# STUDY OF MECHANICAL PROPERTIES OF COCONUT COIR FIBER REINFORCED EPOXY BIOCOMPOSITE

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In Partial Fulfillment of the Requirements

For the Degree of

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In

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In

*"Production and Industrial Engineering"*

Submitted by

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**INTEGRAL UNIVERSITY, LUCKNOW, INDIA**

September, 2021

# CERTIFICATE

This is to certify that **Ms. Anjali Maurya** (Enroll. No. 1900102705) has carried out the research work presented in the thesis titled **"Study of Mechanical Properties of Coconut Coir Fiber Reinforced Epoxy Biocomposite"** submitted for partial fulfillment for the award of the **Degree of Master of Technology in Production and Industrial Engineering** from **Integral University, Lucknow** under my supervision.

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Signature of Supervisor

Dr. P.K. Bharti
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Place: Lucknow

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# DECLARATION

I hereby declare that the thesis titled "**Study of Mechanical Properties of Coconut Coir Fiber Reinforced Epoxy Biocomposite**" is an authentic record of the research work carried out by me under the supervision & co-supervisor **Dr. P. K. Bharti**, Professor & **Er. Sumita Chaturvedi**, Assistant Professor, Department of Mechanical Engineering, Integral University, Lucknow. No part of this thesis has been presented elsewhere for any other degree or diploma earlier.

I declare that I have faithfully acknowledged and referred to the works of other researchers wherever their published works have been cited in the thesis. I further certify that I have not willfully taken other's work, para, text, data, results, tables, figures etc. reported in the journals, books, magazines, reports, dissertations, theses, etc., or available at web-sites without their permission, and have not included those in this M.Tech. thesis citing as my own work.

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# ABSTRACT

Due to increasing environmental awareness nowadays, biocomposites are becoming important and prevalent materials, as they were centuries ago. The development of high-performance engineering products made from natural resources is increasing worldwide. Natural fibre composites have become more and more efficient as new compositions and processing methods are being intensively researched, developed and consequently applied. It play important roles in the production of eco-friendly materials because of their high modulus, meticulous strength and reduced carbon footprint on the environment. Coir fiber was selected for this study as it is non-toxic, low cost, high lignin content, low density, low tensile strength, low tensile modulus and high range of elongation compared to other fibers. Coconut (cocos nucifera) is cultivated extensively in tropical countries for its fruits whereas the husks and shells are mostly disposed as waste. These portions of the coconut plant serve as potential resource for natural fibers which are used to reinforce polymer composite. . In this experiment coconut coir fiber is the natural fiber component chemically treated with alkaline solution. Here chemically treated fibers are mixed separately with epoxy resin and by using hand lay-up technique these reinforced composite material is moulded in to box shape. Specimens will be prepared in two different volume percentages of coir fibers and two different lengths. The developed coconut coir reinforced epoxy composites were then tested for their tensile and flexural and hardness properties.

# CHAPTER-1

## INTRODUCTION

Natural Fiber composites combine plant-derived Fibers with a plastic binder. The natural Fiber components may be wood, sisal, hemp, coconut, cotton, kenaf, flax, jute, abaca, banana leaf Fibers, bamboo, wheat straw or other fibrous material. Its significance revealed due to several reasons such as: the high performance in mechanical properties, many processing advantages, low cost and light weight, availability and renewable, cheap, environmentally friendly, recyclability and degradability features[1] [2]. Enhancing the natural fiber polymers will form a new class of materials that have a good potential in future as a substitute for rare wood based materials in many structural applications [3] [5]. Different cells of hard plant fibers are bonded together by natural substance called lignin, acting as cementing materials. The composites- mainly consist of cellulose fibrils embedded in lignin matrix- exhibits high electrical resistance. Combining this composite into low modulus polymer matrix, will produce materials with better properties appropriate for various applications. [6]. Moreover, electrical properties for the natural fibers polymers such as volume resistivity, dielectric strength are hot areas of research since the significance of these properties in use. [7]. Composite material application is tremendously increased over years, composite materials along with plastic and ceramics are capturing industrial and domestic consumer market. Composite material has significant proportion over other in engineering material market ranging from day to day products to the sophisticated niche application. Composite low weight is major advantage that made them to capture market, but challenge is to make composites available at low cost. Demand of economically attractive composite is ever increasing and resulted in several innovative manufacturing techniques, but manufacturing alone is not enough to overcome the cost hurdles. It is very essential to go concurrent so efforts are diversified towards design, material, process, tooling, quality and program management to give cost effective edge. Aerospace sector has larger application of composite due to low weight advantage, but there is paradigm shift in application composite find vast applications in other commercial uses. Application includes composite armoring designed to resist explosive impacts, fuel cylinders for natural gas vehicles, windmill blades, industrial drive shafts, support beams of highway bridges and even paper making rollers. Application resulted in emphasizes on properties like on properties like chemical resistance, corrosion resistance, shock, vibration absorptions, thermal resistance, distortion. Wider composite application resulted in newer polymers, with modified resin matrix material and high performance glass fibers like carbon and aramid, and also introduction of natural fibers. Selection of composite depends on engineering requirement and composite formation depends on factors like life span of application, shape complexity, cost constraint, manufacturing skill and potential of composites. In some instances, best results may be achieved through the use of composites in conjunction with traditional materials. Epoxy resin, most important matrix in composite polymer for high performance and fibres like bamboo, coir, jute, flux gives advantage over low weight and too Natural fibers are biodegradable, but have lower strength, lower modulus and poor resistance when compared with composite reinforced with synthetic fibre like glass, carbon, aramid [9]. To overcome these limitations studies are carried out on different natural fibers in variety of compositions. Study carried out on hybrid natural fibers sisal and glass fiber with epoxy composite on frictional coefficient, impact, hardness and chemical resistance as function of fiber length and concluded optimum mechanical properties at 2cm fiber length [10]. Bamboo and glass fiber with epoxy resin composite study on frictional, impact, Dielectric strength, and chemical properties was carried out [11]. Research concluded chemically treated fibres have more tensile strength when compared to untreated coconut coir fibers. When the fibers tested in water at different time periods there is a slight change in their tensile properties. The composites having volume of 5% coir fiber showed notable results when compared to high fibres loading composites due to the effect of material stiffness [12]. Studies shows coconut coir composite with varying fibers length have greater influence on hardness, tensile strength, flexural strength, impact strength etc. The fracture surfaces study of coir fibres reinforced epoxy composite after the tensile test, flexural test and impact test has been done. From this study it has been concluded that the poor interfacial bonding is responsible for low mechanical properties [13]. NaOH treatment on coir fiber would remove the impurity and rougher fiber surface may result after treatment. This would increase the adhesive ability of the coir fiber with the matrix in the fabricated composite resulting in good tensile strength. The NaOH treated fibers have better reinforcing property and tensile strength than un-treated fibers. It is observed that by increasing the length of fibers the tensile strength of the composite increases [14]. Tensile strength of the composites treated with 1% NaOH solution display better strength as compared to that by 2% NaOH solution. This is because 1% NaOH improves the surface just the optimum amount by removing lignin, pectin etc. such that fiber strength is not compromised in comparison to 2% NaOH treated composite. It has also been observed that with the increase in the treatment time or the soaking time of the fibres, increases the tensile properties to a certain extent and beyond that further increase in soaking time decreases the properties. The flexural/bending strength values of the untreated fibre are considerably lower than that of the treated fibre [15]. The material Properties (young's modulus, poison's ratio, percentage gain of water, wear and hardness) of fabricated natural fiber reinforced composites were observed and it is found that polymer reinforced natural composites is the best natural composites for manufacturing of automotive seat shells among the other natural fiber combination of coir and jute [16]. Work was carried out with aim to explore the potential of the coir fibre polymer biocomposites and to study the mechanical properties of composites. Coir fibre bio composite has vided application as packaging, furniture and hence mechanical property study was carried out [17].

## 1.1 BIO COMPOSITE

Biocomposite materials on the other hand, defined as: composite materials in which at least one of the constituents is derived from natural resources [4]. This includes composite materials made from the combination of: natural fiber reinforced petroleum derived polymers which are non-biodegradable, and biopolymers reinforced synthetic fibers such as glass and carbon, these two categories are not fully environmentally friendly [8]. The third category which is, biopolymers reinforced by natural fibers which commonly terms as "green bio-composites" are more environmentally friendly.[18]. Then biodegradable bio-composites are those in which the polymeric matrix is biodegradable. It includes two different families: bio-based and petroleum-based. Biodegradable polymers are different than biopolymers in raw materials. Biodegradable polymers can be created from bio-based or petroleum-based and can be classified as green polymeric matrices. In addition, bio-based bio-composites or sometimes called fully biodegradable green composite are terms used when both the fiber and matrix are from renewable resources. These bio-composites have less environmental impact. Among various composites materials, natural fiber-reinforced biocomposites are primarily used as low-cost materials that have functional structural properties. Indeed, the depletion of petrochemical based materials have paved the way to switch to renewable resources based materials.[19]. One of the earlier publications on the topic under discussion is the work of Faruk et al.[2] where they proposed simultaneous incorporation of materials selection, the part geometry and the constraint and characteristics of the production processes in the development of biocomposites component Composite materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components. By taking advantages of natural fibre based composites, spatial distribution of the lignocelluloses fiber, biological, physical and chemical treatments, are associated with each manufacturing process. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter or less expensive when compared to traditional materials.

Composites are made up of individual materials referred to as constituent materials. There are two main categories of constituent materials: matrix (binder) and reinforcement. At least one portion of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impact their special mechanical and physical properties to enhance the matrix properties. A synergism produces material properties unavailable from the individual constituent materials, while the wide variety of matrix and strengthening materials constituents materials, while the wide variety of matrix and strengthening materials allows the designer of the product or structure to choose an optimum combination.

Engineered composite materials must be formed to shape. The matrix can be introduced to the reinforcement before or after the reinforcement material is placed into the mould cavity or onto the mould surface. The matrix material experiences a melding event, after which the part shape is essentially set. Depending upon the nature of the matrix material, this melding event can occur in various ways such as chemical polymerization for a thermo set polymer matrix or solidification from the melted state for a thermoplastic polymer matrix composite.

## 1.2. TYPES OF BIOCOMPOSITE

### 1.2.1 Starch-based composites

Various reinforcing natural fibre, such as caraua, hardwood (HW) and softwood (SW), silk protein, pehuen cellulosic husk, date palm and flax, and newspaper fiber are mixed with starch-based polymers to increase the modulus or impact toughness and reduced water uptake of the thermoplastic composites. Such composites are completely biodegradable and compostable and therefore considered “environmental friendly” since, at the end of their useful life; they can be discarded without causing any damage to the environment. The improvement of the tensile properties of starch-based biocomposites varies depending on the type and nature of the fiber, its orientation (random or unidirectional), content and form (fiber or fabric) and type of blending/plasticizer used (Critical factors on manufacturing processes of natural fiber composites). Teixeira et al. [20] used plasticized cassava starch as a matrix and combined it with cassava bagasse cellulose nanofibrils as reinforcing materials. Expansion of corn starch based biocomposites reinforced with graft copolymers of Saccharum spontaneum L. (Ss) fiber was achieved by Kaith et al. [21]. Recently, Vallejos et al. [22] applied corn and cassava starches plasticized with 30% glycerine as biometrics and using a fibrous material obtained from ethanol-water fractionation of bagasse as reinforcement. Another relevant research based on starch materials was carried out by Duanmu et al. [23]. They determined moisture absorption, dimensional stability, and mechanical properties of wood fibre reinforced alkyl glycidyl ether modified (AGE)–potato starch composites. However, no study has been carried out to evaluate the potential use of sugar palm starch (SPS) as a matrix.

Raw woody hemp core (WHC) was recently used in a thermoplastic composite as a reinforcement agent for a starch based biopolymer. The mechanical properties reported for WHC previously may fulfil some technical requirements. A final illustration of the applications of WHC in composites is the styrene-butadiene rubber composites presented by Wang et al. [24]. The authors stated that the mechanical properties of the composite improved with an increasing content of WHC powder, and interestingly, the short WHC fibre has a positive effect on the elongation at break compared with results obtained for long fiber.

Sahari et al.[45] demonstrates the effect of fiber content on mechanical properties, water absorption behaviour and thermal properties of sugar palm fibre reinforced plasticized sugar palm starch (SPF/SPS) biocomposites. The biocomposites were made with various amounts of fibre (10%, 20% and 30% by weight percent) by utilizing glycerol as plasticizer for the starch. It was declared that the mechanical properties of plasticized SPS enhanced with the inclusion of SPF fiber. The tensile strength and modulus of SPF/SPS biocomposites showed increasing trend with increasing SPF while the addition of the SPF made the elongation fall from 8.03% to 3.32%. This was due to the remarkable intrinsic adhesion of the fibre-matrix interface caused by the chemical similarity of starch (SPS) and the cellulose fibre.

**1.2.2. Poly (hydroxyalkanoate)-based composites**

A variety of fiber materials has been explored to make biocomposites with PHB. It has been shown that the addition of natural fiber increased modulus, *T*g, and heat distortion temperature (HDT) of PHB (or PHBV) composites. Nevertheless, the improvements in tensile strength and toughness were found to be difficult and to depend on many factors, such as fiber length and aspect ratio, interfacial bonding, fiber sources, fibre treatments, and fiber forms (single fibre/fabrics). Various co-polymers of PHB have been combined with PALF, recycled wood fibre (RWF), empty fruit bunch (EFB), and cellulose nanowhisker (CNW) to prepare biocomposites. These studies have shown that the natural fiber can be embedded in the PHBV matrix as an excellent reinforces to improve mechanical properties. Table 8 gathers the reported tensile, mechanical properties of PHA based biocomposites. One of the main advantages of PHA for biocomposite applications is their polar character since PHA show better adhesion to lignocelluloses'' fibre compared to conventional polyolefin's. Taha and Ziegman [25] prepared randomly oriented hemp/Biomer P226 composite specimens by extrusion and tested them in tension and flexure. The highest material properties were measured at 20% volume fraction. The tensile modulus, strength, and elongation were 2.4 GPa, 21.4 MPa, and 4.20%, respectively. The addition of hemp fibre increased the modulus but lowered the strength and elongation relative to the pure polymer. At 20% volume fraction, the flexural modulus and strength were 3.7 GPa and 45.8 MPa, respectively.

