EXPERIMENTAL INVESTIGATION ON MECHANICAL BEHAVIOUR OF HYBRID FIBER REINFORCED POLYMER MATRIX COMPOSITES

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ABSTRACT

In this paper a study of 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 increase interest in natural fiber based composites due to their many advantages. In this connection an investigation has been carried out to make better utilization of coconut coir fiber for making value added products. The objective of the present work is to study the physical, mechanical and water absorption behavior of coir/glass fiber reinforced epoxy-based hybrid composites. The effect of fiber loading and length on mechanical properties like tensile strength, flexural strength, hardness 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. Also, the surface morphology of fractured surfaces after tensile testing is examined using scanning electron microscopy (SEM).

Key words:. Hybrid Fiber Reinforced, Polymer resins, SEM, Mechanical Properties

1.INTODUCTION

Over a past few decades composites, plastics, ceramics have been the leading engineering materials. The areas of applications of composite materials have developed rapidly and have even found new markets. Composite materials consist of many materials being used in refined applications Acha B.A et.al [1]. Kelly [2] defined that the composites should not be regarded simply as a combination of two materials. It clearly states that; the combination has its own unique properties. In terms of strength to resistance to heat or some other desirable quality, it is better to attain properties that the individual components by themselves cannot attain. Zweben C et.al [3] and Sahib D.N [4] et.al studied the composite materials have advantages over other conventional materials due to their higher specific properties such as tensile, flexural and impact strengths, stiffness and fatigue properties, which enable the structural design to be more versatile. John M.J et.al [5] and Ronga M.Z et.al [6] investigated, the natural fibres have a great attention as they are a substitute to the exhausting petroleum sources. Among all reinforcing fibres, natural fibres have increased substantial importance as reinforcements in polymer matrix composites. The benefits accompanying with the usage of natural fibres as reinforcement in polymers are their availability, biodegradability, low energy consumption, non-abrasive nature and low cost. Filho R.D.T et.al [7] and Zhong L.X et.al [8] studied the natural fibres have low density and high specific properties. A great deal of work has been carried out to measure the prospective of natural fibres as reinforcement in polymers. Studies on cements and plastics reinforced with natural fibres such as coir, sisal, bamboo, jute, banana and wood fibres have been reported. Errajhi, et.al [9] and Weitsman et.al [10] studied the all polymers and polymer-based composites absorb moisture in humid atmosphere when immersed in water. In general, moisture diffusion in composites depends on factors, such as the volume fraction of fibre, void volume, additives, humidity, and temperature. The TOPSIS (technique for order performance by similarity to idea solution) was first developed by Hwang & Yoon et.al [11]. It is one of the best grading methods of multi criteria decision making (MCDM) that is taken place in compromising subgroup of compensating models of decision-making Chen, C.T et.al [12]. 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 Olson, D.L et.al [13]. TOPSIS has also been used to compare company performances Deng, Het.al [14] and financial ratio performance within a specific industry Feng C.M et.al [15]. A great deal of work has already been done on the use of TOPSIS for selection of the best alternatives in many fields. However, the use of TOPSIS for selection of the material is hardly been reported.

Based on the exhaustive literature, the present work is undertaken to develop a new class of natural fibre based hybrid composites to study their physical, mechanical and water absorption behaviour. Finally, TOPSIS method is used for the selection of the best material among a set of alternatives.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1Matrix Material

Among different types of matrix materials, polymer matrices are the most commonly used because of many advantages such as cost effectiveness, ease of fabrication with less tooling rate and they also have outstanding room temperature properties. Polymer matrices can be either thermoplastic or thermosetting. The most commonly used thermosetting resins are epoxy, polyester, vinyl ester, Polyurethanes and phenolics. Among them the epoxy resins are generally used for many superior composites due to their many advantages such as tremendous adhesion to wide variety of fibres, superior mechanical and electrical properties and good performance at elevated temperatures. In addition to that they have low shrinkage upon curing and good chemical resistance. Due to numerous advantages over other thermoset polymers, epoxy is chosen as the matrix material for the present research work. It chemically belongs to the 'epoxide' family and its common name of epoxy is Bisphenol-A-Diglycidyl- Ether.

