PROCESSING, CHARACTERIZATION AND MECHANICAL BEHAVIOUR OF COIR/GLASS FIBRE REINFORCED EPOXY BASED HYBRID COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

in

Mechanical Engineering
(Specialization: Production Engineering)

BY

VINEET KUMAR BHAGAT

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MAY 2013

DEPARTMENT OF MECHANICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ODISHA, INDIA

CERTIFICATE

This is to certify that the thesis entitled "**PROCESSING, CHARACTERIZATION AND MECHANICAL BEHAVIOUR OF COIR/GLASS FIBRE REINFORCED EPOXY BASED HYBRID COMPOSITES**", submitted by **MR. VINEET KUMAR BHAGAT** bearing **Roll no. 211ME2167** in partial fulfillment of the requirements for the award of ***Master of Technology*** in the Department of Mechanical Engineering, National Institute of Technology, Rourkela is an authentic work carried out under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

Place: Rourkela

Date:

Prof. Sandhyarani Biswas

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A C K N O W L E D G E M E N T

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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 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 research 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).

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CHAPTER 1
INTRODUCTION

1.1 Background and Motivation

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 [1]. A composite material made from two or more constituent materials like reinforcement (fibres, particles, flakes, and/ or fillers) and matrix (polymers, metals, or ceramics). One or more discontinuous phases are, therefore, embedded in a continuous phase to form a composite. The discontinuous phase is usually harder and stronger than the continuous phase and is called the reinforcement, whereas, the continuous phase is termed as the matrix.

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. 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. Due to their many advantages they are widely used in aerospace industry, mechanical engineering applications (internal combustion engines, thermal control, machine components), electronic packaging, automobile, and aircraft structures and mechanical components (brakes, drive shafts, tanks, flywheels, and pressure vessels), process industries equipment requiring resistance to high-temperature corrosion, dimensionally stable components, oxidation, and wear, offshore and onshore oil exploration and production, marine structures, sports, leisure equipment and biomedical devices [3, 4]. Composites can be classified according to different criteria. Figure 1.1 shows the classification of composites based on the geometry and the physical structure of reinforcement and matrix.

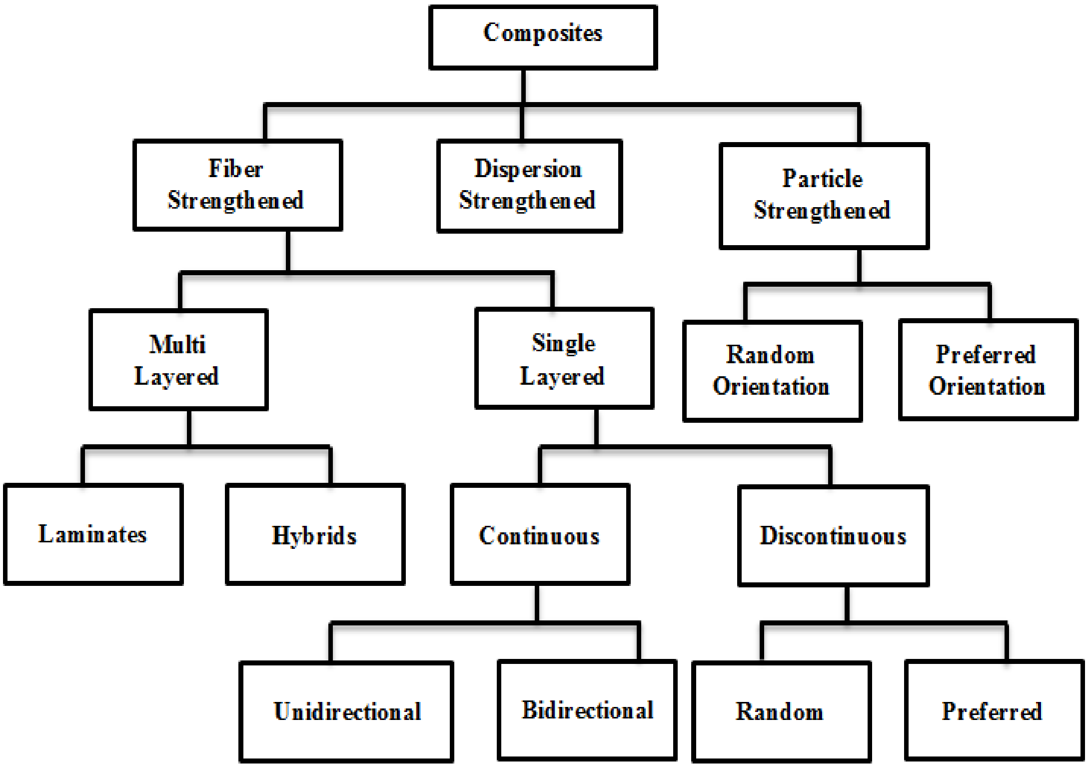

Figure 1.1 Classification of composites based on geometry and physical structure of matrix and reinforcement [5]

According to the type of matrix materials, composite materials are classified into three categories, such as metal matrix composites (MMCs), ceramic matrix composites (CMCs) and polymer matrix composites (PMCs). Each type of composites is suitable for different applications. Among various types of composites, PMC is the most commonly used composites, due to its advantages such as simple manufacturing principle, low cost and high strength. When the matrix material is polymer, the composite is called polymer matrix composites. The reinforcing material can be either fibrous or non-fibrous (particulates) in nature. There are two major classes of polymers used as matrix materials such as thermoplastic and thermosetting. Thermoplastic (e.g. nylons, acrylic, polyethylene, polystyrene etc.) are reversible and can be resized by application of heat and pressure. However, thermosetting (e.g. epoxies, phenolic, polyimides, polyesters etc.) are materials that undergo a curing process through part fabrication, after which they are fixed and cannot be transformed or resized. Epoxy resin is the most commonly used polymer matrix with reinforcing fibres for advanced composites applications. Epoxy resin possesses so many advantages such as very good mechanical properties, and electrical characteristics, chemical resistance and environmental resistance etc.