Wong et al. [26] investigated the use of plasticizers in flax-PHB composites. A weighed amount of flax fiber was added to neat plasticizer followed by heating to 120 °C for eight hours. After heating, excess plasticizer was removed by washing the fibre with acetone and the residual solvent was removed under vacuum. Flax–PHB composites with 1:1 fibre/polymer volume ratios were then made by dissolving PHB in chloroform and mixing plasticizer-modified fiber into the solution. Sample bars were annealed at 70 °C for three hours to allow PHB to crystallise and interact with the fibre. As a control material, PHB containing 4% v/v plasticizer without added flax was prepared and subjected to the same treatment as the PHB-flax composites. The mechanical properties biodegradability of wood fibre reinforced Biopolymer composites were investigated by Peterson et al. [27]. A significant finding was that the wood fiber-Biopolymer composites were highly biodegradable, often degrading faster than pure Biopolymer specimens. Statistical analysis of composite tensile results showed which conditions of pressure, temperature, heating time and time of pressing gave the best strength and modulus results. Process temperature had the greatest influence on composite tensile strength with values varying from 23 MPa at 219 °C to 17 MPa at 240 °C. The tensile modulus varied from 2.9 GPa to 2.15 GPa over the same temperature range.

### 1.2.3 Poly (lactic acid)-based composites

Several researches have been performed to examine the possibility of realizing PLA-based Composites reinforced with natural fiber with enhanced final properties. The fillers used include cotton linters maple hardwood fiber, sweet sorghum fiber, bamboo fiber, ramie fiber, and lyocell fiber. Most of these studies show that it is possible to achieve various degrees of improvement in tensile and flexural strength and significant increases in modulus with the creation of the respective composites. A number of biocomposites systems prepared by different techniques based on PLA as the matrix are listed in Table 8. It has been reported that tensile and flexural properties improved by increasing the content of cellulose fibre reinforcements in PLA-based composites. More recently, Liu et al. [28] proved that the basalt fibre with the adequate sizing can significantly increase tensile, bending and impact strength of PLA. By using 20% of basalt fibre and 20% of ethylene-acrylates-glycidyl methacrylate copolymer (EAGMA) it was possible to further increase the unnotched impact strength of PLA from 19 kJ/m2 to 34 kJ/m2. Finally, it was stated that there is a strong connection between the phases, due to the absence of gaps at the fiber-matrix interface; however, the surface of the fiber was still poorly wetted by the matrix. Kurniawan et al. [29] treated the surface of the basalt fiber by using atmospheric pressure glow discharge plasma polymerization and analyzed the adhesion between the basalt fiber/PLA in hot pressed composites. It was demonstrated that by increasing the plasma polymerization time above 3 min it was possible to increase the tensile strength of the composites above the own strength of PLA. The plasma polymerized fiber was well wetted by the PLA on the electron microscopic micrographs. Our previous study by Jandas et al. [30] examined that the PLA/banana fibre (BF) biocomposites by melt is mixing and compression moulding. Preliminary results showed that the properties of PLA and BF fiber composites are promising. Before composites fabrication, the BF fibre was chemically modified using acetic anhydride, (3-aminopropyl) triethoxysilane (APS), bis-(3-triethoxysilylpropyl) tetrasulfide (Si-69), and mercerized using NaOH solution to improve the compatibility with the PLA matrix. This study concluded that the morphological analysis highlighted a very significant enhancement of the surface wetting as well as on the adhesion level. Song et al. [31] focused on the physical behaviour of hemp/PLA composites, particularly the thermal properties and viscoelastic behaviour. They used twill and plain woven hemp fabrics as reinforcements by stacking film method. The impact and tensile properties of PLA resin reinforced with twill structure fabric were found 15% and 10% higher than the plain woven respectively. Increment of fibre volume fraction from 6 to 20% was the reason why the coefficient of thermal expansion of the fabricated hemp fabric composites decreased considerably (from 70 × 10-6 m/°C to 10 × 10-6 m/°C), which indicates that the composites have great potential for parts experiencing a wide range of temperatures, such as automobile and aerospace applications. Goriparthi et al. [32] developed a biodegradable composite using jute fiber and PLA, but their focus was to improve the adhesion of jute fiber by surface modification using alkali, permanganate, peroxide and silane treatments. Combination of the special prepreg fabrication method along with surface treatment on their composite sample exhibits some enhancement at least 45% on the mechanical properties.

**1.2.4. Soy resin-based composites**

The soy-based biocomposites reinforced with natural fiber were found to have better properties than PP composites with natural fiber. Liu et al. [33] reported the kenaf fiber reinforced soy-based biocomposites were fabricated by extrusion/injection moulding and compression moulding. The compression-moulded samples showed high thermal and mechanical properties, and the modulus, impact strength, and heat deflection temperature values of the biocomposites increased as the fiber length, fiber content, and fiber orientation increased. Researchers recently investigated the effect of stearic acid on tensile and thermal properties of ramie fiber reinforced SPI resin green composites. It was noted that part of the stearic acid crystallized in SPI resin and that the crystallizability was transformed by the addition of glycerol as a plasticizer. The fabricated green composite was found to have enormous potential for certain indoor applications.

Jute fabric was used by Huang and Netravali [34] to reinforce concentrated soy protein (SPC) modified with glutaraldehyde and nonocaly. During composite fabrication, they used metal frame to win the hemp yarns and applied small tension to minimize the yarn shrinkage and misalignment during the drying of the resin. The unidirectional flax yarn strengthened SPC composites proved longitudinal tensile failure stress of 298 MPa and

Young's modulus of 4.3 GPa. The flexural stress was 117 MPa, and the flexural modulus was 7.6 GPa. All those results show that the flax yarn reinforced SPC has the potential to replace non-biodegradable materials in many fields. Behera et al. [35] used woven and a non-woven jute in the different weight percentage (40–80%) to reinforce soy resin (soy milk) based resin. They found that both woven and non-woven jute composites, composite having 60% jute felt showed highest mechanical properties. Tensile strength and tensile modulus were recorded 35.6 MPa and0.972 GPa for woven, 37.1 MPa and 1.04 GPa for the non-woven jute composites respectively. Flexural strength and modulus were documented 33.5 MPa and 1.02 GPa for woven, 38.4 MPa and 1.12 GPa for the non-woven jute composites respectively. Furthermore, both kinds of fabric are different in structure, and their comparison cannot be justified. Reddy and Yang [36] fabricated environment-friendly biocomposites, used jute fiber to reinforce soy protein resin using water without any chemical as plasticizer. Their composite was fabricated using the prepreg method and they found that biocomposites have excellent flexural strength, tensile strength and modulus in comparison to jute/PP composite. Hydrogen bonding interaction is often insufficient to ensure adequate mixing of lignin with protein.

### 1.2.5. Wood-Plastic Composites (WPCs)

In recent years, wood fiber/flour (WF) reinforced biocomposites, named WPCs, play a vital role in the social, economic and environmental growth of human history. The WPCs show characteristics, such as moderate strength, high durability, and light weight. Besides, they are inexpensive and sustainable, which give them attraction for innovative design. WPCs refer to materials or products consisting of one or more lignocelluloses fibre/flours and one or a mixture of polymers. Various wood and natural fibers have been used in the processing of WPCs, for example, hemp, cellulosic fiber and flax. Recently, there has been a commercial interest in the use of thermo-mechanical pulp (TMP) fiber for manufacturing of WPCs. According to Ashori et al. [37], WPCs are based on plant fiber (wood and nonwood) and thermosets (epoxy and phenolic resins) or thermoplastics, such as PE, PP, PS, PVC, and PLA. Additionally, additives, such as coupling agents, colorants, stabilizers, blowing agents, reinforced agents, and lubricants could be applied to improve properties. The characteristics of wood fiber depend primarily on their source. The average lengths of soft and hard wood fiber are 3.3 and 1.0 mm, diameters 33 and 20 μm, and strength 100–170 and 90–180 MPa, respectively. The main applications of WPCs are initially used for construction applications (decking, docks, landscaping timbers, and fencing) and nonstructural applications, but now they have been widely used for a broader range of applications, including automotive, gardening and outdoor products. According to the study by Markarian et al. [38], the WPCs market, including thermoplastics and thermosets, has been estimated globally at 900,000 t, in which, 70% of this volume was consumed by North America, 20% in Europe, and 10% from Asia. In Europe, the market showed growth rates averaging 23% per year from 2003 to 2007 and predicted to continue at 26% per year from 2012. Properties of WPCs depend on many factors like, interaction between wood filler and matrix, including matrix characteristics, chemical and physical characteristics of the wood filler and processing conditions. On the other hand, the components of WPCs contain cellulose, Hemicellulose and lignin, in which the hydroxyl groups build plenty of hydrogen bonds between the macromolecules of the wood polymers. The hydroxyl groups could form new hydrogen bonds with water molecules, which induce the water absorption, creation of micro-cracks in the sample, resulting in reduced mechanical property because stress could not be transferred efficiently from the matrix to the fibre. In order to overcome this disadvantage, different methods are used for the enhancement of mechanical properties and water resistance of WPCs. Some of them are focused on processing the WF, such as MAH grafted copolymer of the matrix polymer, silane treatment, heat treatment, and treatment with sodium hydroxide. Besides, the inclusion of nanoparticles as reinforcing filler is another technique for improving the overall characteristics of lignocelluloses-thermoplastic composites, such as silica nanopowder and montmorillonite clay. However, these methods have their weaknesses, such as complicated processing processes and easy aggregation of nanoparticles that caused poor dispersion in the polymer matrix and a limited increase in overall properties of composites.

### 1.3. FABRICATION METHODS

Fabrication of composite materials is accomplished by a wide variety of techniques, including:

- Vacuum bag moulding
- Woodworking application
- Pressure bag molding
- Autoclave molding
- Resin transfer molding (RTM)
- Compression moulding

Composite fabrication usually involves wetting, mixing or saturating the reinforcement with the matrix, and then causing the matrix to bind together (with heat or a chemical reaction) into a rigid structure. The operation is usually done in an open or closed forming mould, but the order and ways of introducing the ingredients varies considerably.

### 1.3.1 Vacuum Bag Moulding

Vacuum bag moulding uses a flexible film to enclose the part and seal it from outside air. A vacuum is then drawn on the vacuum bag and atmospheric pressure compresses the part during the cure. Vacuum bag material is available in a tube shape or a sheet of material. When a tube shaped bag is used, the entire part can be enclosed within the bag. When bagged in this way, the lower mould is a rigid structure and the upper surface of the part is formed by the flexible membrane vacuum bag. The flexible membrane can be a reusable silicone material or an extruded polymer film. After sealing the part inside the vacuum bag, a vacuum is drawn on the part (and held) during cure. This process can be performed at either ambient or elevated temperature with ambient atmospheric pressure acting upon the vacuum bag. A vacuum pump is typically used to draw a vacuum. An economical method of drawing a vacuum is with a venturi vacuum and air compressor. [24]

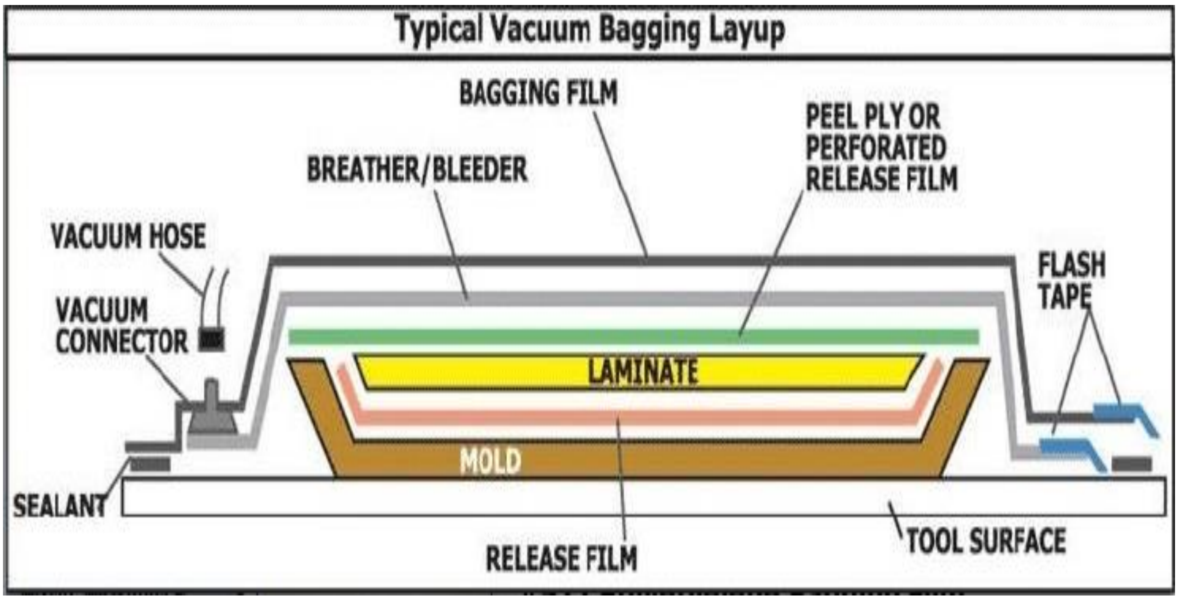


Fig 1.3.1.-Vacuum bag moulding [104]

A vacuum bag is a bag made of strong rubber-coated fabric or a polymer film used to compress the part during cure or hardening. In some applications the bag encloses the entire material, or in other applications a mould is used to form one face of the laminate with the bag being a single layer to seal to the outer edge of the mould face. When using a tube shaped bag, the ends of the bag are sealed and the air is drawn out of the bag through a nipple using a vacuum pump. As a result, uniform pressure approaching one atmosphere is applied to the surfaces of the object inside the bag, holding parts together while the adhesive cures. The entire bag may be placed in a temperature-controlled oven, oil bath or water bath and gently heated to accelerate curing. Vacuum bagging is widely used in the composites industry as well. Carbon Fibre fabric and fibre glass, along with resins and epoxies are common materials laminated together with a vacuum bag operation.[24]

### 1.3.2 Pressure Bag Moulding

Vacuum bag moulding improves the mechanical properties of open-mould laminate. This process can produce laminates with a uniform degree of consolidation, while at the same time removing entrapped air, thus reducing the finished void content. By reducing the pressure inside the vacuum bag, external atmospheric pressure exerts force on the bag. The pressure on the laminate removes entrapped air, excess resin, and compacts the laminate, resulting in a higher percentage of fiber reinforcement.

This process is related to vacuum bag molding in exactly the same way as it sounds. A solid female mould is used along with a flexible male mould. The reinforcement is placed inside the female mould with just enough resin to allow the fabric to stick in place (wet lay-up). A measured amount of resin is then liberally brushed indiscriminately into the mould and the mold is then clamped to a machine that contains the male flexible mould. The flexible male membrane is then inflated with heated compressed air or possibly steam. The female mold can also be heated. Excess resin is forced out along with trapped air. This process is extensively used in the production of composite helmets due to the lower cost of unskilled labor. Cycle times for a helmet bag molding machine vary from 20 to 45 minutes, but the finished shells require no further curing if the molds are heated.