2.1.2 Fibre Material

The natural fibre coir is pull out from the husk of coconut fruit. The husk consists of coir fibre and a corky tissue known as pith. It is a fibre richly available in India. It consists of water, fibres and small amounts of soluble solids. Because of the high lignin content, coir is more robust when compared to other natural fibres.With increasing demand on fuel efficiency, coir-based composites have wider applications in automobiles and railway coaches & buses for public transport system. There is a great opportunity in fabricating coir based composites towards a wide range of applications in building and construction such boards and blocks as reconstructed wood, flooring tiles etc. Natural fibres have the advantages of low density, biodegradability and low cost. Glass is the most widely used synthetic fibre used in polymer matrix composites. Its advantages include its high strength, high chemical resistance, low cost and good insulating behaviour. The type of glass fibre used as reinforcement in this study is E-glass fibre.

3. COMPOSITE FABRICATION

The short coir fibre is collected from local sources and E-glass fibres procured from Saint Gobian Ltd. are taken as reinforcement. Epoxy resin is supplied by Ciba Geigy India Ltd. is taken as matrix material. The low temperature curing epoxy resin and corresponding hardener are mixed in a ratio of 10:1 by weight as recommended. A mould of dimension 210×210×40 mm^3 is used for casting the composite slabs. The short coir/glass fibres are mixed with epoxy resin by the simple mechanical stirring. The composites are prepared with three different fibre loading and four different fibre lengths keeping glass fibre content constant (20 wt%) using simple hand lay-up technique. The mixture is poured into various moulds conforming to the requirements of various testing conditions and characterization standards. The detailed composition and designation of the composites are presented in Table 3.1. The cast of each composite is preserved under a load of about 20 kg for 24 hours before it removed from the mould cavity. Then this cast is post cured in the air for another 24 hours after removing out of the mould. Specimens of appropriate dimension are cut for physical and mechanical tests. Figure 3.1 shows short coir fibre and short glass fibre. Figure 3.2 shows short coir/glass fibre reinforced epoxy hybrid composite.

Table 3.1 Designation of Composites

Composites	Compositions
C1	Epoxy (75wt %) +Glass Fibre (20wt. %) +Coir Fibre (Fibre length 5 mm) (5wt %)
C2	Epoxy (75wt %) +Glass Fibre (20wt. %) +Coir Fibre (Fibre length 10 mm) (5wt%)
C3	Epoxy (75wt %) +Glass Fibre (20wt. %) +Coir Fibre (Fibre length 15mm) (5wt %)
C4	Epoxy (75wt %) +Glass Fibre (20wt. %) +Coir Fibre (Fibre length 20 mm) (5wt%)
C5	Epoxy (70wt %) +Glass Fibre (20wt %) +Coir Fibre (Fibre length 5 mm) (10wt%)
C6	Epoxy (70wt %) +Glass Fibre (20wt %) +Coir Fibre (Fibre length 10 mm)(10wt%)
C7	Epoxy (70wt %) +Glass Fibre (20wt %) +Coir Fibre (Fibre length 15 mm) (10wt%)
C8	Epoxy (70wt %) +Glass Fibre (20wt %) +Coir Fibre (Fibre length 20 mm) (10wt%)

Figure 3.1 Short coir fibre and short glass fibre

Figure 3.2 Short coir/glass fibre reinforced epoxy based hybrid composites

4.MECHANICAL TESTING

As per ASTM D3039-76 test standards the tensile test of composites is done using Universal Testing Machine Instron 1195. A uniaxial load was applied both the ends of composite specimens for the test. The test is repeated two times on each composite type and the mean value is considered. Figure 4.1 shows the experimental set up for tensile test. Figure 4.2 shows the specimens of short coir/glass fibre reinforced epoxy hybrid composites for tensile test. A three point bend test is done to evaluate the flexural strength of the composites Universal Testing Machine Instron 1195. The determination of flexural strength is an important characterization of any structural material. For the test, the cross head speed is taken as 2 mm/min and a span of 40 mm is maintained. The loading arrangement for flexural test is shown in Figure 4.3. Micro-hardness test of composite specimens is done using Leitz micro-hardness tester. Figure 4.4 shows the experimental set up for micro-hardness test.