In fibre reinforcement polymer composites, the reinforcements are either synthetic or natural fibres. Synthetic fibres are made from synthesized polymer or small molecules. The compound used to make this fibre come from raw material such as petroleum based chemicals or petro chemicals. These materials are polymerized in to a long linear chemical that bond to adjacent carbon atoms. Different chemicals compound used to produce different types of fibre. There are different types of synthetic fibres nylon, polyester, carbon fibre, glass fibre, metallic fibre etc. Most synthetic fibres have good elasticity. Glass is the most common fibre used in polymer matrix composites. Its advantages include its high strength, high chemical resistance, low cost and good insulating properties. There are many types of glass fibre S-glass, E-glass, A-glass etc. but only two types of glass fibres such as E-glass and S-glass are most commonly used because of their high tensile strength. Glass fibres are available in different forms like woven fabrics, continuous and chopped. Due to many advantages, E-glass fibre is taken as reinforcement in the present research work.

Now-a-days, the natural fibres have a great attention as they are a substitute to the exhausting petroleum sources [7]. 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. In addition, natural fibres have low density and high specific properties. The specific mechanical properties of natural fibres are equivalent to those of synthetic reinforcements. 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 [8-12]. Among various natural fibres, coir finds a wide variety of applications around the world.

Coir is a natural fibre extracted from the husk of coconut fruit. The husk contains coir fibre and a corky tissue called pith. It is a fibre which is highly available in India the second highest in the world after Philippines [1]. It consists of water, fibres and small amounts of solvable solids. Because of the high lignin content coir is more long-lasting when compared to other natural fibres. Natural fibres such as coir based composites enjoying broader applications in automobiles and railway coaches & buses for public transport system. There exist a very good opportunity in fabricating coir based composites towards a wide array of applications in building and construction such as sheets and slabs as reconstructed wood, flooring tiles etc. Coir nets are used to prevent soil destruction during heavy rains and cyclones. However, the main disadvantages of natural fibres and matrix is the relative high moisture absorption. So, a hybrid composite material that contains two or more different types of fibre in which one type of fibre could complement with what are lacking in the other. Hybridization of natural fibre with high corrosion and stronger resistance synthetic fibres like glass, carbon, aramid etc. can improve the various properties such as strength, stiffness etc. It helps us to achieve a better combination of properties than fibre reinforced composites. Uses of hybrid composites are aeronautical applications (pilot's cabin door), marine applications (ship hulls), wind power generation (blades), telecom applications (hybrid aerial, underground cable) [13].

Table 1.1 Physical properties of various natural fibres [6]

Fibre	Tensile strength(MPa)	Young's modulus(GPa)	Elongation at break(%)	Density (g/cm^3)
Abaca	400	12	3-10	1.50
Alfa	350	22	5.80	0.89
Bagasse	290	17	----	1.25
Bamboo	140-230	11-17	-----	0.60-1.10
Banana	500	12	5.90	1.35
Coir	**175**	**4-6**	**30**	**1.20**
Cotton	287-597	5.50-12.60	7-8	1.50-1.60
Curaua	500-1150	11.80	3.70-4.30	1.40
Flax	345-1035	27.60	2.70-3.20	1.50
Hemp	690	70	1.60	1.48
Henequen	500 70	13.20±3.10	4.80 1.10	1.20
Jute	393-773	26.50	1.50-1.80	1.30
Kenaf	930	53	1.60	----
Nettle	650	38	1.70	----
Oil palm	248	3.20	25	0.7-1.55
Piassava	134-143	1.07-4.59	21.90-7.80	1.40
Pineapple	1.44	400-627	14.50	0.80-1.60
Ramie	560	24.50	2.50	1.50
Sisal	511-635	9.40-22	2.0-2.50	1.50
E-glass	**3400**	**72**	**------**	**2.5**

The properties of some of the natural fibres are presented in Table 1.1. As can be seen from Table 1.1, the tensile strength of glass fibre is substantially higher than the coir fibres even though the density of coir fibre is less than the E-glass fibre. In order to take the advantages of properties of both the fibres, attempt has been to developed a hybrid composite and studies their performance.

Most of the studies made on natural fibre composites reveal that their mechanical properties are strongly influenced by a number of parameters such as volume fraction of the fibres, fibre length, fibre aspect ratio, fibre-matrix adhesion, fibre orientation and stress transfer at the interface. Therefore, both the matrix and fibre properties are important in improving mechanical properties of the composites. A number of investigations have been made on various types of natural fibres to study the effect of these fibre parameters on the mechanical properties of composite materials. Attempt has been made in the current research work to study the effect of fibre loading and length on the performance of composites.

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 [14-15]. Moisture diffusion in polymer composites has been shown to be governed by three different mechanisms. The first involves the diffusion of water molecules inside the micro gaps between the polymer chains. The second involves capillary transportation into the gaps and flaws at the interfaces between the fibre and the matrix. The third involves transportation of micro cracks in the matrix, arising from the swelling of fibres, particularly in the case of natural fibre composites [16- 17]. Hybridization of natural fibre, with stronger and more corrosion-resistance synthetic fibre (e.g., glass fibre), can improve the stiffness, strength, as well as the moisture resistance of the composites, and therefore, a balance between environmental impact and performance may be achieved. Importantly, hybridization between natural fibres and glass fibres is expected to improve the properties of the materials and decrease their water uptake, and subsequently reducing the water absorption problem.

The TOPSIS (technique for order performance by similarity to idea solution) was first developed by Hwang & Yoon (1981). 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 [18]. 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 [19]. TOPSIS has also been used to compare company performances [20] and financial ratio performance within a specific industry [21]. 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.

To this end, 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.

1.2 Thesis Outline

The remainder of this thesis is organised as follows:

Chapter 2: Includes a literature review proposed to provide a summary on the base of information already available concerning the issues of interest.

Chapter 3: The detail description of materials required, fabrication techniques and characterization of the composites under investigation is described in this chapter.

Chapter 4: This chapter presents and discussed the experimental results and selection of best alternative material.