Bag molding can provide a high level of versatility in component design and lamination. Part of this is due to the precision and close thickness tolerance achievable through bag molding. Employing different types of resin compounds and reinforcements can also impact particular physical properties on the molding, allowing for a wide range of component characteristics. Bag molding also relies on relatively inexpensive material, and its tooling and machining costs tend to be low. However, the reliance on operator skill can be one of the process main disadvantages. Proper training and adherence to safety regulations are important, but even minor human errors can result in faulty moldings. Inspection and quality control can also be challenging, as the reliance on individual laminators and hand-rolling naturally results in small inconsistencies between production runs. Finally, the process is a relatively slow one and requires high labor costs.

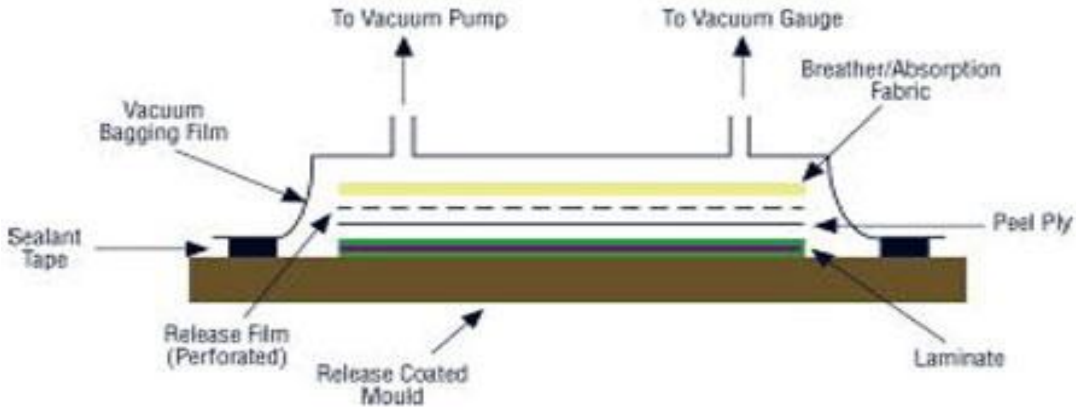


Fig- 1.3.2-Pressure bag molding [105]

**1.3.3 Autoclave Moulding**

A process using a two-sided mould set that forms both surfaces of the panel. On the lower side is a rigid mould and on the upper side is a flexible membrane made from silicone or an extruded polymer film such as nylon. Reinforcement materials can be placed manually or robotically. They include continuous fibre forms fashioned into textile constructions.

Most often, they are pre-impregnated with the resin in the form of prepare fabrics or unidirectional tapes. In some instances, a resin film is placed upon the lower mould and dry reinforcement is placed above. The upper mould is installed and vacuum is applied to the mould cavity. The assembly is placed into an autoclave. This process is generally performed at both elevated pressure and elevated temperature. The use of elevated pressure facilitates a high fibre volume fraction and low void content for maximum structural efficiency.

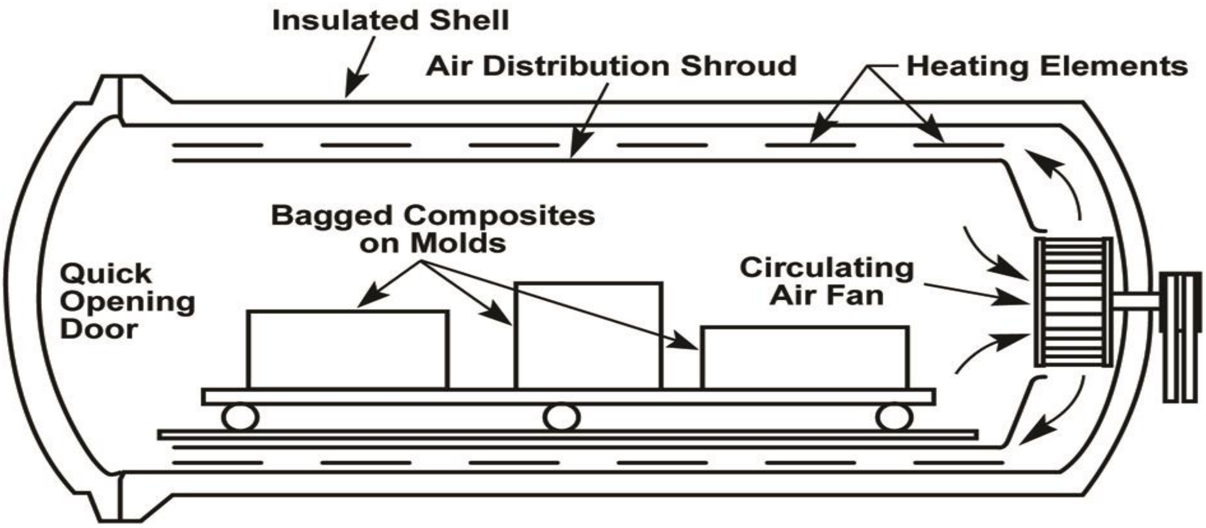

Fig.1.3.3-Autoclave moulding [106]

### 1.3.4 Resin Transfer Moulding (RTM)

Resin transfer molding (RTM) is a method for the production of components made from fiber plastic composites. In the RTM procedure, a reaction resin is poured onto the dry, semi-finished fiber parts, and these parts are consequently immersed by applying pressure within a closed vessel. The following techniques are Natural lightweight hybrid composites for aircraft structural applications 161 notable for the use of pressure: high-pressure injection, vacuum injection, twin wall injection, and differential pressure injection. Rouison et al. [97] manufactured hemp fiber-unsaturated polyester composites using a resin transfer molding (RTM) process to fabricate composites with different fiber contents, which were up to 20.6% in volume [98]. The permeability of the fiber mat with high content showed that the resin injection time increased dramatically. To obtain a fast and homogeneous curing of the composite, the mold temperature must be constant. The comparisons between the predicted and experimental temperatures, however, reveal only a slight difference. Similar results can also be observed between the predicted degree of curing and the resin’s curing rate. Homogeneous structures with no noticeable defects were found in hemp fiber composites manufactured with RTM [98]. The properties of these materials in tensile, flexural, and impact properties were determined to rise linearly with the increase in fiber content. However, the optimum properties were not reached, and the findings revealed that if the fiber content was higher than 35% of volume, it yielded better mechanical properties. Therefore, these natural fibers had much lower performances when compared to glass fiber composites. Various evaluations of composites through RTM have been conducted by researchers. For instance, cure simulation, interfacial adhesion, flow visualization, and effects of fiber surface modification to hemp fiber-reinforced polyester and phenolic resin composites were conducted [99,100]. Furthermore, sisal fiber-reinforced polyester composites created using both the RTM and the compression molding process were compared [99]. Additionally, composites containing flax and hemp fiber with bio-resin [101], jute fiber with polyester resin [102], and flax/jute fiber with epoxy and polyester resin [103] were also fabricated using the RTM process.

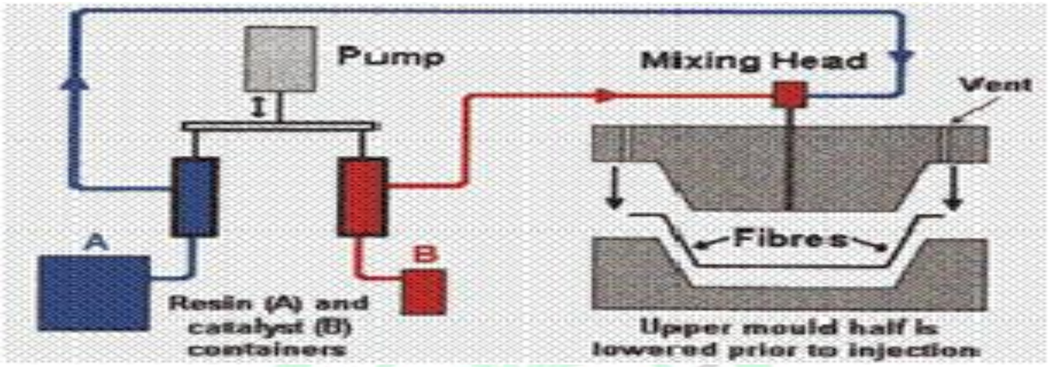


Fig. 1.3.4 -Resin transfer moulding (RTM) [107]

### 1.3.5 Compression molding

Compression molding is the most well-known procedure for the manufacturing of composites, because of its high reproducibility and low cycle time. There are two techniques which are mainly used, namely compression and flow compression molding. The processes differ depending on the kind of semi-finished products used and its cutting. These molding techniques consist of compressing materials which contain a temperature-initiated catalyst in a heated matched metal die by using a vertical press such as the cold press and hot press methods. The underlying approach for this procedure is similar to the hand lay-up method, which requires the composites to be closed before a cure takes place with the application of pressure. By employing this method, about 70% by weight of the fiber strands are incorporated, and the thickness of the product is between 1 and 10 mm. The curing temperature for cold and hot press molding is usually between 40°C to 50°C and 80°C to 100°C, respectively, for 12 hours. The press molding has been effectively utilized for incorporating up to 40% 60% in weight of pineapple fibers [93]. Uncured composite materials with high viscosity were delivered to the molding area, where the temperatures are commonly in the range of 150°C to 160°C. The viscosity of the composite decreases under heat and pressure that approximates 162 Sustainable Composites for Aerospace Applications 1000 psi after the mold is closed. The resin and the isotopically disseminated reinforcements flow to fill the mold cavity. The thermosetting material undergoes a substance change (cure) that permanently hardens the material into the shape of the mold cavity, where the mold remains closed. The mold closure time fluctuates from 30 seconds up to several minutes, according to the design and the material formulation. At the point when the mold is opened, the parts are ready for the process of completion that may involve deflating, painting, bonding, and installing inserts for fasteners.

## 1.4. Advantages of Biocomposite material:

**Light Weight** - Composites are light in weight, compared to most woods and metals. Their lightness is important in automobiles and aircraft, for example, where less weight means better fuel efficiency (more miles to the gallon). People who design airplanes are greatly concerned with weight, since reducing a craft's weight reduces the amount of fuel it needs and increases the speeds it can reach. Some modern airplanes are built with more composites than metal including the new Boeing 787, Dream liner.

**High Strength** - Composites can be designed to be far stronger than aluminum or steel. Metals are equally strong in all directions. But composites can be engineered and designed to be strong in a specific direction.

**Corrosion Resistance** - Composites resist damage from the weather and from harsh chemicals that can eat away at other materials. Composites are good choices where chemicals are handled or stored. Outdoors, they stand up to severe weather and wide changes in temperature.

**High-Impact Strength** - Composites can be made to absorb impacts—the sudden force of a bullet, for instance, or the blast from an explosion. Because of this property, composites are used in bulletproof vests and panels, and to shield airplanes, buildings, and military vehicles from explosions.

**Design Flexibility** - Composites can be molded into complicated shapes more easily than most other materials. This gives designers the freedom to create almost any shape or form. Most recreational boats today, for example, are built from Fiber glass composites because these materials can easily be molded into complex shapes, which improve boat design while lowering costs. The surface of composites can also be molded to mimic any surface finish or texture, from smooth to pebbly.

**Low Thermal Conductivity** - Composites are good insulators—they do not easily conduct heat or cold. They are used in buildings for doors, panels, and windows where extra protection is needed from severe weather.

**Durable** - Structures made of composites have a long life and need little maintenance. We do not know how long composites last, because we have not come to the end of the life of many original composites. Many composites have been in service for half a century.

**1.5. Limitations of Biocomposites** Some of the associated disadvantages of advanced composites are as follows;

- High cost of raw materials and fabrication.
- Composites are more brittle than wrought metals and thus are more easily damaged.
- Transverse properties may be weak.
- Matrix is weak, therefore, low toughness.
- Reuse and disposal may be difficult.
- Difficult to attach.
- Materials require refrigerated transport and storage and have limited shelf life.
- Hot curing is necessary in many cases requiring special tooling.

## 1. 6. Applications of Biocomposites

Now a day's composites are used almost everywhere. Some important fields of application are as follows.

### 1. 6.1 Aerospace

A wide range of load-bearing and non-load-bearing components are already in use in both fixed-wing and rotary wing aircraft. Many military and civil aircraft now contain substantial quantities of lightweight, high-strength carbon-, Kevlar- and glass-fibre composites, as laminated panels and moldings, and as composite honeycomb structures with metallic or resin-impregnated paper honeycomb core materials. They are used in air frames, wing spars, spoilers, tail-plane structures, fuel tanks, drop tanks, bulk heads, flooring, helicopter rotor blades, propellers, and structural components, pressured gas containers, radiomen, nose and landing gear doors, fairings, engine nacelles (particularly where containment capability is required for jet engines), air distribution ducts, seat components, access panels, and so forth. Space applications offer many opportunities for employing light-weight, high-rigidity structures for structural purposes.

Many of the requirements are the same as those for aeronautical structures, since there is need to have low weight and high stiffness in order to minimize loads and avoid the occurrence of buckling frequencies. Dimensional stability is at a premium, for stable Antennae and optical platforms, for example, and materials need to be transparent to radio-frequency waves and stable towards both UV radiation and moisture [42].

Advanced composites consisting of a combination of high-strength stiff fibers embedded in a common matrix material are also widely being used in the aerospace industry.

Some of the key benefits of using composites for aerospace applications include the following:

- Weight reduction up to 20% to 50%.
- . Single-shell molded structures provide higher strength at lower weight.
- High impact resistance. For instance, Kevlar (aramid) armor shields planes have reduced accidental damage to the engine pylons that carry fuel lines and engine controls.
- . High thermal stability.
- . Resistant to fatigue/corrosion.

Composite materials are used extensively in the Eurofighter: the wing skins, forward fuselage, flaperons and rudder all make use of composites. Toughened epoxy skins constitute about 75% of the exterior area. In total, about 40% of the structural weight of the Eurofighter is carbon-fiber reinforced composites by weight: 26% for Dassault’s Rafael and 20 to 25 percent for the Saab Gripen and the EADS Mako.