Figure 4.1 Experimental set up for tensile test

Figure 4.2 Specimen of short coir/glass fibre reinforced epoxy hybrid composites

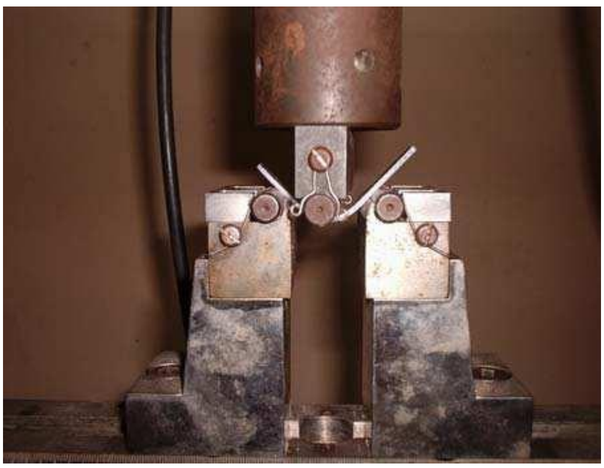


Figure 4.3 Loading arrangement for flexural

test

Figure 4.4 Experimental set up for Micro-

hardness test

4.1 Scanning electron microscopy (SEM)

The fractured surfaces of the composite specimens are examined by scanning electron microscope JEOL JSM-6480LV. Figure 4.5 shows the SEM set up. The samples are washed, cleaned thoroughly, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. Similarly, the composite samples are mounted on stubs with silver paste. To enhance the conductivity of the samples, a thin film of platinum is vacuum-evaporated onto them before the photomicrographs are taken.

Figure 4.5 SEM Set up

4.2 Water absorption test

Moisture absorption studies were performed as per ASTM D 570-98 standards. The weight of the samples was taken before subjecting them to normal water. After exposure for 24h, the specimens were taken out from the moist environment and all surface moisture was removed with a clean dry cloth or tissue paper. The specimens were reweighed to the nearest 0.001 mg within 1 min of removing them from the environment chamber. The specimens were weighed regularly at 24, 48, 72, 96, 120, 144, 168, 192, 216, 240, 264, 288 and 312 hours exposure. The moisture absorption was calculated by the weight difference.

4.5 TOPSIS

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.

5.RESULTS AND DISCUSSIONS

The results of physical, mechanical and water absorption behaviour of short coir/glass fibre reinforced epoxy-based hybrid composites. The effect of fibre parameters such as fibre loading and length on the performance of

composites_ is also discussed. Finally, the ranking of composites based on the TOPSIS method has been done

4.1 Physical and Mechanical Behaviour of Composites

4.1.1 Effect of fibre loading and length on density of composites

The presence of void content in the composites significantly reduces the mechanical and physical properties of the composites. Table 4.1 presents the theoretical density, experimental density and their corresponding void content of all the composite specimens. It can observe from the table that the void content of composites increases with increase in both the fibre loading and fibre length. The similar tread of increase in void content with increase in fibre loading and length has already reported by previous researchers [80].

Table 4.1 Void fraction of hybrid composites

Composites	Theoretical Density (gm/cc)	Exp density (gm/cc)	Vol Fraction Voids (%)
C1	1.248	1.197	4.115
C2	1.248	1.178	5.676
C3	1.248	1.177	5.757
C4	1.248	1.174	5.997
C5	1.254	1.177	6.163
C6	1.254	1.17	6.760
C7	1.254	1.149	8.434
C8	1.254	1.135	9.549

4.1.1 Effect of fibre loading and length on hardness of composites

Surface hardness of the composites is considered as one of the most important factor that governs the wear resistance of the composites. Figure 4.1 shows the effect of fibre loading and length on hardness of composites. The test results show that with the increase of fibre length, micro-hardness of the coir/glass epoxy composites is improved. As far as the effect of fibre loading is concerned composites with 5wt% fibre loading shows better hardness value as compared to 10wt% irrespective of fibre length except for 20mm length. The increase in hardness value is may be due to the incorporation brittle fibres in the epoxy resin.