Chapter 5: This chapter presents the conclusions and recommendations for future work.

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CHAPTER 2
LITERATURE REVIEW

This chapter presents the background information on the issues to be considered in the present research work and to focus the significance of the current study. The objective is also to present a thorough understanding of effect of various parameters influencing on the mechanical behaviour of fibre reinforced polymer composites. The literature survey is based on the following aspects:

- **On the natural fibre based polymer composites**

A great deal of work has already been done on natural fibre based polymer composites by many researchers. Gupta et al. [22] studied the effect of different parameters on mechanical and erosion wear behaviour of bamboo fibre reinforced epoxy composites. It was found that the impact strength increases linearly with increase in fibre loading and then decreases the insignificant amount of energy. Tensile strength is maximum at 40 wt. % fibre loading amongst other composites. The alteration in the tensile strength depends on the kind of fibre that can be caused by other factors, such as the fibre length, and hydrophilicity as well as the difference in the chemical nature of the fibre. The flexural strength increased with the increase in fibre loading up to 20 wt%. Monteiro et al. [23] studied the mechanical performance of coir fibre/polyester composites. The mechanical behaviour of coir fibre/polyester composites which exhibited the lack of an efficient reinforcement by coir fibres is attributed to their low modulus of elasticity, in comparison with the bare polyester resin. Harish et al. [24] studied the mechanical behaviour such as tensile strength, flexural strength and impact strength of coir/epoxy composites.

Rozman et al. [11] studied the effect of lignin as a compatibilizer on the physical properties of coconut fibre-polypropylene composites. It was concluded that the coconut fibre polypropylene composites with lignin as a compatibilizer possess higher flexural properties as compared to the control composites. Tensile properties are not much improved as lignin is incorporated as a compatibilizer. Ayrilmis et al. [25] studied on coir fibre reinforced polypropylene composite panel for automotive interior applications. This study showed that the coir fibre is a potential candidate in the manufacture of reinforced thermoplastic composites, especially for partial replacement of high-cost and heavier glass fibres. With increasing coir fibre content up to 60 wt %, the flexural and tensile strengths of the composites increased by 26% and 35%, respectively. However, the further increment in fibre content decreases the flexural and tensile strengths because polymer matrix is insufficient to cover all the surfaces of the coir fibre. Biswas et al. [26] studied with the effect of length on mechanical behaviour of coir fibre reinforced epoxy composites. It was reported that the hardness is decreasing with the increase in fibre length up to 20 mm. Junior et al. [27] studied on tensile behaviour of coir fibre reinforced polyester composites. Basiji et al. [28] studied the effects of fibre length and fibre loading on the mechanical properties of wood-plastic (polypropylene) composites. Vilay et al. [29] studied the effect of fibre surface treatment and fibre loading on the properties of bagasse fibre reinforced unsaturated polyester composites. Higher tensile and flexural properties were obtained for treated fibre composites compared to those of untreated fibre based composites. The addition of higher amount of fibre results in higher tensile and flexural properties of the bagasse fibre reinforced polyester composites. Goud et al. [30] studied the effect of fibre content and alkali treatment on mechanical behaviour of Roystonea regia-reinforced epoxy composites. It was found that the tensile strength, tensile modulus and percentage of elongation of untreated and alkali-treated

Roystonea regia natural fibre-reinforced epoxy composites were increased with increase in fibre content and are highest at 20 wt.%. Luo et al. [31] studied the mechanical and thermal properties of environment-friendly "green" composites made from pineapple leaf fibres and poly (hydroxybutyrate-covalerate) resin. Tensile and flexural properties of the "green" composites with different fibre contents were measured. It was found that the composites increased significantly compared with pure resin, in the longitudinal direction but decreased in the transverse direction with increase in fibre content. Gowda et al. [32] studied the mechanical properties of untreated jute fabric-reinforced polyester composites. The mechanical properties of jute/polyester composites do not possess strengths and moduli as high as conventional composites. They do have better strengths than wood composites and some plastics. Therefore, these composites could be considered for future materials use. Masoodi et al. [33] studied the moisture absorption and swelling in bio-based jute-epoxy composites. It shows that both the water absorption and swelling measurements were higher for the bio-epoxy composites compared to the epoxy composites, possibly due to the use of cellulose and the hydroxyl group of bio-epoxies. Alamri et al. [34] studied the mechanical and water absorption behavior of recycled cellulose fibre reinforced epoxy composites. It shows that water absorption was observed to increase with increasing fibre content. Exposure to moisture for two weeks caused a reduction in flexural strength, flexural modulus and fracture toughness due to the degradation of bonding at the fibre-matrix interfaces. However, impact strength was found to increase slightly after water absorption. The effect of water absorption on mechanical properties was more pronounced at high fibre content than at the low fibre content. Hu et al. [35] studied the moisture absorption, tensile strength behaviour of short jute fibre/polylactide composite in hygrothermal environment. It was reported that for uncoated sample, the moisture absorption process includes three distinct stages such as quick moisture absorption stage, a slow steady increasing of moisture uptake stage and a very rapid moisture absorption stage. The whole moisture absorption process until the complete relaxation of the samples does not show moisture saturation. Bhaskar et al. [36] studied the water absorption and compressive properties of coconut shell particle reinforced epoxy composite. It was concluded that the water absorption capacity was found to be maximum of 30 with % of coconut shell particles.

