it fiber ply of another kind was put and rolled. Rolling was done using cylindrical mild steel rod. This procedure was repeated until eight alternating fibers have been laid. On the top of the last ply a polymer coating is done which serves to ensure a good surface finish. Finally a releasing sheet was put on the top; a light rolling was carried out. Then a 20 kgf weight was applied on the composite. It was left for 72 hrs to allow sufficient time for curing and subsequent hardening.

Fabrication of hybrid composites (with fillers)

Hand lay-up technique is used to fabricate E-Glass reinforced epoxy based particulate filled composites. Those particulate fillers are coal powder/coal fly ash/Bagasse ash with 5wt% 10wt% of composition. The designation and composition of Epoxy, Glass fiber, Fillers and hardener are fixed and shown in Table3.1. Before mixing the fillers with epoxy it is dried at 105°C in a woven for 2 hours. Then the fillers are added with epoxy and stirred using a round glass or wooden stirrer for 30 minutes before the mixing of hardener and then hardener is mixed, the same procedure of fabrication of composite without filler is followed in the fabrication of composites with fillers. Mild steel roller is moved on the each layer of the glass fiber to spread the resin uniformly and to remove the air entrapped in the composite. This procedure is repeated up to 8 layers of glass fiber and then composites are cured at atmospheric temperature for 72hours.

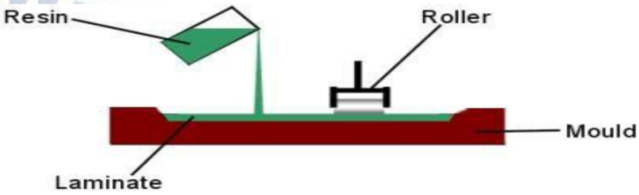

Fig 2.1 Hand layup process

Specimen preparation

From the molds the fabricated E-Glass reinforced particulate filled epoxy based hybrid composites were taken out and as per ASTM standards they are cut in to the specimens of perfect dimensions from the composite slabs for mechanical characterization (i.e. Tensile test, flexural and impact tests) by using hack saw and various tools in engineering work shop various specimens of shapes and sizes are shown below.

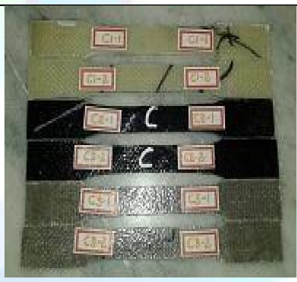

Fig 2.2. Tensile test specimens before Test

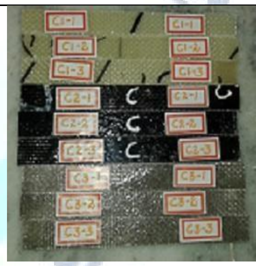

Fig 2.3 Flexural test specimens before Test

Fig 2.4 Impact test specimens before Test

Material Test Details

Tensile strength and tensile modulus

The tensile strength of a material is the maximum amount of tensile stress that it can take before failure. The commonly used specimen for tensile test is the dog- bone type. During the test a uni-axial load is applied through both the ends of the specimen. The dimension of specimen is per ASTM D638 (TENSILE). Typical points of interest when testing a material include, ultimate tensile strength (UTS) or peak stress; offset yield strength (OYS) which represents a point just beyond the onset of permanent deformation ; and the rupture (R) or fracture point where the specimen separates into pieces. The tensile test is performed in the universal testing machine (UTM) Instron 1195(capacity 40 ton) and results are analyzed to calculate the tensile strength of composite samples .Tensile strength is calculated by dividing the load at break by the original minimum cross sectional area. The result is expressed in mega Pascal's (MPa).

Flexural and Inter laminar shear strength

Flexural strength is defined as a materials ability to resist deformation under load. The short beam shear (SBS) tests are performed on the composites samples. It is a 3-point bend test, which generally promotes failure by inter-laminar shear. This test is conducted as per ASTM D790 (FLEXURAL) using UTM (capacity 60T). The loading arrangement is shown in figure. The flexural strength is expressed as modulus of rupture (MR) in psi (MPa) .Flexural MR is about 10 to 20 present of compressive

strength depending on the type, size and volume of coarse aggregate used. However the best correlation for specific materials is obtained by laboratory tests for given materials and mix design.