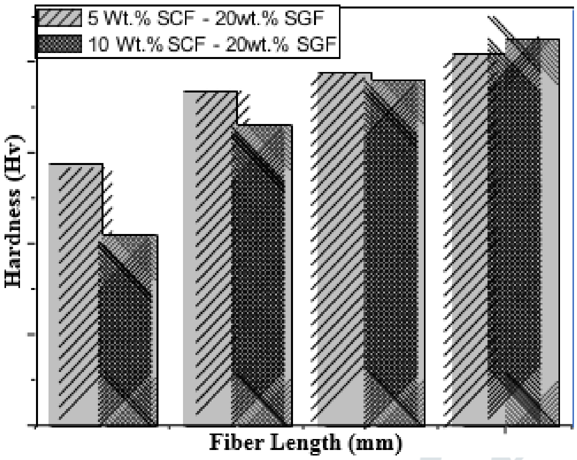


Figure 4.1 Effect of fibre loading and length on hardness of composites

4.1.1 Effect of fibre loading and length on tensile properties composites

The effect of fibre loading and length on the tensile strength and modulus are shown in Figure 4.2 and 4.3 respectively. A gradually increase in tensile strength can be observed with the increase in the fibre length up to 15 mm of coir/glass epoxy based hybrid composites. This is due to the proper adhesion between the both types of fibre and the matrix. However, further increase in fibre length i.e. 20 mm there is a decrease in the tensile strength. The reason may be due to the curling effect of the long coir fibre [81]. The curly nature of fibres prevents the proper alignment of fibres in the (longitudinal direction) composites. The maximum tensile strength is observed for the composite with 10wt% fibre loading at 15mm length. Figure 4.3 shows the variation of the tensile modulus of coir/glass fibre reinforced hybrid composites with different fibre loading and lengths. It can be observed that with the increase of fibre length, the tensile modulus increases irrespective of fibre loading. As far as the effect of fibre loading is concerned, tensile modulus increases with increase in fibre loading irrespective of fibre length. Previous reports reveal that normally the fibres in the composite restrain the deformation of the polymer matrix, reducing the tensile strain [82-83]. So even if the strength decreases with fibre loading, the tensile modulus of the composite is expected to increase as has been observed in present investigation. The maximum tensile modulus is observed in composites with 5wt% fibre loading and 20mm fibre length.