- **On synthetic fibre based polymer composites**

Many researchers have studied the effect of various parameters on the mechanical behaviour of synthetic fibre based polymer composites. Cho and Jung [37] studied the electrically conducting high-strength aramid composite fibres prepared by vapour-phase polymerization of pyrrole and shows that the composite fibres gives good thermal stability in conductivity within a range of 170^0C. The mechanical properties were affected little by polymerization of pyrrole, and could maintain good mechanical properties of the original aramid fibre. The electrical resistance of the composite fibres initially increased slowly with increasing elongation, but increased sharply near breaking point. Chauhan et al. [38] studied the effect of fibre loading on mechanical properties, friction and wear behaviour of vinyl ester composites under dry and water lubricated conditions. It was reported that the density of composite specimens is affected marginally by increasing the fibre content. For the composites with a higher percentage of fibre content, cured at room temperature shows slight increase in density. Kutty and Nando [39] studied the effect of processing parameters on the mechanical properties of short Kevlar aramid fibre-thermoplastic polyurethane composite and observed that processing parameters like nip gap, friction ratio and mill roll temperature have extreme influence on the fibre orientation and hence on the mechanical properties of short Kevlar aramid fibre-thermoplastic polyurethane composite. Allaoui et al. [40] studied on mechanical and electrical properties of composite with different weight percentages of nanotubes. It has been seen that the addition of 1 and 4 wt. % of CNT into the epoxy matrix gives a remarkable effect on the mechanical properties. The Young's modulus and the yield strength of the 1 wt. % composite have been increased by respectively 100 and 200% compared to the pure matrix. Jansons et al. [41] studied on the effect of water absorption, elevated temperatures and fatigue on the mechanical properties of carbon-fibre-reinforced epoxy composites for flexible risers. It has been seen that the long-term exposure of unloaded specimens to pure water at 70°C and specimens loaded in three-point bending to water at room temperature practically did not affect their flexural stiffness (the maximum variation was less than 4%), while the flexural strength after 500 h of exposure dropped by 16% and 10%, respectively. Taghavi [42] studied for moisture effects on high performance polymer composites. It was concluded that both glass-epoxy and carbon-epoxy composites lost some dry weight during the immersion period in 90°C water therefore the real absorption pattern could be obtained by using the linear solids mass loss data, in combination with the experimental moisture absorption data. Also it was found that for all the composites immersed in the 90°C water the maximum moisture content was higher than those of 60°C water. Huang et al. [43] studied the effect of water absorption on the mechanical behaviour of glass/polyester composites. It was concluded that the breaking strength and tensile stress of the composites decreased gradually with increased water immersion time because the weakening of bonding between fibre and matrix.

- **On hybrid based polymer composites**

Multi-component composites consisting of a matrix phase reinforced with two or more types of fibre as reinforcements are termed as hybrid composites. Research on hybrid composites reinforced with both synthetic and natural fibres has already been done by many researchers.