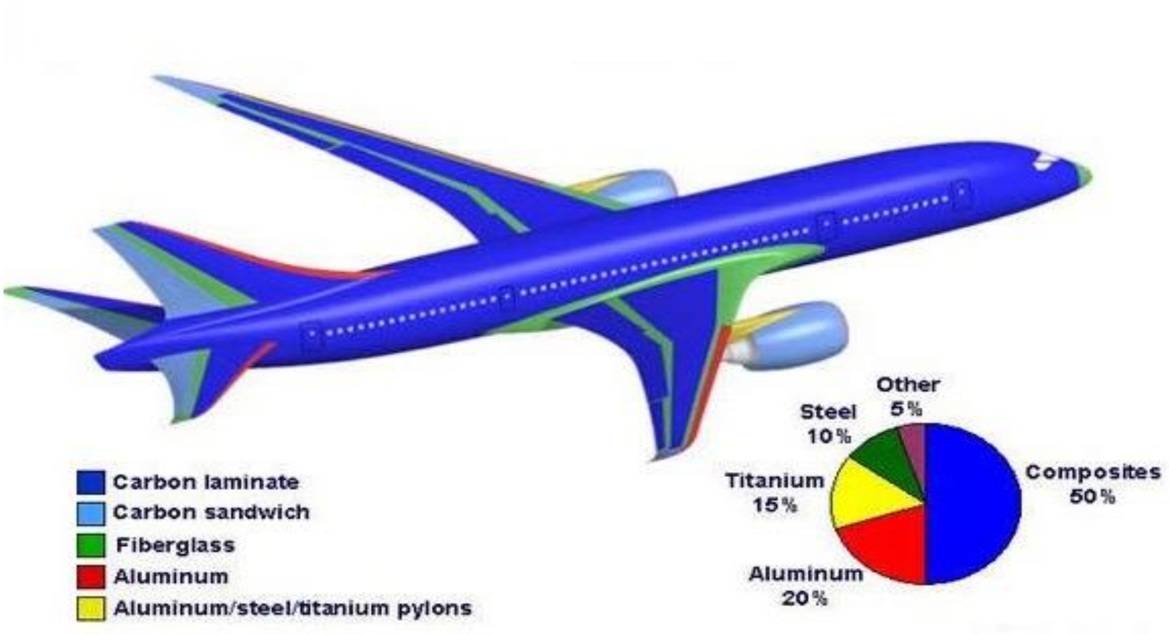


Fig. 1.6.1- Aerospace [108]

### 1.6.2 Automotive Engineering

There is increasing interest in weight reduction in order to permit both energy conservation and increased motoring economy. Reduction in the weight of an automobile structure achieves primary weight-saving and if carried to sufficiently great lengths enables the designer to use smaller power plants, thus achieving substantial secondary improvements in fuel economy. The majority of automotive applications involve glass-reinforced plastics because the extra cost of carbon or aramid fibre is rarely considered to be acceptable in this market. Even so, the cost of using GRP is usually being weighed against the much lower cost of pressed steel components, and the substitution is often rejected on purely economic grounds, leaving aside the question of energy saving. A wide range of car and truck body, moldings, panels and doors is currently in service, including complete front-end moldings, fascias, bumper moldings, and various kinds of trim.

There is considerable interest in the use of controlled crush components based on the high energy-absorbing qualities of materials like GRP. Leaf and coil springs and truck drive shafts are also in service, and GRP wheel rims and inlet manifolds have been described in the literature. Selective reinforcement of aluminum alloy components, such as pistons and connecting rods, with alumina fibres is much discussed with reference to increased temperature capability.

The Tepex continuous-fiber-reinforced composites from LANXESS are being used in large-scale production of various structural components for lightweight automotive design.

**The table below shows the values of fuel consumption and fuel efficiency for different types and vehicles weight.**

| Design/Engine type | Vehicle weight | Fuel consumption(lit per 100 km and (mgh) | Fuel efficiency increase |
|---|---|---|---|
| **State of the art** | **500kg** | 10(23.5) | 0% |
| **High strength steel plus structural bonding** | **350kg (30%)** | **9.58(24.6)** | **4.20%** |
| **Carbon fiber composite for structure and closures** | **270kg (42%)** | **9.31(25.3)** | **7%** |
| **Diesel Engine** | | **7(33.6)** | **30%** |
| **Full Hybrid (Otto)** | | **6.5(36.2)** | **35%** |
| **Full hybrid (diesel)** | | **5.5(42.8)** | **45%** |

The Mercedes C-class contains 20 components made from natural material composites

Fig. 1.6.2-Automotive Engineering [109]

Thermoplastics are getting serious consideration as well, thanks primarily to their ease of processing and recyclability. Carbon fiber manufacturer Teijin is working in a joint venture with General Motors (GM) on thermoplastics composites manufacturing process to make automotive parts in less than 60 seconds. Neither GM nor Teijin is talking about the process, but reliable reports from within the industry indicate that the companies are at or near 60 second per cycle.

**1.6.3 Bio Engineering**

Carbon-fibre-reinforced plastic and carbon components are in use for prosthetic purposes, such as in orthopedic fracture fixation plates, femoral stems for hip replacements, mandibular and maxillary prostheses (jaw remodeling, for example), and for external orthotic supports in cases of limb deformity b *etc*. Pyrolytic carbon is used to manufacture heart valve components, and the substitution of a carbon/carbon composite is not unlikely.

Composite materials have found wide use in orthopedic applications, as summarized by Evans, 2 particularly in bone fixation plates, hip joint replacement, bone cement, and bone grafts. In total hip replacement, common materials for the femoral-stem component such as 316L stainless steel, CoCr alloys, and Ti-6A1-4V titanium alloy have very high stiffness compared with the bone they replace. Cortical bone has a stiffness of 15GPa and tensile strength of 90 MPa. Corresponding value for titanium is 110 GPa and 800 MPa, which are clearly very high. This produces adverse bone remodeling and stress shielding, which over the proximal region. Fiber composite can be tailored to match the specific mechanical properties of the adjacent bone. Carbon-fiber composites in PEEK or polysulfone matrices can be fabricated with stiffness in the range 1 to 170 GPa and tensile strength from 70 to 900 MPa. Examples are press-fit femoral stems made from laminated unidirectional carbon fibers in PEEK, polysulfone, liquid crystalline polymer (LCP), 10 and polyetherimide (PEI). These composites are difficult to fabricate and have not had very encouraging durability, but they continue to be developed for the inherent advantages of tailor-ability, flexibility, non-corrosiveness, and radioucency.

Composite have been by far the most successful in dental applications by meeting several stringent design requirements difficult to achieve with homogeneous materials such as ceramics and metal alloys. Whether it is preparation of crowns, repairs of cavities, or entire tooth replacement, the product needs to be aesthetically matched in color and translucence with other teeth and retain its gloss.

Consequently many composite biomaterials have recently been studied and tested for medical application. Some of them are currently commercialized for their advantages over traditional materials. Most human tissues such as bones, tendons, skin, ligaments, teeth, etc., are composites, made up of single constituents whose amount, distribution, morphology and properties determine the final behavior of the resulting tissue or organ. Man-made composites can, to some extent, be used to make prostheses able to mimic these biological tissues, to match their mechanical behavior and to restore the mechanical functions of the damaged tissue.

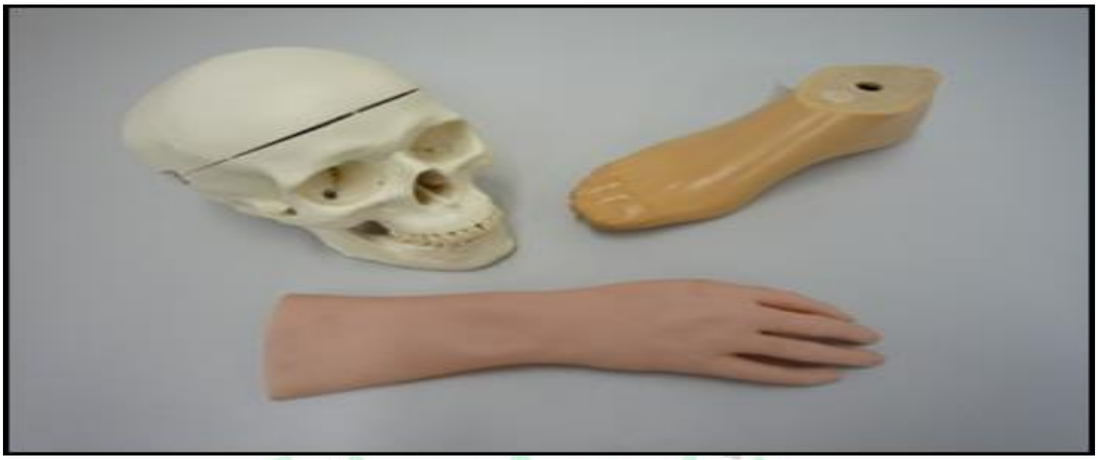

Fig.1.6.3- Bio Engineering [124]

**1.6.4 Chemical Engineering**

A substantial amount of GRP is currently in use in chemical plant for containers, pressure vessels, pipe-work, valves, centrifuges etc. These may be filament-wound or molded components for containment of process fluids.

Advantages of composites of fire resistance properties, lightweight, mold ability, and resistance to chemicals has made the material used in the chemical industry.

Composites are extensively used in industrial gratings, scrubbers, ducting, piping, exhaust stacks, pumps and blowers, structural supports, storage tanks, columns, reactors etc. for alkaline & acidic environments. Some applications are drive shaft, fan blades, ducts, stacks, underground storage tanks, casings, composite vessels etc. Internationally, composites applications in chemical industry are a relatively small segment in relation to the total usage of composites.

Composite materials based on special imported resins, reinforced with glass fiber, in highly corrosive media (hydrochloric and sulfuric acid solutions) are studied. It is shown that equipment manufactured from carbon steel with a coating of composite material based on special imported resins may be used in quite corrosive hydrochloric and sulfuric acid media at elevated temperature instead of expensive equipment made from corrosion-resistant steels and alloys. It is also expedient to use composites as a coating in repairing equipment and pipelines subject to corrosion, including penetration corrosion.

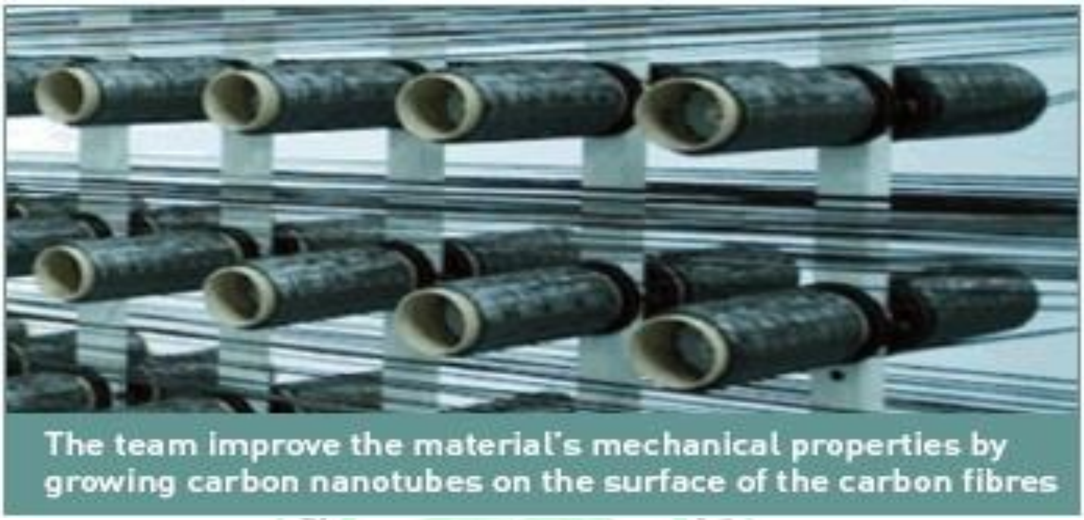


Fig.1.6.4-Chemical Engineering [110]

**1.6.5 Domestic**

Injection-molded reinforced thermoplastics and polyester moulding compounds are perhaps the most common composites used in consumer items for the domestic market, and the range is vast.

Mouldings of all kinds, from kitchen equipment of all kinds to casings for the whole gamut of domestic and professional electrical equipment, motor-cycle crash helmets, television and computer casings, and furniture.

Fig. 1.6.5(a)- Domestic [111]

Fig. 1.6.5(b) Domestic[112]

**1.6.6 Electrical Engineering**

Typical applications are radomes, structural components for switch gear, power generator coolant containment and large-diameter butterfly valves, high-strength insulators (*e.g.* for overhead conductor systems), printed circuit boards, and casings for electronic equipment. The majority of applications in this field again use GRP, although the use of composites which are more thermally stable and more.

Moisture-resistant is increasingly predicated for sensitive, small-scale electronic components. Many prototype and practical wind-generator designs incorporate GRP or hybrid blading.

Fig. 1.6.6(a) Engineering Wire [113]    Fig 1.12(b) - Electrical Engineering [113]

**1.6.7 Marine Engineering**

Marine applications include surface vessels, offshore structures and underwater applications. Off-shore structures such as oil rigs also make use of reinforced plastics, especially if they can be shown to improve on the safety of steel structures, for fire protection piping circuits, walkways, flooring, ladders, tanks and storage vessels, blast panels, and accommodation modules. High specific compression properties also make composite materials attractive for submersibles and submarine structures, both for oil exploration and for military purposes, and for towed transducer arrays for sea-bed sonar mapping.

**Ferrocement** – Ferrocement is probably the earliest use of composites in the Marine industry, used for developing low-cost barges. A steel frame formed of reinforcing rod that is covered with chicken wire, is used as 'template' to form the hull by pouring cement around the template. It is then plastered with ferrocement and then cured. Although it is an inexpensive composite, armature corrosion is a common problem under chemically aggressive marine condition. However, there are still a number of ferroboats in use today.

**Glass reinforced plastic** – Glass fibers became available just after the developed of polyester resins. Soon, glass reinforced plastic boats came into existence since the early

1950s and continue to be significant composite constriction technique in Marine applications today.

**Wood/ Adhesive Composites -** Wartime requirements led to the development of 'hot molded' and 'cold molded' boat building techniques based on laying thin wood veneers over a frame. On the other hand, high-performance, urea-based adhesives have also been widely developed for molding marine hulls and in aircraft manufacture to help speed up the production process and reduce dependency on aluminum and steel.

**Aramid fiber Composites –** Aramid fibers are being widely used to strengthen sailing yacht structures like keel and bo sections. Also, Aramid fiber composites also have improved shock absorption characteristics, perfect for ocean racing applications.

**Carbon fiber –** Carbon fibers are increasingly used for sailboats, furniture on super-yachts and high strength interior moldings as they offer vessel stability benefits and high performance with minimal weight. Carbon fibers are also seen as a trendy material, often substituted for not only superior material characteristics but the aesthetics component of the woven material.

Fig. 1.6.7- Marine Engineering [114]

**1.6.8 Sport**

Perhaps the most visible development in the use of composites has been in the sports goods industry. Manufacturers have been quick to seize on the potential advantages of new materials like carbon and boron fibre composites over conventional wood and metal for sports equipment of all kinds.GRP vaulting poles were perhaps the earliest of the composite sports gear, but one can now obtain tennis rackets, cricket bats, golf clubs, fishing rods, boats, oars, archery equipment, canoes and canoeing gear, surf boards, wind-surfers, skateboards, skis, ski-poles, bicycles, and protective equipment of many sorts in composite materials of one kind or another.

Fig.1.6.8 (a) [115]    Fig. 1.6.9(b) [116]

## 1.7. FILLER SELECTION

Fillers can be subdivided according to their origin, i.e. as either synthetic or natural fibers as illustrated in Figure 1.2.0. The selection of the filler can be linked directly, to the desired properties.