Flexural Strength = □□□□/□□□

The ILSS equation is **ILSS** = □□/□□□

Here, p is the maximum load applied, b is the width of specimen and d is the thickness of the specimen. The same value of p is used to calculate the flexural strength also. A span of 52mm is used for obtaining both ILSS and Flexural strength.

2.5.3 Impact strength

Impact strength, is the capability of the material to withstand a suddenly applied load and is expressed in terms of energy. Often measured with the Izod impact strength test or Charpy impact test. Low velocity instrumented impact tests are carried out on composite specimens. The tests are done as per ASTM D 256 using an impact tester (Figure 3.9). The charpy/Izod impact testing machine ascertains the notch impact strength of the material by shattering the V-notched specimen with a pendulum hammer, measuring the spent energy, and relating it to the cross section of the specimen. The standard specimen for ASTM D 256 is 64 x 12.7 x 3.2 mm and the depth under the notch is 10.2 mm.

2.6 TOPSIS Ranking:

The TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is implemented to measure the proximity to the ideal solution. The basic concept of this method is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution. Positive ideal solution is composition of the best performance values demonstrated (in the decision matrix) by any alternative for each attribute. The negative-ideal solution is the composite of the worst performance values. The steps involved for calculating the TOPSIS values are as follows [29]:

Step 1

This step involves the development of matrix format. The row of this matrix is allocated to one alternative and each column to one attribute. This matrix is called as a decision matrix (D). The matrix can be expressed as:

□1 □11 □12 . □1□ □1□
□2 □21 □22 . □2□ □2□
□3 . . . . .
□□ □□1 □□2 . □□□ □□□
. . . . .
□5 □□1 □□2 . □□□ □□□

Step 2

Calculate the normalized decision matrix. The normalized value r_{ij} is calculated as follows:

$$r_{ij} = x_{ij}\sqrt{\sum_{i=1}^{m} x_{ij}^{2}} \quad i = 1, 2, \ldots, m \text{ and } j = 1, 2, \ldots, n.$$

Step 3

Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as follows:

$$v_{ij} = r_{ij} \times w_j \quad i = 1, 2, \ldots, m \text{ and } j = 1, 2, \ldots, n.$$

Where w_j is the weight of the j^{th} criterion or attribute and $\sum_{j=1}^{n} w_j = 1$.

Step 4

Determine the ideal (A^*) and negative ideal (A^-) solutions.

$$A^* = \{(\max_i v_{ij} \mid j \in C_b), (\min_i v_{ij} \mid j \in C_c)\} = \{v_j^* \mid j = 1,2,\ldots,m\}$$

$$A^- = \{(\min_i v_{ij} \mid j \in C_b), (\max_i v_{ij} \mid j \in C_c)\} = \{v_j^- \mid j = 1,2,\ldots,m\}$$

Step 5

Calculate the separation measures using the m-dimensional Euclidean distance. The separation measures of each alternative from the positive ideal solution and the negative ideal solution, respectively, are as follows:

$$S_i^* = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^*)^2}, \; j = 1,2,\ldots,m$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^-)^2}, \; j = 1,2,\ldots,m$$

Step 6

Calculate the relative closeness to the ideal solution. The relative closeness of the alternative A_i with respect to A^* is defined as follows:

$$RC_i^* = \frac{S_i^-}{S_i^* + S_i^-}, \; i = 1,2,\ldots,m$$

Step 7

Rank the preference order.

III. RESULTS AND DISCUSSION

3.1. Composite Characterization

Mechanical properties of composites the characterization of the composites reveals that inclusion of any particulate filler has strong influence on the physical and mechanical properties of composites. The modified values of the properties of the composites under this investigation are presented and compared against the unfilled glass epoxy composite in Table 3.1.