Gururaja et al. [44] studied a review on recent applications and future prospects of hybrid composites. Efforts have been focused on the applications of hybrid composites for better understanding of the phenomena associated with the cutting edge technology. Glass and carbon fibre reinforced epoxy based composites have been investigated. Jawaid et al. [45] studied the effect of jute fibre loading on tensile and dynamic mechanical behaviour of oil palm epoxy composites. Due to jute fibre loading on oil palm epoxy composites the tensile properties increased with the increase in the ratio of jute fibre in the hybrid composites. When jute fibre loading is increased, the effectiveness of stress-transfer is increasing. Thwe et al. [46] studied the durability of bamboo/glass fibre reinforced polymer matrix hybrid composites. It was concluded that both the tensile strength and modulus of bamboo fibre reinforced polymer and bamboo/glass fibre reinforced polymer composites have decreased after aging in water at 25°C and 75°C for prolonged periods. Tensile strength and stiffness are enhanced by the inclusion of a compatibilizer, MAPP, in matrix material as a result of improved interfacial bonding. Mishra et al. [47] studied the mechanical properties of bio fibre/glass reinforced polyester hybrid composites. It was concluded that the pineapple leaf fibres (PALF)/glass and sisal/glass hybrid fibre reinforcements in polyester resin having encouraging mechanical properties. Ahmed et al. [48] studied the tensile, flexural and inter-laminar shear properties of woven jute and jute-glass fabric reinforced polyester composites. It has been revealed that the layering sequence (altering the position of glass plies) significantly affects the flexural and inter-laminar shear strength. Sreekala et al. [49] studied the hybrid effect of glass fibre and oil palm empty fruit bunch fibre on the tensile, flexural and impact response of the phenol-formaldehyde-based composites. It has been concluded that the Glass and oil palm empty fruit bunch hybrid fibre reinforcement in PF resin resulted in cost effective and light weight composites having good performance qualities. Girisha et al. [50] studied the water absorption and mechanical behaviour of sisal/coconut coir fibre reinforced epoxy Composites. It was concluded that with the increase in fibre content at dry condition, the tensile and the flexural strength increased. At wet condition, the tensile and flexural strength have a high-level reduction. Velmurugan et al. [51] studied the mechanical properties of palmyra/glass fibre reinforced hybrid composites. It was concluded that hybridization of palmyra/glass fibre with synthetic fibre is a viable approach for enhancing mechanical properties and durability of natural fibre composites. Venkateshwaran et al. [52] studied the mechanical and water absorption behaviour of banana /sisal reinforced hybrid composites. It was reported that hybridization of banana /sisal reinforced fibre composite by another natural fibre does not yield superior mechanical properties as hybridization by glass fibre and carbon fibre and hence this kind of hybrid composite are suitable for low cost applications. Ahmed et al. [53] studied the elastic properties, notched strength and fracture criterion in untreated woven jute/glass fabric reinforced polyester hybrid composites. It was observed that in untreated woven jute/glass fabric reinforced polyester hybrid composites, the young's modulus in warp and weft direction increases whereas the poisson's ratio decreases with the increase in glass fibre content. This indicates that, jute composites undergo more transverse strain and less longitudinal strain than jute/glass hybrid composites. Rao et al. [54] studied the effect of fibres on mechanical properties of bamboo/glass fibre based hybrid composites. It was reported that hybrid composites with alkali treated bamboo fibres were found to possess higher impact properties. Treated composites also proved that they have good dielectric properties at 40/0 bamboo/glass fibre weight ratio. Joseph et al. [55] studied the comparison of the mechanical properties of phenol formaldehyde composites reinforced with banana fibres and glass fibres. It was showed that an increase in bamboo fibre content of up to 40% (by mass) in bamboo fibre reinforced polymer results in a 60% increase in tensile modulus. Both banana fibre and glass fibre composites have an increase in tensile, flexural and impact properties with increasing fibre loading. The hybrid composites with alkali-treated bamboo fibres were found to possess higher tensile properties [56-57]. Thwe et al. [58] studied the characterization of bamboo-glass fibre reinforced polymer matrix hybrid composite. It was concluded that the bamboo/glass fibre reinforced polypropylene hybrid systems depend on fibre weight ratios, fibre length, and adhesion characteristics between the fibres and the matrix. Yang et al. [59] studied the mechanical properties of hybrid reinforced rigid polyurethane composite foam. It was concluded that the tensile strength of the polyurethane composite foam is optimal when the content of SiO_2 and glass fibre is 20 and 7.8%, respectively. The tensile strength of polyurethane composite foam reinforced with 3-5% carbon fibre is optimal. Goud et al. [60] investigated the tensile, flexural, impact and hardness properties of hybrid composites considerably increased with increase in glass fibre loading. But electrical conductivity and dielectric constant values decreased with increase in glass fibre content at all frequencies. Junior et al. [61] studied the thermal, mechanical and dynamic mechanical analyses of hybrid interlaminate curaua-glass composites. It was reported that the increase in density of the composites for higher glass content and overall fibre volume fraction, barcol hardness and impact strength followed the same trend due to the intrinsic characteristics of the glass fibre such as stronger adhesion to the matrix and higher energy dissipation at the interface in comparison with the vegetable fibre. Bledzki et al. [62] studied the natural fibre reinforced polyurethane micro foams. It was concluded that the dynamic mechanical properties can be significantly enhanced at higher fibre content. Increasing micro void content in the matrix induces only a limited effect on the shear modulus and impact strength. The flax fibre based composites exhibit higher strength and stiffness than the jute fibre. Pothan et al. [63] studied the dynamic mechanical and dielectric behaviour of banana/glass hybrid fibre reinforced polyester composites. It was concluded that the volume fraction of glass involved in the hybridization, an intimate mixture of banana and glass or a layering pattern with detailed distribution of both the fibres gives better properties. Kim et al. [64] studied the effect of moisture absorption on the flexural properties of basalt/CNT/Epoxy Composites. They concluded that the flexural strength and modulus of the moisture absorbed specimen were 22% and 16% lower, respectively, than those values of the dry specimen. The decrease in these values for moisture absorbed specimens was due to the weakening of the interfacial bonding due to swelling of the epoxy matrix. Zamri et al. [65] studied the effect of water absorption on pultruded jute/glass fibre reinforced unsaturated polyester hybrid composites. They concluded that hybridization of natural fibres with synthetic fibres decreases the maximum moisture absorption and increases the mechanical properties of the composites. Silva et al. [66] studied the effect of water aging on the mechanical properties of curaua/glass fibre reinforced hybrid composites. It shows that the water absorption of the laminated hybrid was higher for distilled water (2.10%) than in sea water (1.95%). However, the saturation time was approximately the same for both conditions. Jahani et al. [67] studied the effect of epoxy-polyester hybrid resin on mechanical properties, rheological behavior and water absorption of polypropylene wood flour composites. They concluded that maleic anhydride grafted PP improve the interfacial interaction of cured epoxy resin with PP and leads to higher tensile strength and elastic modulus, and reduce moisture absorption. Dixit et al. [68] studied on the effect of hybridization on mechanical behaviour of coir/sisal/jute fibres reinforced polyester composite material. It was concluded that the tensile properties of natural fibre composites can be significantly improved by natural fibres in a sandwich construction. Yuan et al. [69] studied the reinforcing effects of modified Kevlar fibre on the mechanical properties of wood-flour/polypropylene composites and observed that the addition of Kelvar Fibre improved the mechanical properties of wood flour/polypropylene composites. Treatment of Kelvar fibre with NaOH resulted in improvement in mechanical strength. Addition of 3% MAPP and 2% hydrolyzed KF led to an increment of 93.8% in unnotched impact strength,17.7% in notched impact strength, 86.8% in flexure strength, 50.8% in flexure modulus, and 94.1% in tensile strength compared to traditional WF/PP composites.

- **On TOPSIS**

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. [70] 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. [71] 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. [72] studied the selection of an optimal refinement condition to achieve maximum tensile properties of Al-15%Mg_2Si 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. [73] 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 [74] studied the combined TOPSIS-AHP-method-based approach for non-traditional machining processes selection and also includes the design and development of a TOPSIS-AHP-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 [75] studied a multi-criteria decision making approach (ANP-TOPSIS) to evaluate suppliers in Iran's auto industry. Lin et al. [76] 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 [77] 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.

2.1 Objectives of the Present Research Work

Keeping in view of the current status of research the following objectives are set in the scope of the present research work.

1. Fabrication of coir/glass fibre reinforced epoxy composites
2. To study the influence of fibre length and fibre loading on physical, mechanical and water absorption behaviour of composites.
3. To study the surface morphology using SEM study.
4. To select the best alternative from a set of alternative materials using TOPSIS method.

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CHAPTER 3
MATERIALS AND METHODS

This chapter describes the details of materials used, processing of the composites and the experimental procedures followed for their characterization.

3.1 Materials

3.1.1 Matrix 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.

3.1.2 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.

3.2 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

3.3 Physical property tests

3.3.1 Density

The actual density (ρ_{ce}) of the composite can be obtained experimentally by water immersion technique. The theoretical density of composite materials can easily be obtained as per the following equations given by Agarwal and Broutman [78].

$$\rho_{ct} = \frac{1}{\left(\frac{w_f}{\rho_f} + \frac{w_m}{\rho_m}\right) + (w_m + \rho_m)} \quad (3.1)$$

Where, w and ρ represent the weight fraction and density respectively.

The suffix m, f, and ct stand for the matrix, fibre and the composite materials respectively.