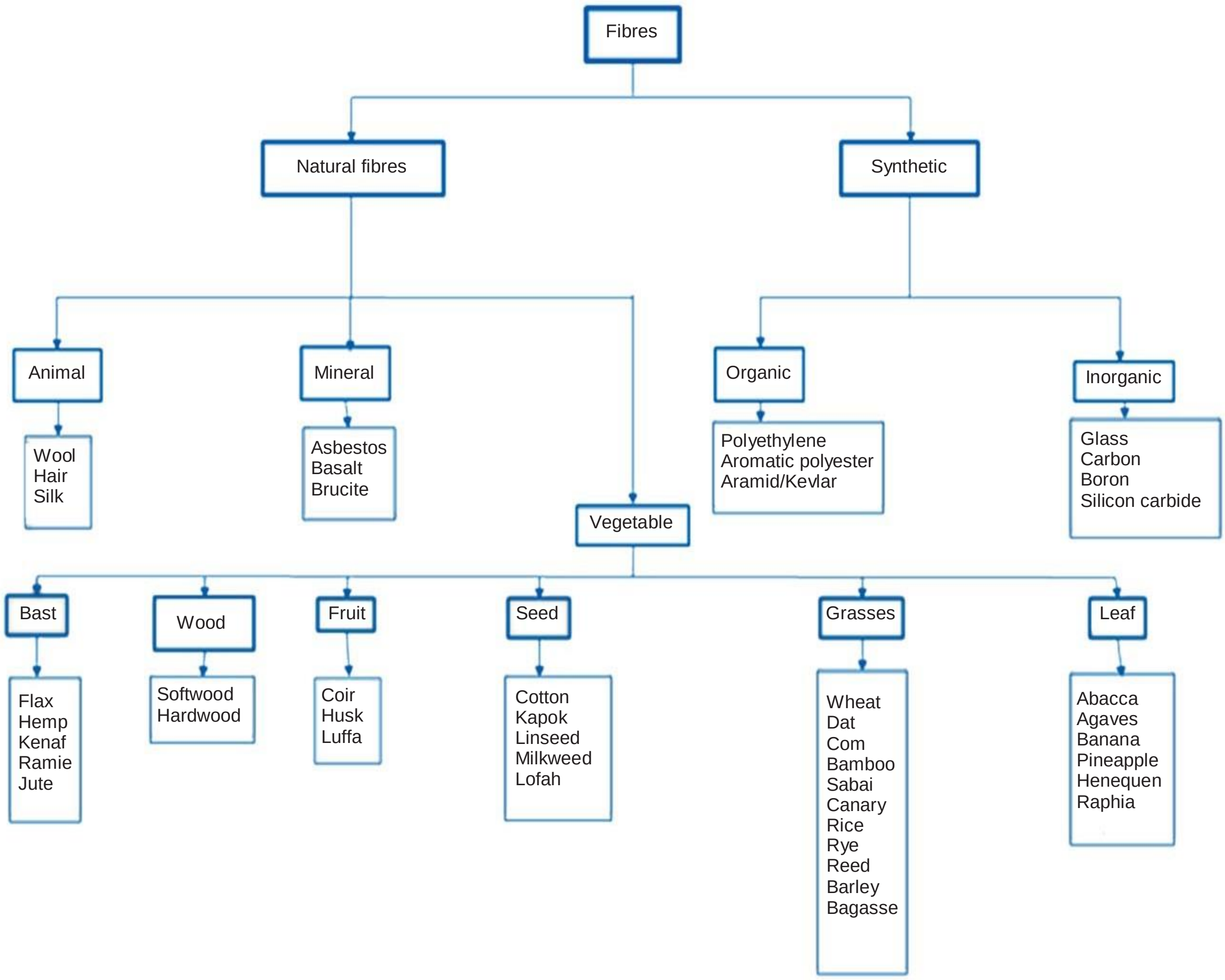


Fig.1.7 – Fillers [117]

Fiber is a class of material that is a continuous filament or discrete elongated pieces, similar to the lengths of thread. They can be spun into filaments, rope or string.

The two main sources of natural fibers are plants and animals. The main component of animal-based fibers is protein, examples include mohair, wool, silk, alpaca, angora, and so on. The major components of plants fibers are cellulose micro fibrils, lignin and hemicelluloses, examples include cotton, jute, flax, ramie, sisal, hemp, and so on.

Among plant-based natural fibers, jute appears to be the most useful, inexpensive and commercially available fiber. Jute fibers contain 82%-85% of holocellulose of which 58-63% is cellulose. Jute fibers possess some possess some disadvantages such as high moisture absorption, poor dimensional stability, intrinsic polarity, low thermal resistance, anisotropic fiber resistance and the two main sources of natural fibers are plants and animals.

**1.8. PLANT FIBER**

Plant fibers are a composite material designed by nature. The fibers are basically a rigid, crystalline cellulose micro fibril-reinforced amorphous lignin and/or with hemi cellulosic matrix. Most plant fibers are composed of cellulose, hemicelluloses, lignin, waxes, and some water-soluble compounds. The percentage composition of each of these components varies for different fibers. Generally, the fibre contains 60-80 % cellulose, 5-20% lignin and up to 20 % moisture (Taj et al., 2007; Wang et al., 2008). During the biological synthesis of plant cell walls, polysaccharides such as cellulose and 27 hemicelluloses are produced simultaneously. Lignin fills the space between the polysaccharide fibers, cementing them together. This lignifications process causes a stiffening of cell walls and the carbohydrate is protected from chemical and physical damage (Taj et al., 2007). The chemical composition of natural fiber varies depending upon the type of fibers. The chemical composition as well as the structure of the plant fibers is fairly complicated. Hemicelluloses is responsible for the biodegradation, micro absorption and thermal degradation of the fibers as it shows least resistance, whereas lignin is thermally stable but prone to UV degradation [43]

(a) (b) (c)

(d) (e)

Fig.1.8 (a) Jute yarn [108] (b) Sisal fibre [109] (c) Hemp fibre [110] (d) Cotton fibre [111] (e) Coir fibre [112]

## Table 1.Chemical composition of fibers [123]

| Fibre-type | Cellulose [%] | Lignin [%] | Hemicellulose [%] | Pectin [%] | Wax [%] | Ash [%] | Microfibrillar angle [°] |
|---|---|---|---|---|---|---|---|
| Abaca | 53–63 | 7–9 | 20–25 | – | 3 | | 20–25 |
| Bamboo | 26–43 | 1–31 | 30 | – | 10 | – | – |
| Banana | 63–83 | 5 | – | – | 11 | – | 11–12 |
| Coconut coir | 36–43 | 0.15–0.25 | 41–45 | 3–4 | – | – | 30–49 |
| Cotton | 83–91 | – | 3 | 0.6 | 8–9 | – | – |
| Flax | 64–72 | 2–2.2 | 64–72 | 1.8–2.3 | – | – | 5–10 |
| Hemp | 70–74 | 3.7–5.7 | 0.9 | 0.8 | 1.2–6.2 | 0.8 | 2–6.2 |
| Jute | 61–72 | 12–13 | 18–22 | 0.2 | 0.5 | 0.5–2 | 8 |
| Kenaf | 45–57 | 22 | 8–13 | 0.6 | 0.8 | 2–5 | 2–6.2 |
| Nettle | 86 | 4.0 | 5.4 | 0.6 | 3.1 | – | – |
| Rachis | 43 | 26 | – | – | – | – | 28–37 |
| Ramie | 69–91 | 0.4–0.7 | 5–15 | 1.9 | – | – | 69–83 |
| Rice husk | 38–45 | – | – | – | – | 20 | – |
| Sisal | 78 | 8 | 10 | – | 2 | 1 | – |
| Hardwood | 43–47 | 25–35 | – | – | – | – | – |
| Softwood | 40–44 | 25–29 | – | – | – | – | – |

## Table 2. Physical properties of fiber [123]

| Source | Annual production [million | Origin | Price kg$^{-1}$ [USD] | Density [g/cm$^3$] | Tensile strength [MPa] | Young's modulus [GPa] | Elongation [%] | Moisture content [%] |
|---|---|---|---|---|---|---|---|---|
| Abaca | 0.07 | Leaf | 1–1.5 | 1.5 | 430–813 | 31.1–33.6 | 2.9–10 | 14 |
| Bagasse | Abundant | Grass | 0.2 | 0.89 | 350 | 22 | 5.5 | |
| Bamboo | 100 | Grass | 2.2–3.25 | 0.6–1.25 | 290 | 11–17 | – | 9 |
| Banana | 2.5 | Leaf | 0.1–0.75 | 1.35 | 529–914 | 27–32 | 2.6–5.9 | 10–11 |
| Coir | Abundant | Fruit | 0.2–0.4 | 1.15–1.25 | 131–220 | 4–6 | 15–40 | 10 |
| Cotton | 0.0185 | Seed | 1.5–2.2 | 1.51 | 400 | 12 | 3–10 | 33–34 |
| Date palm | 4.2 | | 0.025 | 0.7–1.2 | | 60–80 | 2–19 | |
| Flax | 0.81 | Stem | 3.11 | 1.4 | 800–1500 | 60–80 | 1.2–1.6 | 7 |
| Hardwood | | Wood | 0.44 | 0.3–0.88 | 51–121 | 5.2–15.6 | | |
| Hemp | | Stem | 1.55 | 1.48 | 550–900 | 70 | 1.6–4.0 | 8 |
| Jute | 0.25 | Plants | 0.926 | 1.3–1.48 | 393–800 | 13–26.5 | 1.16–1.8 | 12 |
| Kenaf | 0.77 | Stem | 0.378 | –1.4 | 284–930 | 21–60 | 1.6 | 6.2–20 |
| Nettle | | Bast | – | 1.51 | 650 | 38 | 1.7 | 11–17 |
| Pineapple | Abundant | Leaf | 0.1–018 | 1.44 | 413–1627 | 60–82 | 14.5 | 10–13 |
| Ramie | 0.1 | Stem | 2 | 1.5 | 500 | 44 | 2 | 12–17 |
| Sisal | 0.3 | Plants leaf | 0.65 | 1.3–1.4 | 390–450 | 12–41 | 2.3–2.5 | 11 |
| Softwood | | Wood | 0.44–0.55 | 0.30–0.59 | 45.5–111 | 3.6–14.3 | – | – |
| Wool | | Animal | | | | | | |
| Silk | | | | | | | | |
| Feather | | | | | | | | |
| Basalt | | Mineral | | 2.8 | 2800 | 8.5 | 2.8 | |
| S-Glass | – | – | 2 | 2.5 | 2000–3500 | 70–73 | 1.8–3.2 | – |
| E-Glass | – | – | 2 | 2.55 | 3–3.5 | 63–67 | 2.5 | – |
| Aramid | – | – | | 1.44 | 3000 | 124 | 2.5 | – |
| Carbon | – | – | 8–14 | 1.4 | 400 | 230–240 | 1.4–1.8 | – |
| Silicon carbide | | | | 3.16 | | 360–440 | – | – |

# CHAPTER 2

## LITERATURE REVIEW

**Sahari et al.** demonstrates the effect of fiber content on mechanical properties, water absorption behavior and thermal properties of sugar palm fiber reinforced plasticized sugar palm starch (SPF/SPS) biocomposites. The biocomposites were made with various amounts of fiber (10%, 20%, and 30% by weight percent) by utilizing glycerol as plasticizer for the starch. It was declared that the mechanical properties of the starch. It was declared that the mechanical properties of plasticized SPS enhanced with the inclusion of SPF fiber. The tensile strength and modulus of SPF/SPS biocomposites showed increasing trend with increasing SPF while the addition of the SPF made the elongation fall from 8.03% to 3.32%. This was due to the remarkable intrinsic adhesion of the fiber-matrix interface caused by the chemical similarity of starch (SPS) and the cellulose fiber. Water uptake and moisture content of SPF/SPS composites decreased with the characters of fiber, which is due to better interfacial bonding the matrix and fiber as well as the consumption to absorption caused by the fiber. [45]

**Isiaka Oluwole Oladele et al** The use of natural fibers for the reinforcement of polymers intended for different applications has been on the increase in the recent years due to its advantages. In this study, bagasse/sugarcane (Saccharum officinarum) fiber was used to reinforce unsaturated polyester material in order to assess the viability of the composite materials developed for engineering applications. Sugarcane fibers gotten from the farm plantation were purified by washing thoroughly with water followed by sun drying and pulverizing. The particles were then sieved into 75 μm and added to the polyester in predetermined proportions of 5, 10, 15 and 20 weight percent (wt %) for the production of the composites. Mechanical tests (tensile and hardness) were carried out on the samples from where it was observed that the reinforcement was able to enhance the mechanical properties of the developed composites with a verge point value of 10 wt% reinforcement[69].

**G.C. Onuegbu et al** investigated the mechanical properties of polypropylene composites with ground nut husk powder at different particle sizes and found that the presence of ground nut husk improved the tensile strength, modulus, flexural strength and impact strength of the composites,[57].

**Vasanta V Cholachagudda et al** found that coir fiber as the major reinforcement and bagasse as an additional fiber improves the mechanical property of polymer composites were prepared by hand lay-up process according to ASTM standards, he also found that there is an increase in tensile and flexural[58].

**Haque et al.** also studied the chemical treatment of abaca and coir fiber with benzene diazonium salt. Due to the treatment, the interfacial bonding between the abaca and coir fiber with PP matrix increased, resulting in composites of high TS, BS and IS [46].

**Haque et al.** observed that TS and BS of palm fiber/PP composites increase with the increase in percentage of palm fiber content up to 10% in the composites [47].