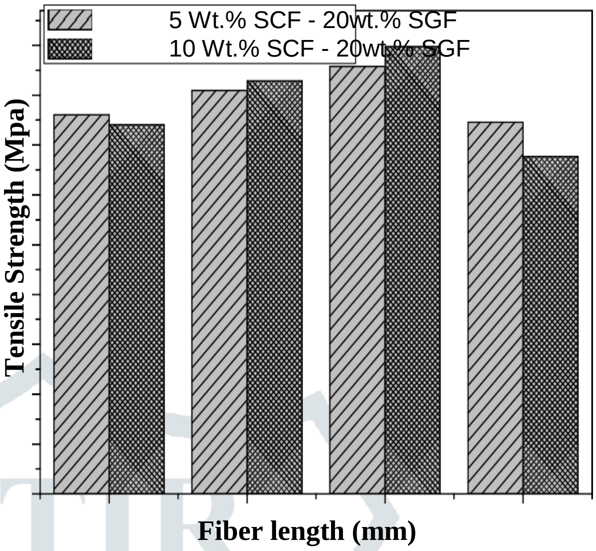


Figure 4.2 Effect of fibre loading and length on tensile strength of composites

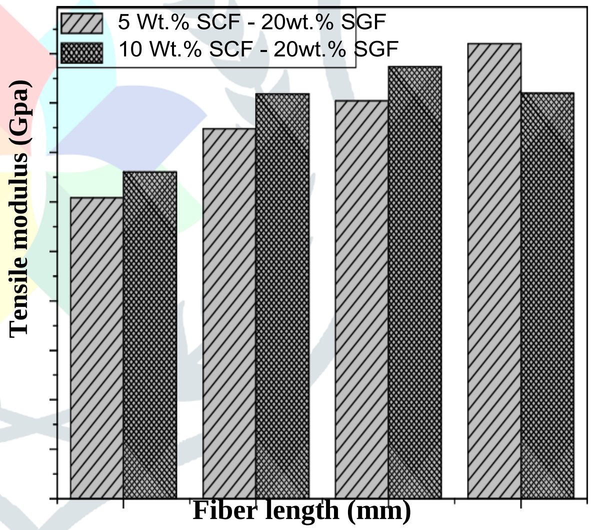


Figure 4.3 Effect of fibre loading and length on tensile modulus of composites

4.1.1 Effect of fibre loading and length on flexural strength of composites

The effect of fibre loading and length on flexural strength of composites is shown in Figure 4.4. It is evident from the figure that the flexural strength of composite increases with increase in fibre length up to 15mm. However, further increase in fibre length (up to 20mm) the value decreases.

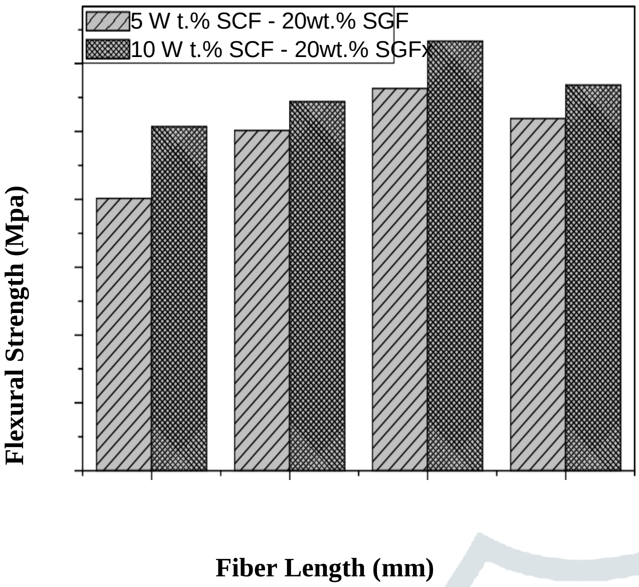
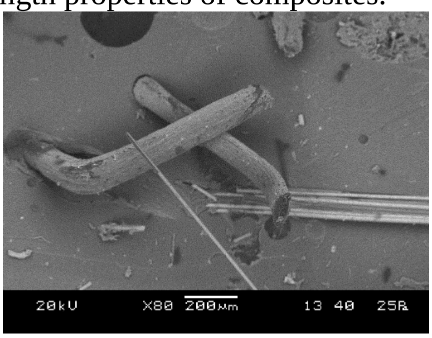


Figure 4.4 Effect of fibre loading and length on flexural strength of composites

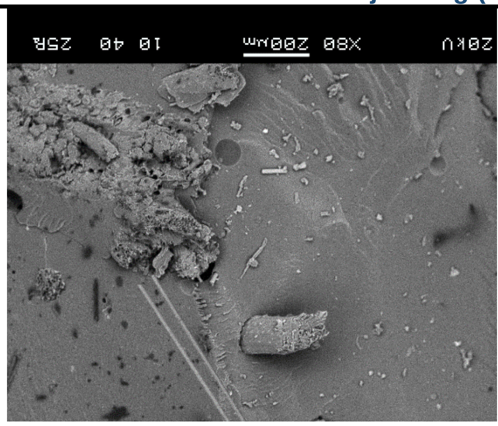
As far as the effect of fibre loading is concerned, composites with 10wt% fibre loading shows better flexural strength value as compared to 5wt% fibre loading. The maximum flexural strength of 63MPa is observed for composites with 10wt% fibre loading at 15mm length.

4.1 Surface Morphology

Figure 4.5a and 4.5b shows the fracture surfaces of coir/glass fibre reinforced epoxy based hybrid composite after the tensile test with different fibre loading and fibre length. Figure 4.5a shows the tensile fracture of composite with 10wt% fibre loading and 20mm fibre length. It can be clearly observed from the figure that the fibres pull out from the resin surface due to poor interfacial bonding. Figure 4.5b shows the tensile fracture surface of composites reinforced with 10wt% fibre loading at 15mm fibre length. It is evident from the figure that surface without much fibre pull out is clearly visible may be due to the better adhesion fibre and matrix which leads to better of strength properties of composites.