The volume fraction of voids (Vv) in the composites is calculated by the following equation:

$$V_v = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \quad (3.2)$$

3.4 Mechanical property tests

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 3.3 shows the experimental set up for tensile test. Figure 3.4 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 3.5. Micro-hardness test of composite specimens is done using Leitz micro-hardness tester. Figure 3.6 shows the experimental set up for micro-hardness test.

Figure 3.3 Experimental set up for tensile test

Figure 3.4 Specimen of short coir/glass fibre reinforced epoxy hybrid composites

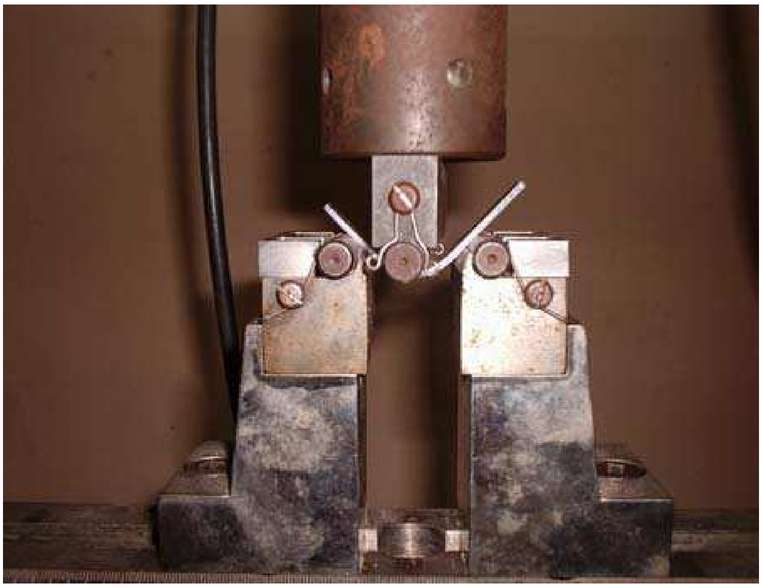

Figure 3.5 Loading arrangement for flexural test

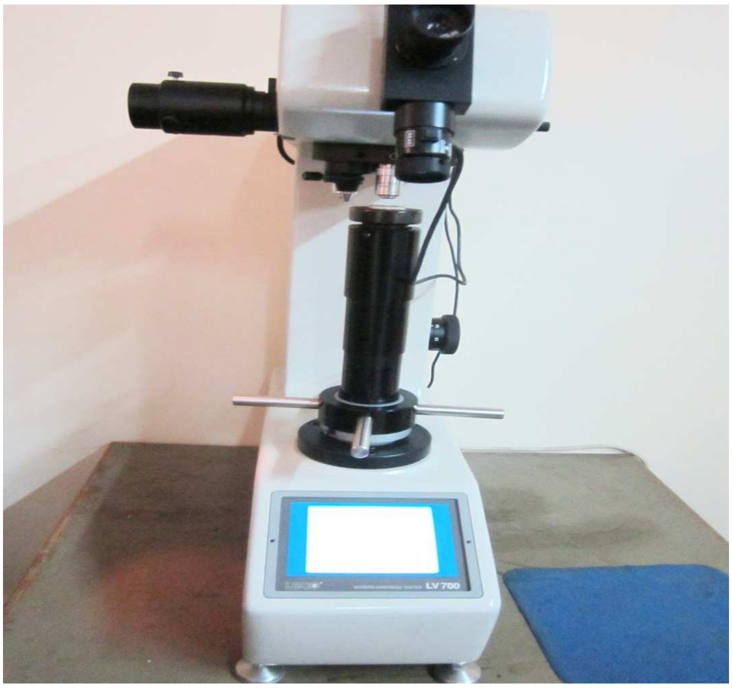

Figure 3.6 Experimental set up for Micro-hardness test

3.5 Scanning electron microscopy (SEM)

The fractured surfaces of the composite specimens are examined by scanning electron microscope JEOL JSM-6480LV. Figure 3.7 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 3.7 SEM Set up

3.6 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. The percentage weight gain of the samples was measured at different time intervals by using the following equation:

$$\%M = \frac{(W_t - W_o) \times 100}{W_o} \quad (3.3)$$

Where W_t is the weight of specimen at a given immersion time and W_0 is the oven-dried weight.

3.7 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. The steps involved for calculating the TOPSIS values are as follows [79]:

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:

$$D = \begin{matrix} A_1 \\ A_2 \\ \cdot \\ A_i \\ \cdot \\ A_m \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdot & x_{1j} & x_{1n} \\ x_{21} & x_{22} & \cdot & x_{2j} & x_{2n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ x_{i1} & x_{i2} & \cdot & x_{ij} & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ x_{m1} & x_{m2} & \cdot & x_{mj} & x_{mn} \end{bmatrix} \tag{3.4}$$

STEP 2: Then, the normalized decision matrix or R matrix is calculated with r_{ij} as the normalized value:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{3.5}$$

Here, r_{ij} represents the normalized performance of A_i with respect to attribute X_j.

STEP 3: obtain the weighted normalized decision matrix, $V = \left| v_{ij} \right|$ can be found as:

$$V = w_j r_{ij} \tag{3.6}$$

Here, $\sum_{j=1}^{n} w_j = 1$

STEP 4: Determine the ideal (best) and negative ideal (worst) solutions in this step. The ideal and negative ideal solution can be expressed as:

The ideal solution:

$$A^{+} = \left\{ \left(\max_{i} v_{ij} \middle| j \in J \right), \left(\min_{i} v_{ij} \middle| j \in J^{'} \middle| i = 1, 2, \ldots\ldots. m \right) \right\} \quad (3.7)$$

$$= \left\{ v_1^{+}, v_2^{+}, \ldots\ldots. v_j^{+}, \ldots.. v_n^{+} \right\}$$

The negative ideal solution:

$$A^{-} = \left\{ \left(\min_{i} v_{ij} \middle| j \in J \right), \left(\max_{i} v_{ij} \middle| j \in J^{'} \middle| i = 1, 2, \ldots\ldots. m \right) \right\} \quad (3.8)$$

$$= \left\{ v_1^{-}, v_2^{-}, \ldots\ldots. v_j^{-}, \ldots.. v_n^{-} \right\}$$

Here,

$j = \{ j = 1, 2, \ldots\ldots, n | j \}$ Associated with the beneficial attributes