**Salim et al.** evaluated properties of biocomposites from oil palm empty fruit bunch (EFB) fiber blended with poly(3-hydroxybutyrate-co-38 mol%-3-hydroxyvalerate) [P(3HB-co-38 mol%-3HV)].The authors used malefic anhydride (MAH), and benzyl peroxide (DBPO) to enhance the miscibility between PHBV and EFB fiber. On the basis of this study, the possibility of utilizing biodegradable PHBV/EFB blends showed fewer chemicals leached compared to commercial packaging.[48]

**Song et al.** focused on the physical behavior of hemp/PLA composites, particularly the thermal properties and viscoelastic behavior. They used twill and plain woven hemp fabrics as reinforcements by stacking film method. The impact and tensile properties of PLA resin reinforced with twill structure fabric were found 15% and 10% higher than the plain woven respectively. Increment of fiber volume fraction from 6% to 20% was the reason why the coefficient of thermal expansion of the fabricated hemp fabric composites decreased considerably.[31]

**Huda et al**. have studied PLA/recycled cellulose composites prepared by extrusion and injection moulding, finding that the filler (up to 30%) significantly improved the rigidity without affecting the crystallinity degree and thermal stability [50]

**Huzaifah et al.** investigated the mechanical, physical and thermal properties of vinyl ester composites with sugar palm fibre at different particle sizes and found that the presence of sugar palm fibre improved the tensile strength, modulus, flexural strength and impact strength of the composites.[49]

**Almeida et al.** investigated the structural characteristics and mechanical properties of coir fiber/polyester composites. The as-received coir fiber was characterised by scanning electron microscopy and X-ray dispersion analysis. Composites were prepared with two moulding pressures and they noted that with 50 wt% fiber, rigid composites were obtained and with prepared with higher content the composites performed more like flexible agglomerates.[51]

**Bensely et al.** investigated and evaluates the mechanical properties of coir fiber composites using scanning electron micrographs obtained from fractured surface to evaluate the interfacial properties of coir/epoxy and compared with glass fiber epoxy. The result indicate that coir fiber can used as a potential reinforcing material for making low load bearing plastic composite.[24]

**Junior et al.** studied the tensile properties of post-cured polyester matrix composites incorporated with thinnest coir fibers. Tensile specimens with up to 40 vol. % of long and aligned coir fibers were tested and their fracture surfaces analysed by scanning electron microscopy. A relative improvement was found in the tensile properties. [71]

**Yan Chouw et al.** observed that the interfacial gaps between coir fibers and epoxy resin were mitigated with alkali treatment of the fibers giving a stronger interfacial adhesion. [72]

**Perez-Fonseca et al.** also noted that the treatment of coir fibers with 3 fiber-wt% Maleated Polyethylene improved the compatibility with polyethylene resin. It was also reported that chemically treated coir fibers showed better fiber dispersion into polypropylene matrix yielding a better fiber/matrix interfacial bonding the untreated fiber composites. [73]

**Luz et al.** examined the correlation between the interfacial adhesion and mechanical properties of coir fibers and epoxy matrix and compared the results with the properties of pineapple leaf fibre also embedded in epoxy matrix. The results from the analysis showed that coir fiber (diameter 314 μm) have a critical length of 12.4 mm and an interfacial strength of 1.42 MPa. However, it exhibited weaker interfacial strength compared to pineapple leaf fibre (diameter 238 μm) whose reinforcement in epoxy matrix gave a critical length of 7.3 mm and interfacial strength of 4.93 MPa The critical length is inversely proportional to the interfacial strength. Hence the higher the critical length, the weaker the interfacial strength between the fiber and the matrix. [74]

**Nam et al.** obtained interfacial shear strength of 2.054 MPa for coir fiber reinforced poly (butylene succinate) biodegradable composites. The low strength was attributed to the incompatibility between the fiber and matrix as well as the presence of impurities on the fiber surface. [75]

**Tran et al.** also inferred qualitatively that coir fibers have higher interfacial strength in polyvinylidene fluoride (PVDF) and maleic anhydride-grafted polypropylene (MAPP) than in polypropylene. The interfacial strength of fiber composites can be improved by fibre surface modifications or treatment processes using various chemicals such as silane, sodium hydroxide, anhydrides, peroxide, organic and inorganic acids. Surface modification reduces moisture absorption and hydrophilic nature of the fibers providing better bonding to matrix. [76]

**Dong et al.** noted that increasing fiber content decreases the thermal stability of Coir-PLA composites which is due to the lower degradation temperature of the coir fibers. This conclusion was draw from the TGA of treated and untreated Coir-PLA bio-composites which gave 313, 347, 333 and 327°C for fibre contents of 5, 10, 20 and 30 wt% respectively for the untreated composites and arrange of 321–297°C for treated composites. [77]

**Bhagat et al.** noted that the effects of fiber length, finer loading and immersion time on the water absorption properties of coir/glass/epoxy composites were investigated at room temperature. It was reported that the rate of moisture absorption increased with increase in fiber length, fiber loading and also with increase in immersion time reaching a saturation point after about 192 h. [78]

**Brahmakumar et al.** observed that the natural waxy surface coir provided a strong interfacial bonding between coir and polyethylene matrix since polyethylene is anon-polar matrix. [79]

**Luz et al.** concluded that the relatively high interfacial strength of PALF epoxy composite over coir epoxy composite could be justified by the rougher surface of PALF and the wax present on coir fiber surface. However, alkali treatment of coir fibers removes the waxy layer and increases the surface roughness of the fiber thereby improving the fiber-matrix adhesion and resulting in increasing mechanical properties. [80].

**Santhosh et al.** they've taken both treated and untreated banana fiber for the development of the hybrid composite material. In this study, the untreated banana fiber was treated by NaOH to increase wettability. The untreated banana fiber and NaOH treated banana fiber were used as reinforcing material with both Epoxy resin matrix and Vinyl ester resin matrix. Coconut shell powder was used along with both untreated and treated banana fiber as a filler material. They've concluded that the alkali treatment of banana fiber improved the mechanical properties like tensile, flexural and impact strength of both the epoxy/ vinyl ester and hybrid composite.[81]

**Kumar et al.** the researcher evaluated the tensile strength, flexural strength and surface hardness of the bamboo – epoxy composites. The effect of fiber loading on tensile strength, flexural strength and surface hardness also was studied on the bamboo epoxy composite. In this study, with the hand layup technique it was found that maximum value tensile strength, flexural strength, and micro surface hardness of bamboo–epoxy composite was achieved at 25% wt of fiber loading.[82]

**Saba et al.** investigate that the kenaf fiber has good tensile strength and flexural strength which was proved by many mechanical tests which enables it to utilize in variety of applications, such as auto-industrial, light weight constructional applications, customary products like yarns, fabrics and ropes. He also found that kenaf/epoxy composites showed better mechanical properties in comparison with polymeric matrix. [83]

**Rout et al.** studied the significance of surface treatment on the coir reinforced polyester composites. The coir fiber was subjected to alkali treatment, vinyl grafting, and bleaching before adding them with general purpose polyester resin. The mechanical charecteristics like tensile strength, bending and impact strength were increased because of surface treatment. Bleached fiber composite (at 65$_{0}$C) showed better flexural strength. NaOH treated fiber/polyester composite exhibited better tensile strength. Because of the chemical treatments of fibers the water absorption tendency of composite was reduced.[84]

**Biswas et al. [16**] carried out a study on the significance of fiber length on the mechanical character of coir/epoxy composite. It was found that the hardness of the composite decreases by increasing length of fiber up to 20 mm and then after it increases. They also concluded that fiber length has a major influence on enhancing mechanical properties like tensile strength, flexural strength and impact strength.[85]

**Romli et al.** done a factorial study upon tensile strength of coir reinforced epoxy composite. In their study, the volume fraction, curing time and compression load during the solidification of composites were taken as parameters. From the results, they concluded that volume fraction influences the tensile strength of the composites. Authors also increased the percentage volume fraction of fiber and found that the tensile properties of composites increased to some extent. Curing time also showed some effects on the characteristics of composites meanwhile the influence of compression load on the properties of composites were not revealed properly.[86]

**Samal et al. [19]** prepared bamboo as well as glass fiber filled polypropylene hybrid composites and examined their mechanical, thermal and morphological properties. They also added maleic anhydride grafted polypropylene (MAPP) to the composite in order to enhance the interfacial bonding between the fibers and matrix. It was reported that the hybrid composite shows improved mechanical properties like tensile, impact and flexural strength as compared with virgin polypropylene. SEM micrograph of the composites showed a reduction in the interfacial gap between fiber and matrix. TGA showed the improved thermal stability of hybrid composite compared to the polymer.[87]

**Mishra and Biswas** fabricated jute fiber epoxy composites by hand lay-up method and studied the physical and mechanical properties of the prepared composites. They concluded that the presence of voids in the composites adversely affect its mechanical properties.[88]

**Mir et al.** performed surface treatment on coir fiber, after that a systematic investigation on the mechanical and physical properties of coir-polypropylene bio composites had conducted. For improving the compatibility with polypropylene matrix, the coir fiber was reacted with basic chromium sulphate and sodium bicarbonate salt in acidic solution. Composites with fiber percentage of 10, 15 and 20 were prepared. The study reveals that the chemically treated fiber based composite showed good mechanical characters than untreated. The composite with 20% fiber weight concentration exhibited optimum mechanical property compared to other. During surface treatment, the OH groups of untreated coir cellulose which were hydrophilic in nature had been changed to hydrophobic –OH-Cr groups. Because of this, the water absorption amount of composite was also lowered.[89]

**Reddy et al.** treated glass/bamboo hybrid fiber reinforced polyester composites with some chemicals such as sodium carbonates, sodium hydroxide, acetic acid, benzene, carbon tetrachloride, ammonium hydroxide, toluene and water to check the chemical resistivity of the composite. It was observed that the hybrid composites showed excellent resistance to chemicals and the tensile strength of alkali treated hybrid composite was also improved. The reason found that once the fiber subjected to alkali treatment, the amorphous hemicelluloses can be removed to certain extent and eventually composite may show some crystalline behaviour.[90]

**Sreenivasan et al**. compared the mechanical properties of untreated and surface treated Sansevieria cylindrica fibers (SCFs) /polyester composites. Surface treatments such as alkali, potassium permanganate, benzoyl peroxide and stearic acid were performed in order to modify the fiber surface. They concluded that the surface treated fiber showed improved mechanical property than the untreated fiber. Composites with potassium permanganate treated fiber exhibited better mechanical property due to better compatibility of fiber upon matrix. [91]

**Monteiro et al.** conducted a study on the mechanical characteristics of coir fiber reinforced polyester composites. The coir fiber percentage was increased up to 80 % and found that up to 50% fiber loading, composites were become rigid, and after those composites behaves like agglomerates.[92]

**Rozman et al.** study on the influence of lignin as a compatibiliser on the physical property of coir fiber reinforced polypropylene composites. They made the conclusion that the coir fiber filled polypropylene composites with lignin as a compatibilizer was performed better flexural properties than control composites. Tensile properties were not at all improved where lignin was incorporated as a compatibilizer.[93]

**Ayrilmis et al.** studied the use of coir fibre reinforced polypropylene composite for the panel of automotive interior applications was studied by [94]. This study proved that the coir fibre would be a vital component in the production of thermoplastic composites, especially for the effective replacement of comparatively highly expensive and dense glass fibres. When the coir fiber quantity increased up to 60 wt %, the flexural and tensile properties of the composites improved by 26% and 35%, respectively. Even if the further increase in fibre quantity caused to decreases the flexural and tensile properties because of the inadequate coverage of all the surfaces of the coir fibre in polymer matrix.[94]

**Pothan et al.** studied the significance of fiber length and fiber quantity on short banana fiber filled polyester composite. The maximum tensile strength was obtained at a fiber length of 30 mm and impact strength was getting maximum at of 40 mm fiber length banana fiber polyester composite. As the fiber quantity increased up to 40%, the tensile strength increased by 20% and there was a 34% increase in impact strength also.[95]

## 2.1. CONCLUSION FROM LITERATURE REVIEW

Researchers have developed various types of short natural and artificial fiber reinforced thermoplastic composite at different fiber loading. The collected data from literature presented is to summaries the potential usage of coir fibers and other natural fibers in composite materials. Although the use of fibers could result in a reduction in some of the properties of composite like modulus of elasticity and compressive strength, the addition of natural fibers to composite can reduce both the development of cracks and damage. Besides that, if the proper fibers content and selection of the material ratio are carried out, these materials could be incorporated in composite for good thermal insulation. The literature review gives a summary of the use of fibers as filler in fiber reinforced polymer composites. The properties of the fiber (chemical, mechanical, microstructural and water absorption) were also discussed. Fiber surface modification (fiber treatment) was seen to be playing a greater role in the performance of these composites as it greatly improves fiber/matrix interfacial adhesion thereby enhancing the above mentioned properties. The most popular treatment method was seen to be alkalization by NaOH and most researchers also prefer to use hand lay-up molding in the fabrication of coir fiber reinforced polymer composites. However, the dosage and length of fibers could be limited based on the summarized findings in this literature review to meet the standards for adequate composite performance. In these research paper conclude the fiber orientation increase the mechanical properties.

**2.2 OBJECTIVE OF RESEARCH WORK**

To develop a new class of composite by reinforcing coconut coir fiber in epoxy matrix with two fiber percentage and two length reinforcement. Fabrication of composite by using hand lay-up process. To perform following tests:

. Tensile Testing

. Flexural Testing

. Hardness Testing

. Water absorption test

In the present work, coconut coir fiber is incorporated in epoxy resin matrix for preparing composite specimens at various fiber percentage and length. The developed coconut coir fiber reinforced epoxy composites were then tested for their tensile and flexural properties.

# CHAPTER-3
# FABRICATION AND METHODOLOGY

This chapter contains the details about materials and the experimental procedure that were considered for the fabrication of composite and the test procedure followed for testing the characterization of composites, respectively. The raw materials used for fabrication are

1. Coir fiber
2. Epoxy
3. Hardener

## 3.1 MATERIAL PREPERATION

**Treatment of the fiber** The coconut coir fibers were collected from local area. Coir washed several times with distilled water in order to remove the cellulose content and other impurities and then was soaked in 5% NaOH concentrated water for 30 minutes. The soaked fibers were then washed with detergent water followed by pure water then were dried in oven at 85°C. Clean fibers from dirt and impurities are obtained. [4]

### 3.1.1 Coconut coir fiber

Coconut coir fiber is a natural fiber extracted from the outer husk of coconut. Coir is the fibrous material found between the hard, internal shell and the outer coat of a coconut. The coconut is steeped in hot seawater, and subsequently, the fare removed from the shell by combing and crushing, the same process as jute fiber. The individual fiber cells are narrow and hollow with thick walls made of cellulose, and each cell is about 1mm long and 10-20 µm in diameter. The raw coconut fibers show length varying from 15 to 35cm and diameter from 50 to 300 µm. When they are immature and then become hardened and yellowed because a layer of lignin is deposited on their walls. Coconut fiber shows a good stiffness .Coconut fiber has a high lignin content which makes it resilient, strong, and highly durable. It is graded into “bristle” fiber (random fibers approximately 2-10 cm long). The fiber finds application in residential furnace and ventilation filter pads. It is often combined with hogs hair in natural filters. [71]

3.1.1(a)- Coconut coir before treatment

3.1.2(b)- Fibers soaked in NaOH

3.1.3(c)- Coconut coir after treatment

**Table No.3- Chemical compositions of coconut coir fiber [9-43]**

| | |
|---|---|
| Cellulose | 30.44% |
| Hemicelluloses | 0.25% |
| Lignin | 45-70% |
| Ash | 0.13% |
| Total | 100% |

### 3.1.2 Plant description

A coconut tree or a coconut palm is a member of the species Cocos nucifera. This is a member of the palm family, and it’s a tree that’s cultivated the world over for its fruit, the coconut. Despite its name, the coconut is not, it’s a particular kind of fruit. The coconut has a fibrous outer husk, a hard shell, an interior containing a thick layer of coconut “meat” water in the deepest part of the interior. Coconut trees have a textured trunk. Cocoas nucifera is large palm, growing up to 30m(100ft) tall, with pinnate leaves 4-6m (13-20 ft) long, and pinnae 60-90 cm (2-3ft) long; old leaves break away cleanly, leaving the trunk smooth. On fertile soil, a tall coconut palm tree can yield up to 75 fruits per year, but more often yields less than 30. Coconut trees are found throughout the southern hemisphere in place where its humid and hot. Tropical and subtropical climates see the most proliferation in the growth of coconut trees. Coconut tree growth in the continental United States is limited to the southern part of the state of Florida .Malaysia; Indonesia, the Philippines and Thailand are other places where coconuts are prevalent and widely grown.