Table 3.1 Mechanical Properties of Composites

Composite Designation	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	ILSS (GPa)	Impact Strength J/m²	Hardness(Hb)
C1	252.18	6.292	666.58	12.30155	2.2	47
C2	249	5.225	488.4	9.013	1.85	58
C3	181.786	5.665	750.54	25.188	5.6	61
C4	234.47	5.850	525.42	9.696	1.34	54
C5	175.133	7.823	693.07	24.247	4	56
C6	175.71	9.562	214.43	6.542	3.6	89
C7	159.91	5.688	189.58	7.84	4	85.66

3.2 Tensile Strength & Tensile Modulus of Composites

The test results for tensile strengths & Tensile Modulus are shown in Table 3.1. Composite C1 (50 wt % Epoxy Resin + 50 wt % Glass Fiber) Exhibited the maximum Tensile Strength of 252.18MPa & Composite C6(45 wt % Epoxy Resin + 50 wt % Glass Fiber + 5 wt % Bagasse Ash) Exhibited a maximum Tensile Modulus of 9.562GPa

The declines in Tensile strength& Tensile Modulus of composites are because of

- Presence of pores at the interface between filler particles and the matrix. The interfacing adhesion may be too weak to transfer the tensile stress.
- In the matrix base stress concentration results due to the irregular shaped particulates.

3.3. Flexural strength& ILSS Properties

The test results to flexural strengths are shown in Table 3.1. It is seen that Composite C3(40 wt % Epoxy Resin + 50 wt % Glass Fiber + 10 wt % Coal Powder) Exhibited Maximum Flexural & ILSS as shown in Graph

There can be two reasons for the decline in the Flexural strength properties of the unfilled composites compared to particulate filled composites.

1. The in compatibility of the particulates and the epoxy matrix, leading to poor interfacial

bonding.

2. The lower values of flexural strength may also be attributed to fiber to fiber interaction, voids and dispersion problems.

However it also depends on other factors such size, shape, type and loading on filler on material.

3.4 Hardness of Composites

From Table 3.1 It is seen thatC6-45 wt % Epoxy Resin + 50 wt % Glass Fiber + 5 wt % Bagasse Ash Exhibited maximum Hardness of 89 and for remaining composites hardness is decreased. With the addition of filler 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

3.5. Impact Strength of Composites

The impact energy values of different composites recorded during the impact tests are given in Table 3.1. It shows that the resistance to impact loading of glass epoxy composites improves with addition of particulate filler in composite C3 The Impact strength of Composite C3(40 wt % Epoxy Resin + 50 wt % Glass Fiber + 10 wt % Coal Powder) is5.6J/m^2 and decreased for other filled and unfilled composites. 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.

Ranking of Composites by TOPSIS Method

All the composite materials are compared based on the TOPSIS 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 in Tables below. Finally the ranking of different composite based on their properties is being shown.

STEP-1: This step involves the development of matrix format. The row of this matrix is allocated to one alternative and each column to one attribute. This matrix is called as decision matrix

Table 3.2: Decision Matrix (D) of Composites

Composite Designation	DECISION MATRIX(D)					
	T.S	T.M	F.S	IS	H	ILSS
C1	252.18	6.292	666.58	2.2	47	12.30155
C2	249	5.225	488.4	1.85	58	9.013
C3	181.786	5.665	750.54	5.6	61	25.188
C4	234.47	5.85	525.42	1.34	54	9.696
C5	175.133	7.823	693.07	4	56	24.247
C6	175.71	9.562	214.43	3.6	89	6.542
C7	159.91	5.688	189.58	4	85.66	7.84

STEP-2: Calculate the normalized decision matrix. The normalized value r_{ij} is calculated as follows:

Table 3.3: Normalized Matrix

Composite Designation	NORMALIZED MATRIX					
	T.S	T.M	F.S	IS	H	ILSS
C1	0.45985271	0.35273296	0.46169016	0.23671231	0.26866076	0.30255086
C2	0.45405395	0.29291635	0.33827819	0.19905354	0.33153882	0.22167051