$j^{'} = \{ j = 1, 2, \ldots\ldots., n | j \}$ Associated with non- beneficial attributes

STEP 5: Determine the distance measures. The separation of each alternative from the ideal solution is given by n- dimensional Euclidean distance from the following equations:

$$S_i^{+} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{+} \right)^2} \quad (3.9)$$

$$S_i^{-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^{-} \right)^2} \quad (3.10)$$

STEP 6: Calculate the relative closeness (closeness coefficient, CC) to the ideal solution:

$$C_i^{+} = \frac{S_i^{-}}{S_i^{+} + S_i^{-}}, i = 1, 2, \ldots\ldots.. m; 0 \le C_i^{+} \le 1 \quad (3.11)$$

STEP 7: Rank the preference order: the alternative with the largest relative closeness is the best choice.

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CHAPTER 4
RESULTS & DISCUSSIONS

This chapter presents 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)	Experimental density (gm/cc)	Volume Fraction of 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

4.1.2 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.

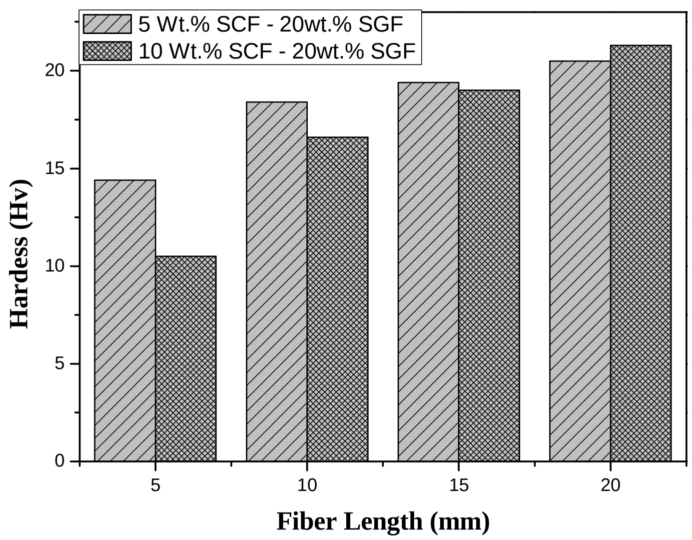


Figure 4.1 Effect of fibre loading and length on hardness of composites

4.1.3 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.

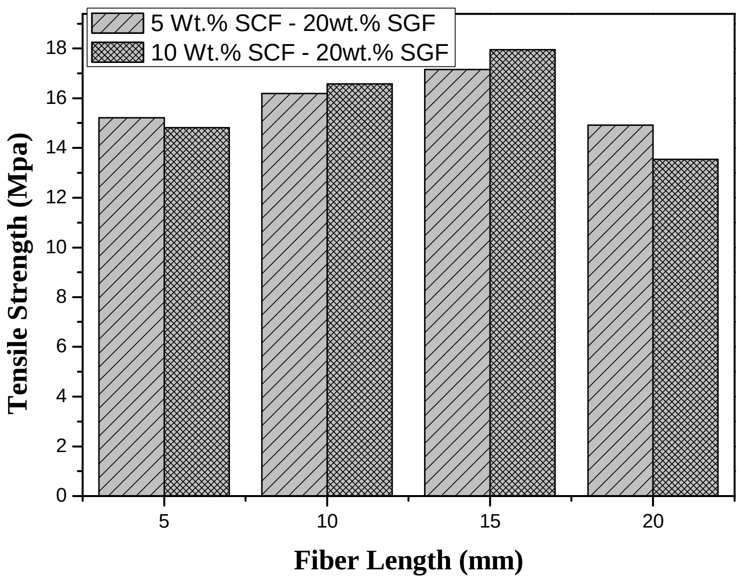


Figure 4.2 Effect of fibre loading and length on tensile strength of composites

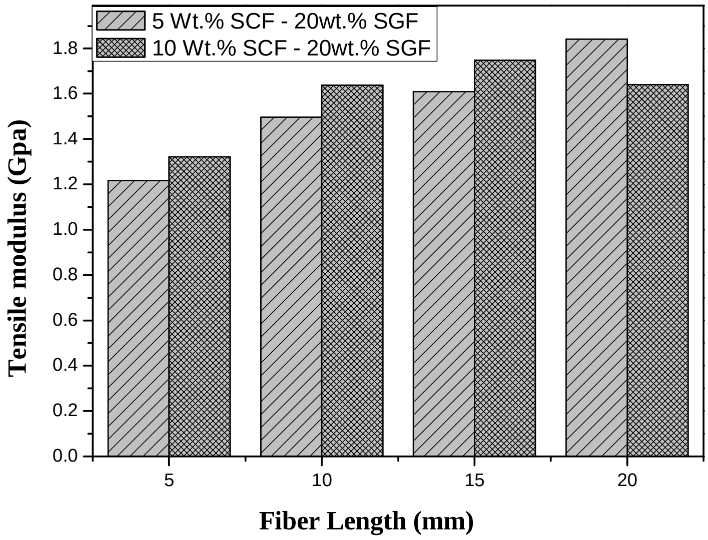


Figure 4.3 Effect of fibre loading and length on tensile modulus of composites

4.1.4 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.