(a)



(b)

Figure 4.5 Scanning electron micrographs of coir/glass fibre reinforced epoxy composite specimens after tensile test

4.1 Water absorption properties of composites

The effect of fibre loading and length on the water absorption of the coir/glass fibre reinforced composites with increase in immersion time is shown in Figure 4.6. It is evident from the figure that the rate of moisture absorption increases with increase in fibre lengths. Generally, the rate of water absorption is greatly influenced by the materials density and void content. It has been reported by earlier researchers that the incorporation of long coir fibres into the mix decreased workability and increased the void space [84]. Consequently, the longer the fibre, the higher is the water absorption. As far as effect of fibre loading is concerned composites with 10wt% fibre loading shows higher water absorption rate as compared to 5wt% fibre loading. The reason may be due to that coir fibres contain abundant polar hydroxide groups, which result in a high moisture absorption level of natural fibre reinforced polymer matrix composites and are a major obstacle for preventing extensive applications of these materials [85].

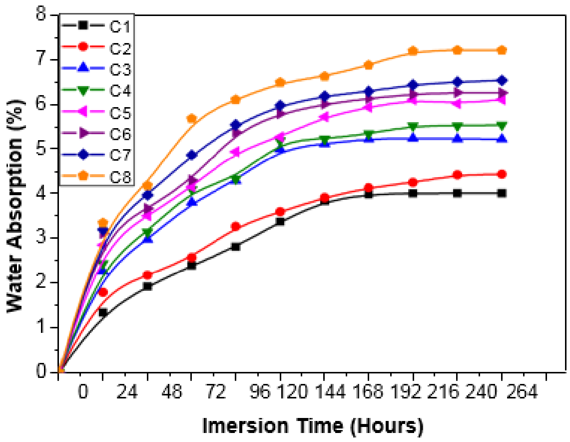


Figure 4.6 Effect of fibre loading and length on water absorption of composites

The minimum water absorption rate is observed for composites with 5wt% fibre loading and at 5mm fibre length. It is also observed from the figure that the water absorption rate generally increases with immersion time, reaching a certain value at a saturation point where no more water is absorbed. The maximum weight gain from 3.34% to 7.25% (weight fraction) is observed by the composite specimens at room temperature.

4.2 Ranking of composites by TOPSIS method

All the composite materials 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 in Tables 4.3, 4.4, 4.5, 4.6, 4.7, 4.8 respectively. Finally the ranking of different composite based on their properties is being shown in the Figure 4.7. It has been observed that ranking of composite materials are as follows: Rank 1(C3), Rank 2 (C2), Rank 3 (C4), Rank 4 (C7), Rank 5 (C8), Rank 6 (C6), Rank 7 (C1) and Rank 8 (C5).

Table 4.2 Decision matrix (D)

Composites	Tensile strength (MPa)	Flexural strength (MPa)	Hardness (Hv)	density (gm/cc)	Water absorption (%)
C1	15.223	40.144	14.4	1.197	4.005
C2	16.189	50.160	18.4	1.178	4.426
C3	17.162	56.340	19.4	1.177	5.221
C4	14.928	51.912	20.5	1.174	5.538
C5	14.823	50.709	10.5	1.177	6.104
C6	16.584	54.395	16.6	1.170	6.254
C7	17.958	63.356	19.0	1.149	6.531
C8	13.543	56.885	21.3	1.135	7.205

Table 4.3 Normalization matrix (R)

Composites	Tensile strength (MPa)	Flexural strength (MPa)	Hardness (Hv)	density (gm/cc)	Water absorption (%)
C1	0.339	0.265	0.285	0.361	0.246
C2	0.360	0.332	0.364	0.356	0.272
C3	0.382	0.373	0.384	0.355	0.321
C4	0.332	0.343	0.406	0.354	0.340
C5	0.330	0.336	0.208	0.355	0.375
C6	0.369	0.360	0.329	0.353	0.384
C7	0.400	0.419	0.376	0.347	0.401
C8	0.301	0.376	0.422	0.343	0.443