Fig 3.1.2-Coconut tree [114]

### 3.1.3 Fiber extraction

The coconut coir fiber was obtained from locally available shop. Coir fiber is collected with or without relting from the fibrous outer cover of the coconut palm fruit. In this process, bundles of coconut coir fiber were soaked for one week in a water bath, then rubbed by hand and rinsed in water until the excess greasy materials were removed and the fine fiber was separated. Finally, the harvested fiber was carefully washed in plenty of clean water to eliminate any excess waste before being air dried for 24 hours before being dried in an oven at 80℃. Finally, continuous fiber with a length of up to 1.5 m was collected. The fiber used for composite preparation had an average diameter of 0.2 to 0.3 mm. Sodium hydroxide (NaOH) was used as a chemical treatment solution and was obtained from a local supplier. This solution was formulated in a container as a liquid with a concentration of 1 M. The experiment's two concentrations (0.25 M and 0.5 M) were calculated using the following formula:

$$A_1V_1=A_2V_2$$

Where

A1 is the concentration of solution in condition1;

V1 is the volume of solution in condition1;

A2 is the concentration of solution in condition 2.

The alkali treatment was done with 0.25 M and 0.5 M NaOH at three different soaking times: 1 hour, 4 hours, and 8 hours. These changes were introduced in order to improve the therapy parameter. Water was added at various percentages of the initial NaOH (1 M). Coconut coir fiber was soaked in NaOH solution at varying concentrations and soaking periods, and the solution was often rinsed until neutral (pH7). The fibers were then processed in an oven at 85°C.

### 3.1.4 Selection of Base Material

Thermoplastics have the simplest molecular structure, with chemically independent macromolecules by heating, they are softened or melted, then shaped, formed welded, and solidified when cooled. Multiple cycles of heating and cooling can be repeated without severe damage, allowing reprocessing and recycling. Often some additives or fillers are added to the thermoplastic to improve specific properties such as thermal or chemical stability, UV resistance, etc. Composites are obtained by using short, long or continuous fibers. Alloys of compatible thermoplastics allow applications to benefit from the attractive properties of each polymer while masking their defects. Some thermoplastics are crosslink able and are used industrially in their two forms, thermoplastic and thermo set; for example, the polyethylene or the vinyl acetate-ethylene copolymers (VAE) (the links created between the chains limit their mobility and possibilities of relative displacement). Thermoplastic consumption is roughly 80% or more of the total plastic consumption.

Epoxy resin refers to a type of reactive prepolymer and polymer containing epoxide groups. These resins react either with themselves in the presence of catalysts, or with many co-reactants like amines, phenols, thiols etc. Epoxy resin has many industrial applications for a variety of purposes. It possesses higher mechanical properties and more thermal and chemical resistance than other types of resin. Epoxy resin is also called polyepoxides. Epoxy resin is a type of resin that possesses tough mechanical properties, good chemical resistance, and high adhesive strength, which makes it highly useful for various applications. [83]

Epoxy resins uses are:

- Metal coatings
- Use in electronic and electrical components
- Electrical insulators
- Fiber- reinforced plastic materials
- Structural adhesives

Epoxy resin also finds uses in caulking and casting compounds, sealants, varnishes and paints, and other industrial applications.

Epoxy resin is superior to other types of resins because it has low shrink during cure, and excellent moisture and chemical resistance. It is impact resistant; it has good electrical and insulating properties, and a long shelf life. The various combinations of epoxy resins and reinforcements gives a wider range of properties obtainable in molded parts.

Epoxy resin is different from polyester resins with regard to curing. It is cured by a curing agent called “hardener” rather than a catalyst. Although some epoxy resins bond better than others to different materials, all epoxies are not recommended for long- term submersion or for use below the water line in marine applications.


Fig. 3.1.4(a)-Epoxy Resin


Fig. 3.1.5(b)- Hardener

## 3.2 Fabrication

- Compounding of materials (Epoxy resin, coconut coir).
- Preparation of specimen by hand -lay up process for these tests-

| MECHANICAL PROPERTIES | STANDARD |
|---|---|
| Tensile Strength | ASTM D638 |
| Flexural Strength | ASTM D790 |
| Impact Strength | ASTM D256 |
| Hardness | ASTM D2240 |

**Table 4- Material Composition**

| Epoxy (Reinforcement in wt%) | Coconut coir fiber (Reinforcement in wt%) | Fiber type |
|---|---|---|
| 95% (BATCH 1) | 5% | Short |
| 90% (BATCH 2) | 10% | Short |
| 95% (BATCH 3) | 5% | Long |
| 90% ( BATCH 4) | 10% | Long |

### 3.2.1 Compounding and specimen Preparation

The hand lay-up method was used to prepare the specimens, and the mould was made of composite boards with dimensions of 12 inch (L) x 12 inch (w) and a thickness of 3.5 mm. Wood, steel sheet, spacer plates, and other materials were used to make the mould for the hand lay-up operation. The mould was constructed out of wood and steel sheet, with an iron bar used to create a square shape during the process. The mould scale was used to cut the processed and untreated fibers. Then the fiber was placed over the transparent plastic in the bottom of the mould prepared earlier. To make a matrix, epoxy and hardener were combined in a 2:1 weight ratio, then poured over the fiber and compressed and spread uniformly until the thickness was between 3.0 mm and 4 mm, according to ASTM 638-99.

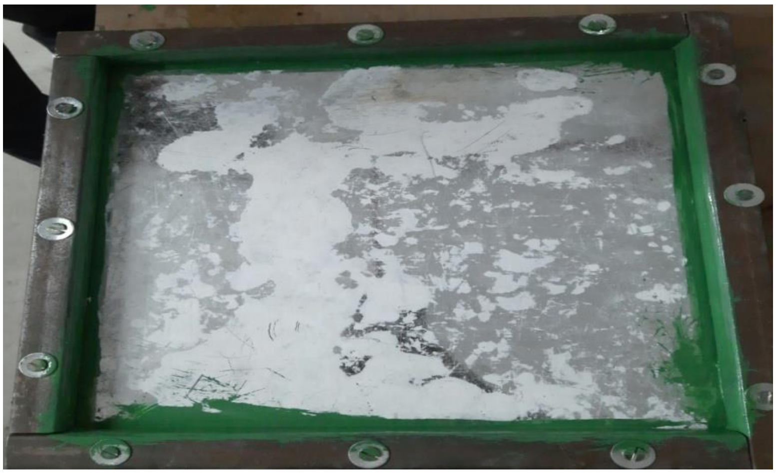

Fig- 3.2.1- Mould

### 3.2.2 Fabrication Method-Hand- layup process

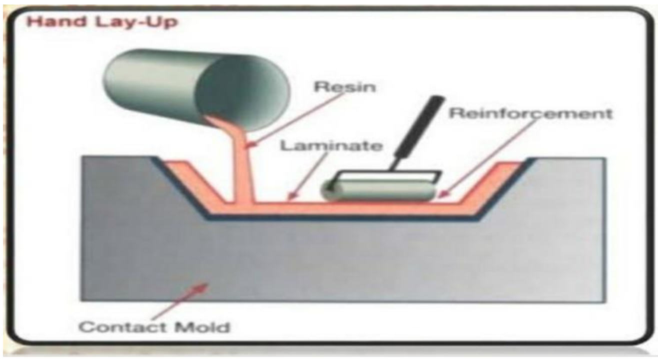


Fig- 3.2.2(a)-Hand layup process [115]

Hand lay-up is the simplest and oldest open molding method for fabricating composites. At first, dry fibers in the form of woven, knitted, stitched, or bond fabrics are manually placed in the mold, and a brush is used to apply the resin matrix on the reinforcing material. Subsequently, hand rollers are used to roll the wet composite to ensure an enhanced interaction between the reinforcement and the matrix, to facilitate a uniform resin distribution, and to obtain the required thickness. Finally, the laminates are left to cure under standard atmospheric conditions. Generally, this process is divided into four steps: mold preparation, gel coating, lay-up, and curing. Curing is the process of hardening the fiber-reinforced resin composite without external heat. A pigmented gel coat is first applied to the mold surface to obtain a high-quality product surface [85].

There are several disadvantages of this method. The skills to laminate the reinforcement and matrix, such as resin mixing, laminate resin contents, and the quality of the laminate, are crucial. The laminate is usually achieved with the incorporation of excessive quantities of voids. The lower molecular weights of the hand lay-up resins mean that they have the potential to be more harmful than higher molecular weight products. The lower viscosity of the resins also implies that they have an increased tendency to penetrate clothing. Resins need to be low in viscosity to be workable by hand. This usually compromises their mechanical/thermal properties, due to the need for high diluents/styrene levels. Moreover, the amount of fiber loading relies heavily on the processing method. This is also influenced by the anatomical features of the fibers, which have intra-fiber voids called lumen. The hand lay-up fabrication process is mainly used in marine and aerospace structures [85].

Fig-3.2.2(b) Mould box with treated fibers and resin mixture

Fig- 3.2.2(c) complete composite plate

- First of all the coconut is obtained from local shop.
- Then bundles of coconut coir fiber were soaked in NaOH solution.
- Then rubbed by hand and rinsed in water until the excess greasy materials were removed and then air dried for 24 h before being dried in the oven at 85 °C for another 24 h.
- Then treated fibers were cut in 2mm size. Then the fiber was placed over the transparent plastic in the bottom of the mould prepared earlier.
- . Then epoxy and hardener were mixed with 3:1 ratio together based on the weight percentage to form a matrix, and then matrix was poured over fiber and compressed.
- After that, the remaining mixture of epoxy resin and hardener was poured over the unfinished composite plate and pressed and pushed down with the finger to remove bubbles. .
- Releasing agent is used on mould sheet which gives easy to remove of composite from the mould.
- After pouring in to the mould the curing time was around 20-24h applied at room temperature.
- After curing is done, the composite board is taken out from the mould.
- After removing the composite board from mould box, it was cut as per the ASTM standard.

- Specimens for mechanical properties of coconut coir fiber epoxy composites were prepared by cutting composite boards into test sample (three specimens for each type of fiber model were tested).
- The cutting process was made using handsaw and other equipments (jigsaw).

# CHAPTER-4

## TESTING AND RESULTS

### 4.1 Mechanical Testing

There are various tests that are performed on materials for accessing mechanical properties. Various testing performed are listed below.

**Tensile Testing ASTM D638** subjects a sample to uniaxial tension until it fails. Element tensile testing capabilities include: wedge tensile testing, axial tensile testing, weld tensile testing, castings tensile testing, elevated temperature tensile, tensile testing for machined specimens, full-size tensile testing and yield tensile, plus heat treatment capabilities

**Izod Test ASTM D256** is most commonly used to evaluate the relative toughness or impact toughness of materials and as such is often used in quality control applications where it is a fast and economical test. It is used more as a comparative test rather than a definitive test. This is also in part due to the fact that the values do not relate accurately to the impact strength of molded parts or actual components under actual operational conditions.

**Flexural Test ASTM D790** measures the force required to bend a beam under three point loading conditions. The data is often used to select materials for parts that will support loads without flexing. Flexural modulus is used as an indication of a material's stiffness when flexed. Since the physical properties of many materials (especially thermoplastics) can vary depending on ambient temperature, it is sometimes appropriate to test materials at temperatures that simulate the intended end use environment.

**Hardness Testing ASTM D2240** is the measure of how resistant solid matter is to various kinds of permanent shape change when a force is applied. Methods include: shore D hardness, Rockwell standard testing, Rockwell superficial testing, Knoop & Vickers micro hardness testing, and Brinell hardness testing.

### 4.1.1 TENSILE TESTING

Tensile testing ASTM D638, also known as tension testing, is a fundamental materials science test in which a sample is subjected to a controlled tension until failure. The results from the test are commonly used to select a material for an application, for quality control, and to predict how a material will react under other types of forces. Properties that are directly measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength characteristics. Uniaxial tensile testing is the most commonly used for obtaining the mechanical characteristics of isotropic materials. For anisotropic materials, such as composite materials and textiles, biaxial tensile testing is required.

The Tensile test is carried out in universal testing machine accordance with ASTM D-638 standard. The testing out carried out in Lucknow University. Universal Testing Machine code no. PTC/083/ME having maximum working ranges 100 KN and accuracy ± 0.06%. Through this testing the ultimate tensile strength, modulus value and strain determined. The specimen is hold by the grip and load applied until the failure.


Fig- 4.1.1(a) –Universal Testing Machine

**Machine Specification:-**

Name of Equipment: Universal Testing Machine

CODE NO: TFUN-100

MAKE/TYPE: INSTRON, USA

WORKING RANGE: MAX. 100 KN

ACCURACY: +-1%

PURPOSE: MECH. TESTING

The most common testing machine used in tensile testing is the universal testing machine. This type of machine has two crossheads; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. There are two types: hydraulic powered and electromagnetically powered machines.

The machine must have the proper capabilities for the test specimen being tested. There are four main parameters: force capacity, speed, and precision and accuracy. Force capacity refers to the fact that the machine must be able to generate enough force to fracture the specimen. The machine must be able to apply the force quickly or slowly enough to properly mimic the actual application. Finally, the machine must be able to accurately and precisely measure the gauge length and forces applied; for instance, a large machine that is designed to measure long elongations may not work with a brittle material that experiences short elongations prior to fracturing.

Alignment of the test specimen in the testing machine is critical, because if the specimen is misaligned, either at an angle or offset to one side, the machine will exert a bending force on the specimen. This is especially bad for brittle materials, because it will dramatically skew the results. This situation can be minimized by using spherical seats or U-joints between the grips and the test machine. If the initial portion of the stress–strain curve is curved and not linear, it indicates the specimen is misaligned in the testing machine.