C3	0.33148856	0.31758299	0.51984298	0.60254044	0.34868737	0.61948706
C4	0.42755835	0.32795419	0.36391918	0.14417932	0.30867407	0.23846858
C5	0.31935674	0.43856165	0.48003781	0.43038603	0.32010644	0.59634361
C6	0.32040891	0.5360509	0.14851964	0.38734742	0.50874060	0.160897427
C7	0.291597459	0.31887239	0.131307903	0.430386032	0.48964854	0.192821129

STEP-3: Calculate the weighted normalized decision matrix. The weighted normalized value v_{ij} is calculated as follows:

Table 3.4: Weight Normalized Matrix (W)

Composite Designation	WEIGHT NORMALIZED MATRIX					
	T.S	**T.M**	**F.S**	**IS**	**H**	**ILSS**
C1	0.07664211	0.05878882	0.076948361	0.039452053	0.044776795	0.050425144
C2	0.07567565	0.04881939	0.056379699	0.03317559	0.05525647	0.036945086
C3	0.05524809	0.0529305	0.086640498	0.100423407	0.058114563	0.103247844
C4	0.07125972	0.05465903	0.060653197	0.024029887	0.051445679	0.039744763
C5	0.05322612	0.07309361	0.080006302	0.071731005	0.053351074	0.099390602
C6	0.05340148	0.08934182	0.024753274	0.064557905	0.0847901	0.026816238
C7	0.04859957	0.05314539	0.021884651	0.071731005	0.08160809	0.032136855

STEP-4: Determination of ideal (A^*) and negative ideal (A^-) solutions.

Table 3.5: Best & Worst Solutions

Ideal Solution	BEST & WORST SOLOTIONS					
	T.S	**T.M**	**F.S**	**IS**	**H**	**ILSS**
Positive Ideal Solution(A^*)	0.07664	0.08934	0.08664	0.10042	0.08479	0.10325
Negative Ideal Solution(A^-)	0.0486	0.04882	0.02188	0.02403	0.04478	0.02682

STEP-5: Calculate the separation measures using the m-dimensional Euclidean distance. The separation measures of each alternative from the positive ideal solution and the negative ideal solution respectively are as follows

Table 3.6: Separation Measures Of Attributes

Composite Designation	Separation Measures Of Attributes	
	S^*	**S^-**
C1	0.060121454	0.068653513
C2	0.060787206	0.047108769
C3	0.055408491	0.126925152
C4	0.063412028	0.047564683
C5	0.081103152	0.107724731
C6	0.030354291	0.07011881
C7	0.046766812	0.060652058

STEP6&7: Calculate the relative closeness to the ideal solution. The relative closeness of the alternative A_i with respect to A^* is defined as follows & Rank the preference order.

Table 3.6: Relative Closeness(C1*) & Composite Ranking®

Composite Designation	Relative closeness & Composite Ranking	
	C1*	R
C1	0.466872215	3
C2	0.563387151	2
C3	0.303885176	6
C4	0.571399417	1
C5	0.42950835	5
C6	0.30211361	7
C7	0.435368682	4

IV. CONCLUSION

Project conclusion

The experimental investigation on the effect of fiber loading and filler content on mechanical behavior of fiber reinforced epoxy composites were conducted. Properties such as the Tensile strength, flexural strength, Impact energy were evaluated. The experiments lead us to the following conclusions obtained from this study:

1. The successful fabrications of a new class of epoxy based hybrid composites reinforced with glass fiber and filled with various fillers coal powder/coal fly ash/Bagasse ash have been done.
2. Mechanical characterization has been done and effect of filler material on mechanical properties has been studied.
3. Selection of composite has been done by TOPSIS based on mechanical properties.

Possible use of these composites such as pipes carrying coal dust, industrial fans, helicopter fan blades, desert structures, low cost housing etc. is recommended. However, this study can be further extended in future to new types of composites using other inorganic materials/fillers and the resulting experimental findings can be similarly analyzed.

Scope for future work

There is a very wide scope for future scholars to explore this area of research. This work can be further extended to study other aspects of such composites like use of other potential fillers for development of hybrid composites and evaluation of their mechanical and erosion behavior and the resulting experimental findings can be similarly analyzed.

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