Table 4.4 Weight normalized matrix

Composites	Tensile strength (MPa)	Flexural strength (MPa)	Hardness (Hv)	density (gm/cc)	Water absorption (%)
C1	0.067868	0.053199	0.057111	0.07238	0.049249
C2	0.072189	0.066472	0.072975	0.071201	0.054426
C3	0.076527	0.074662	0.076941	0.07114	0.064209
C4	0.066566	0.068794	0.081303	0.070959	0.068108
C5	0.066097	0.067201	0.041643	0.071171	0.075063
C6	0.073952	0.072085	0.065836	0.070717	0.076906
C7	0.080077	0.08396	0.075354	0.069448	0.080316
C8	0.060376	0.075385	0.084476	0.068602	0.088607

Table 4.5 Positive-ideal (best) and negative-ideal (worst) Solution

Solution	Tensile strength	Flexural strength	Hardness	Density	Water absorption
A^+ (ideal solution)	0.080077	0.08396	0.084476	0.068602	0.049249
A^-(negative ideal solution)	0.060376	0.053199	0.041643	0.07238	0.088607

Table 4.6 Separation measures of attributes

Composites	S^+	S^-
C1	0.04311	0.042946
C2	0.023106	0.04967
C3	0.019649	0.050638
C4	0.027997	0.047714
C5	0.054625	0.020339
C6	0.035991	0.03558
C7	0.032389	0.050479
C8	0.04484	0.048385

Table 4.7 Calculate the relative closeness (c_i*)

Composites	Relative closeness (C*)	Ranking of composites
C1	0.49905	7 th
C2	0.68250	2nd
C3	0.72044	1st
C4	0.63021	3th
C5	0.27131	8th
C6	0.49712	6th
C7	0.60914	4th
C8	0.51901	5th

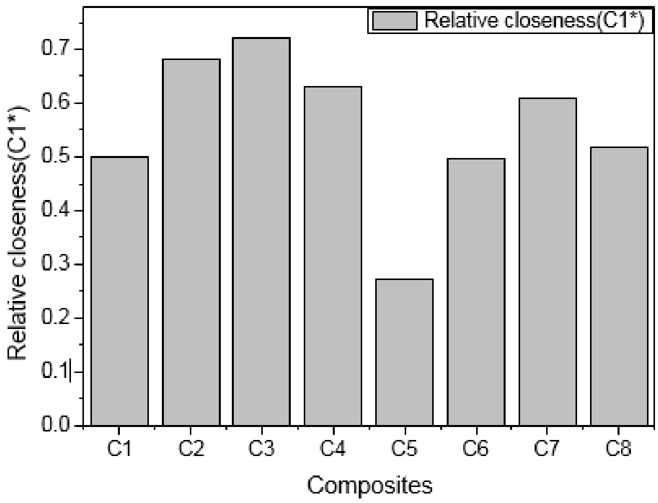


Figure 4.7 Ranking of the different composites

6.CONCLUSIONS

The experimental investigation on the physical, mechanical and water absorption behaviour of coir/glass fibre reinforced epoxy-based hybrid composites lead to the following conclusions:

1. Successful fabrication of hybrid coir/glass fibre reinforced epoxy composites by simple hand lay- up technique.
2. It has been noticed that the various properties of the composites are greatly influenced by the fibre loading and fibre length. The void content of composites increases with increase in both the fibre loading and fibre length. The micro-hardness value increases with increase in fibre length. As far as the effect of fibre loading is concerned composites with 5wt% fibre loading shows better hardness value as compared to 10wt% irrespective of fibre length except for 20 mm length. A gradually increase in tensile and flexural strength can be observed with the increase in the fibre length up to 15 mm of composites. However, further increase in fibre length i.e. 20 mm there is a decrease in the strength properties. It can be observed that with the increase in fibre length, the tensile modulus increases irrespective of fibre loading.
3. SEM images of the fracture surfaces of composites after the tensile test shows that the increase in strength properties of composites at 10wt% fibre loading and 15mm length is due to the better adhesion between fibre and matrix.
4. The rate of moisture absorption increases with increase in both fibre loading and fibre lengths. The minimum water absorption rate is observed for composites with 5wt% fibre loading and at 5mm fibre length.

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