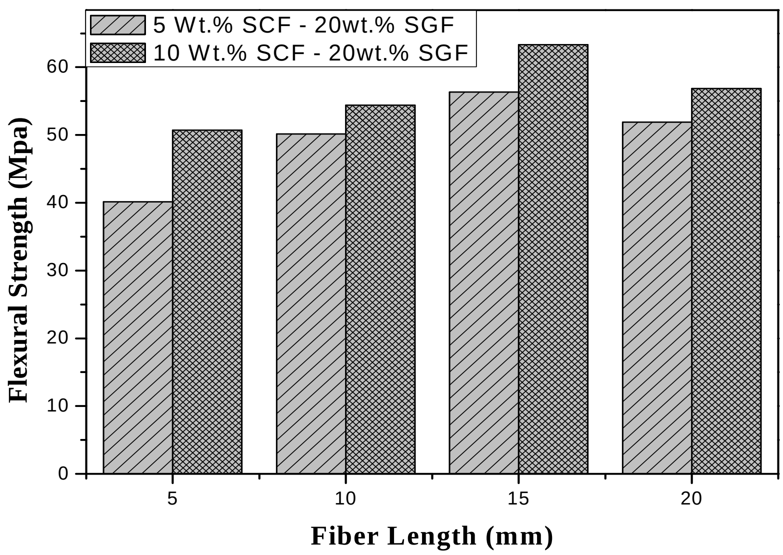
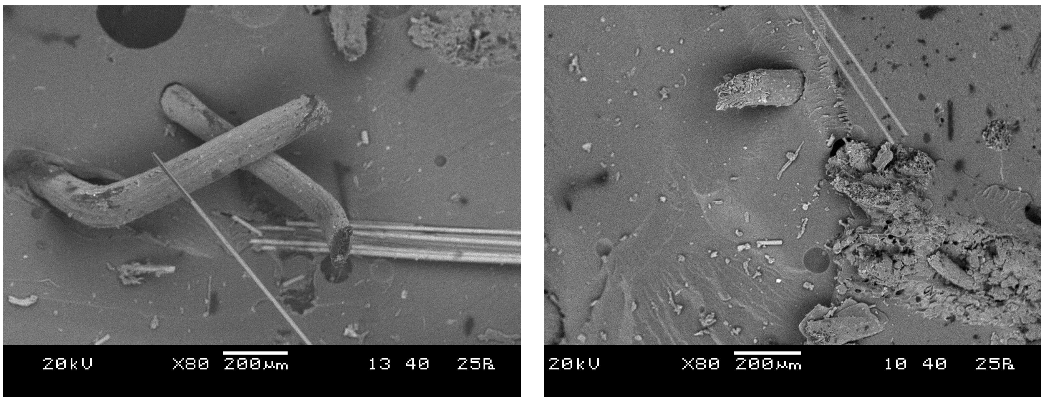


Figure 4.4 Effect of fibre loading and length on flexural strength of composites

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.

4.2 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

4.3 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].

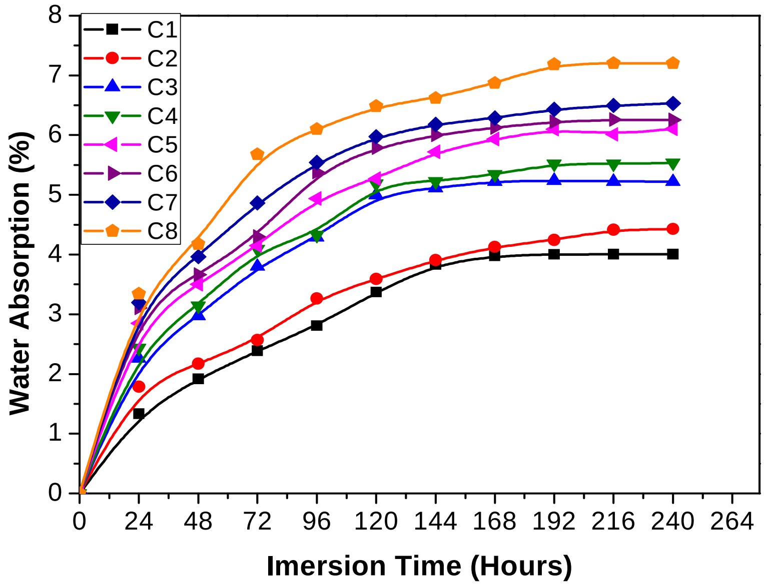


Figure 4.6 Effect of fibre loading and length on water absorption of composites

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.

4.4 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	2^{nd}
C3	0.72044	1^{st}
C4	0.63021	3th
C5	0.27131	8^{th}
C6	0.49712	6^{th}
C7	0.60914	4^{th}
C8	0.51901	5^{th}

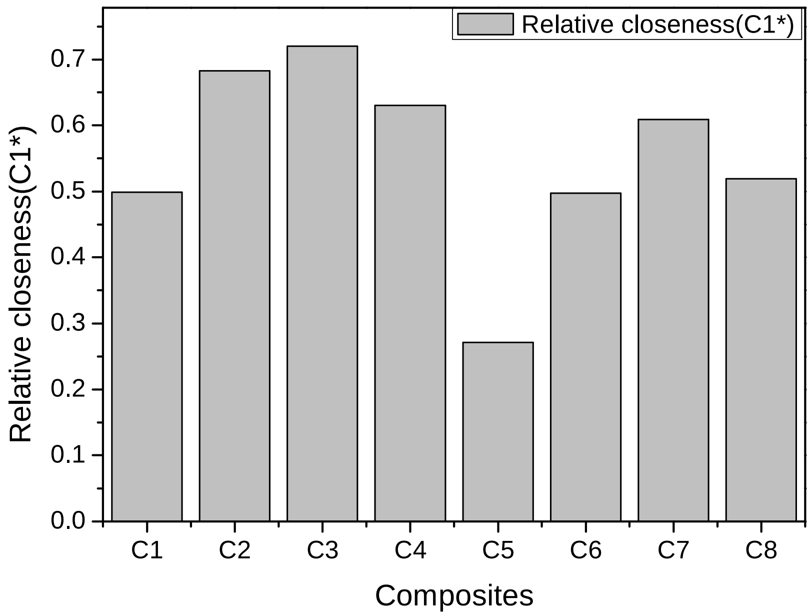


Figure 4.7 Ranking of the different composites

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CHAPTER 5
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.

5. TOPSIS method is used to select a best alternative from a set of alternatives. 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).

1.1 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 physical behavior.

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