Fig 4.1.1(b) tensile specimen before fracture (Batch 1)

4.1.1(c)- Tensile specimen before fracture (Batch 2)

Fig- 4.1.1(d)-Tensile specimen before fracture (Batch 3)

Fig 4.1.1(e)-Tensile specimen before fracture (Batch 4)

Fig. 4.1.1(f)-Tensile specimen after fracture (Batch 1)

Fig. 4.1.1(g) tensile specimen after fracture (Batch 2)

Fig 4.1.1(h)-Tensile specimen after fracture (Batch 3)

Fig 4.1.1(i)- Tensile specimen after fracture (Batch 4)

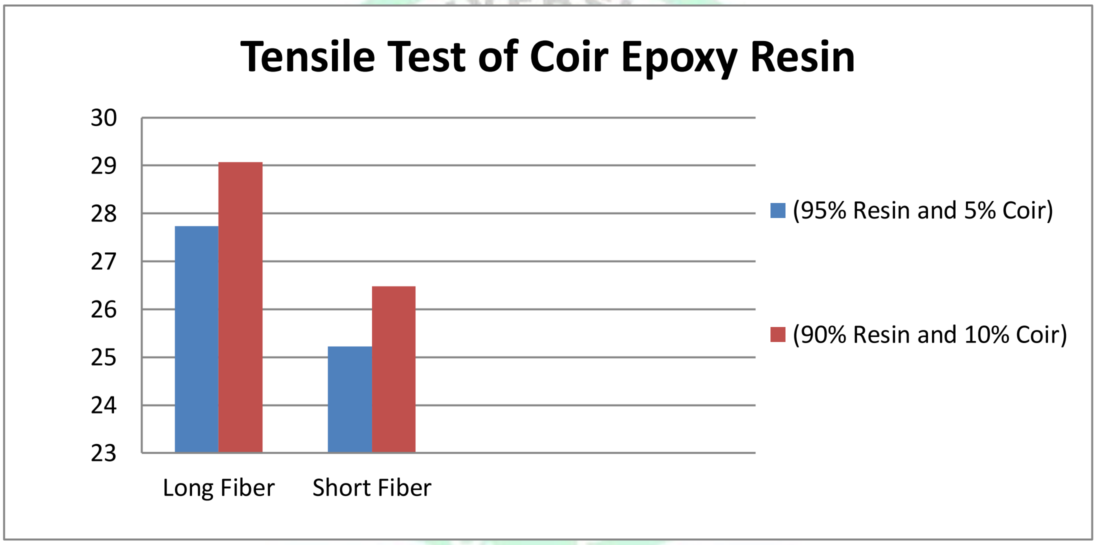


Fig. 4.1.1(j) Tensile strength of coir/epoxy Resin composite

**Table 5-Tensile Test (batch 1)**

| Specimen No. | TEST | STANDARD | TEST VALUE(MPa) |
|---|---|---|---|
| 1 | **Tensile** | ASTM-D638 | 25.12 |
| 2 | **Tensile** | ASTM-D638 | 25.42 |
| 3 | **Tensile** | ASTM-D638 | 25.14 |

**Mean value of tensile strength for batch 1 = 25.22 MPa**

**Table 6-Tensile Test (batch 2)**

| Specimen No. | TEST | STANDARD | TEST VALUE(MPa) |
|---|---|---|---|
| 1 | **Tensile** | ASTM-D638 | 26.68 |
| 2 | **Tensile** | ASTM-D638 | 26.54 |
| 3 | **Tensile** | ASTM-D638 | 26.24 |

**Mean value of tensile strength for batch 2= 26.48 MPa**

**Table 7-Tensile Test (Batch 3)**

| Specimen No. | TEST | STANDARD | TEST VALUE(MPa) |
|---|---|---|---|
| 1 | **Tensile** | ASTM-D638 | 27.91 |
| 2 | **Tensile** | ASTM-D638 | 27.25 |
| 3 | **Tensile** | ASTM-D638 | 28.03 |
| | | | |

**Mean value of tensile strength for batch 3 = 27.73 MPa**

**Table 8-Tensile Test (Batch 4)**

| Specimen No. | TEST | STANDARD | TEST VALUE(MPa) |
|---|---|---|---|
| 1 | **Tensile** | ASTM-D638 | 29.39 |
| 2 | **Tensile** | ASTM-D638 | 29.05 |
| 3 | **Tensile** | ASTM-D638 | 28.77 |
| | | | |

**Mean value of tensile strength for batch 4 = 29.07 MPa**

Ultimate Tensile Strength for Batch 1(95% Resin and 5% Coir) Short -= 25.22 MPa

Ultimate Tensile Strength for Batch 2(90% Resin and 10% Coir) Short = 26.48 MPa

Ultimate Tensile Strength for Batch 3(95% Resin and 5% Coir) Long = 27.73 MPa

Ultimate Tensile Strength for Batch 4(90% Resin and 10% Coir) Long = 29.07 MPa

### 4.1.2 Flexural Testing

The flexural test **ASTM D790** measures the force required to bend a beam under three point loading conditions. The data is often used to select materials for parts that will support loads without flexing. Flexural modulus is used as an indication of a material's stiffness when flexed. Since the physical properties of many materials (especially thermoplastics) can vary depending on ambient temperature, it is sometimes appropriate to test materials at temperatures that simulate the intended end use environment. The flexural test is carried out in a Universal Testing Machine and it is made by INSTRON, USA and there is a code no. PTC/083/ME. There is a working range maximum 100 kN and accuracy is ±0.066%. It is used for mechanical property. The Flexural test is carried out in a UMT no samples cut in accordance with ASTM D-790 standard the testing procedure is as per the three-point bending test by placing the specimen on the Universal Testing Machine and applying load till the specimen fracture and break. Result is compared and flexural strength of the material is identified.

Fig. 4.1.2(a)-Flexural specimen before fracture (Batch 1)

Fig. 4.1.2 (b) Flexural specimen before fracture (Batch 2)

Fig. 4.1.2(c)-Flexural specimen before fracture (Batch3)

Fig. 4.1.2(d) Flexural specimen before fracture (Batch 4)

Fig. 4.1.2(e)-Flexural specimen after fracture (batch 1)

Fig. 4.1.2(f)- Flexural specimen after fracture (batch 2)

Fig. 4.1.2 (g)-Flexural specimen after fracture (Batch 3)

Fig. 4.1.2(h)-Flexural specimen after fracture (batch 4)

**Table 9--Flexural Test (batch 1)**

| Specimen No. | TEST | STANDARD | TEST VALUE(MPa) |
|---|---|---|---|
| 1 | **Flexural** | ASTM-D790 | 34.23 |
| 2 | **Flexural** | ASTM-D790 | 34.74 |
| 3 | **Flexural** | ASTM-D790 | 34.69 |

**Mean Value of flexural test for Batch 1= 34.55 MPa**

**Table 10- --Flexural Test (batch 2)**

| Specimen No. | TEST | STANDARD | TEST VALUE(MPa) |
|---|---|---|---|
| 1 | **Flexural** | ASTM-D790 | 35.67 |
| 2 | **Flexural** | ASTM-D790 | 35.88 |
| 3 | **Flexural** | ASTM-D790 | 35.52 |

**Mean Value of flexural test for Batch 2 = 35.69 MPa**

**Table 11-Flexural test (batch 3)**

| Specimen No. | TEST | STANDARD | TEST VALUE(MPa) |
|---|---|---|---|
| 1 | **Flexural** | ASTM-D790 | 36.63 |
| 2 | **Flexural** | ASTM-D790 | 36.58 |
| 3 | **Flexural** | ASTM-D790 | 36.78 |

**Mean Value of flexural test for Batch 3= 36.66 MPa**

**Table 12-Flexural Test (batch 4)**

| Specimen No. | TEST | STANDARD | TEST VALUE(MPa) |
|---|---|---|---|
| 1 | **Flexural** | ASTM-D638 | 38.53 |
| 2 | **Flexural** | ASTM-D638 | 38.83 |
| 3 | **Flexural** | ASTM-D638 | 38.65 |

**Mean Value of flexural test for Batch 4= 38.67 MPa**

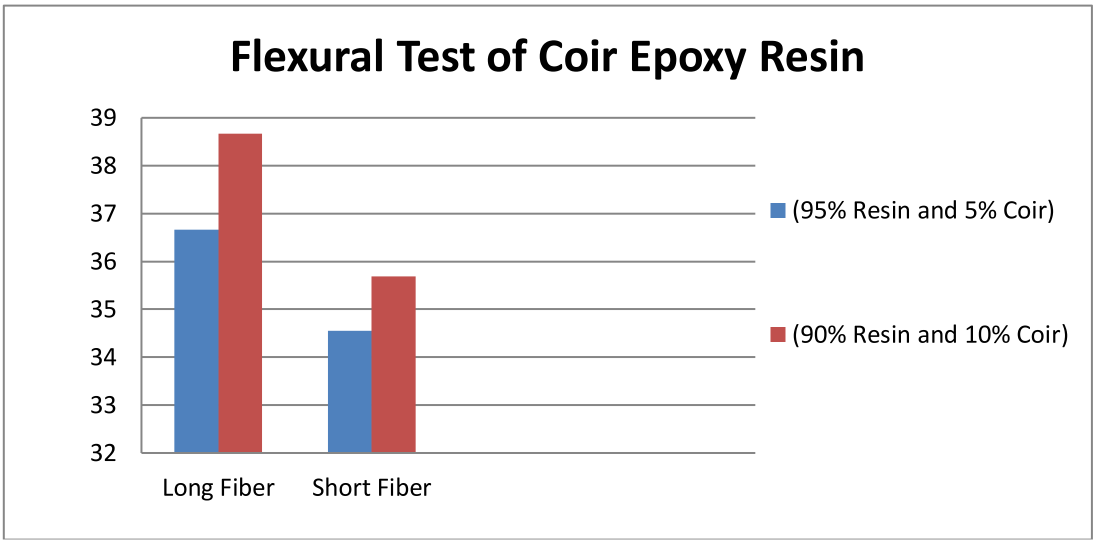


**Fig 4.1.2 (i) -Flexural strength of coir/epoxy resin composite**

Flexural Strength for batch 1(95% Resin and 5% Coir) Short = 34.55 MPa

Flexural Strength for batch 2(90% Resin and 10% Coir) Short = 35.69 MPa

Flexural Strength for batch 3(95% Resin and 5% Coir) Long= 36.66 MPa

Flexural Strength for batch 4(90% Resin and 10% Coir) Long = 38.67 MPa

### 4.1.3 Hardness Test

The Rockwell scale is a hardness scale based on indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload. There are different scales, denoted by a single letter, that use different loads or indenters. The result is a dimensionless number noted as HRA, HRB, HRC, etc., where the last letter is the respective Rockwell scale .When testing metals, indentation hardness correlates linearly with tensile strength. This important relation permits economically important nondestructive testing of bulk metal deliveries with lightweight, even portable equipment, such as hand-held Rockwell hardness testers. The differential-depth method subtracted out the errors associated with the mechanical imperfections of the system, such as backlash and surface imperfections. The Brinell hardness test, invented in Sweden, was developed earlier – in 1900 – but it was slow, not useful on fully hardened steel, and left too large an impression to be considered non-destructive.

The determination of the Rockwell hardness of a material involves the application of a minor load followed by a major load. The minor load establishes the zero position. The major load is applied, then removed while still maintaining the minor load. The depth of penetration from the zero data is measured from a dial, on which a harder material gives a higher number. That is, the penetration depth and hardness are inversely proportional. The chief advantage of Rockwell hardness is its ability to display hardness values directly, thus obviating tedious calculations involved in other hardness measurement techniques.

It is typically used in engineering and metallurgy. Its commercial popularity arises from its speed, reliability, robustness, resolution and small area of indentation.

In order to get a reliable reading the thickness of the test-piece should be at least 10 times the depth of the indentation. Also, readings should be taken from a flat perpendicular surface, because convex surfaces give lower readings. A correction factor can be used if the hardness of a convex surface is to be measured

Digitally hardness testing machine measure the indentation capacity of the material. This machine has model RBHT, M scale which having specification are 100 Kg load carrying capacity, M scale, and 1/4'' ball indenter.

**Table 14-Hardness Test Result (Batch 1)**

| S. No | Test value |
|---|---|
| Sample 1 | 40.45 |
| Sample 2 | 39.58 |
| Sample 3 | 40.77 |

**Mean Value of Hardness for batch 1 = 40.26 HRM**

**Table 14-Hardness Test Result (Batch2)**

| S. No | Test value |
|---|---|
| Sample 1 | 42.23 |
| Sample 2 | 42.54 |
| Sample 3 | 42.83 |

**Mean Value of Hardness for Batch 2= 42.53 HRM**

**Table 15-Hardness Test Result (Batch 3)**

| S.No | Test value |
|---|---|
| Sample 1 | 45.71 |
| Sample 2 | 45.78 |
| Sample 3 | 45.06 |

**Mean Value of Hardness for batch 3 = 45.51 HRM**

**Table 16-Hardness Test Result (Batch 4)**

| S.No | Test value |
|---|---|
| Sample 1 | 49.36 |
| Sample 2 | 49.98 |
| Sample 3 | 48.54 |

**Mean Value of Hardness for batch 4 = 49.29 HRM**

Fig.- 4.1.3 Hardness test Machine

# CHAPTER-5
## CONCLUSIONS

- The incorporation of coconut coir fiber into the epoxy matrix has shown an improvement in mechanical properties of the biocomposite.
- The tensile strength and flexural strength for batch 4 is higher than batch 3, which clearly indicates that the mechanical properties are increased with increasing percentage of coir fiber in the biocomposite.
- The tensile strength and flexural strength for batch 4 is higher than batch 2, which clearly indicates that mechanical properties are increased with increasing length of the fiber in biocomposites.
- The tensile strength of batch 2 is 29.07 MPa which is higher as compared to batch 3 which has a tensile strength of 27.73 MPa as batch 4 contains 10% coir fiber.
- The tensile strength of long fiber is 27.73 MPa which is higher as compared to short fiber which has a tensile strength of 25.22 MPa.
- The flexural strength of batch 4 is 38.67 MPa which is higher as compared to batch 13which has a flexural strength of 36.66 MPa as batch 2 contains 10% coir fiber.
- The flexural strength of the long fiber is 36.66 MPa which is higher as compared to short fiber which has a flexural strength of 34.55 MPa.
- The hardness for batch 1 is higher than batch 2, which clearly indicates that hardness is increased with increasing percentage of coir fiber in composite.
- The hardness of short fiber is 49.29 HRM which is higher as compared to long fiber which has a hardness of 40.26 HRM.
- On M-scale the hardness reading is 49.29 HRM which shows that coir fiber epoxy biocomposite will resists a localized plastic deformation induced by either mechanical indentation or abrasion.

# CHAPTER- 6
## SCOPE OF FUTURE WORK

There is a wide scope for future to scholars to explore the current research field. The present work can be further continued to study other aspects of composites like,

- Use of other natural fibres and their behavior on the basis of same parameters used here,
- Study of composite properties on the basis of different fabrication techniques other than hand lay-up method like spray up method, compression molding method, filament winding method etc. can be done.
- Evaluation and optimization of tribological, electrical, physical properties etc. and the experimental results can be analyzed..

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