CHAPTER 1

INTRODUCTION

1.1 MATERIALS FOR ENGINEERING APPLICATIONS

Conventional materials used in engineering applications are usually homogeneous in nature. They are being replaced by composite materials which are heterogeneous in nature, so as to achieve improved mechanical properties such as high specific strength, stiffness and toughness. Composite materials constitute of reinforcement materials having high load carrying strength embedded in matrix materials which are relatively weaker.

In recent years, fibers are used as reinforcement fillers for thermosetting and thermoplastic matrices to prepare the composites, which are termed as Fiber Reinforced Polymers (FRP). Thermoplastics for example Polyethylene, Polysterene, Polyamides, Nylons, Polypropylene and thermosetting plastics such as Polyester, phenolic epoxy resins are used as matrix materials.

Fibers act as reinforcement and improve the mechanical properties as well as corrosion resistance. For example, the glass fiber improves the mechanical strength and strength to weight ratio.

In fiber reinforced polymer composites, the fibers can be either synthetic fibers or natural fibers. Synthetic fibers for instance glass fibers are environmentally hazardous, whereas natural fibers such as bamboo, sisal, jute etc., are Eco friendly. Also, Natural fibers can improve mechanical properties considerably, in addition to their ability to be recycled at lower cost. The synthetic fibers used for reinforcement are glass, carbon, aramid, Kevlar etc. The fibers derived from natural resources like plants are termed as Natural fibers.

1.2 FACTORS AFFECTING THE SELECTION OF MATERIALS FOR ENGINEERING PURPOSES

The most important factor affecting selection of materials for engineering design is the properties of the materials in relation to their intended use. The properties of the material define specific characteristics of the material and form a basis for producing behaviour of the material under different conditions.

The important properties of materials are:

1. Mechanical e.g., stresses
2. Thermal e.g. heat or cold
3. Chemical e.g. atmosphere, water, chemicals
4. Electrical e.g. power, current
5. Radiation e.g. light, Ultraviolet, Nuclear.

1.2.1 Performance Requirements

The material of which a part is composed must be capable of embodying or performing a part's function without failure. For example, a component part to be used in a furnace must be of that material which can withstand high temperatures. While it is not always possible to assign quantitative values to the functional requirements, they must be related as precisely as possible to specified values of the most closely applicable mechanical, physical, electrical or thermal properties.

1.2.2 Material's Reliability

A material in a given application must also be reliable. Simply stated, reliability is the degree of probability that a product, and the material of which it is made, will remain stable enough to function in service for the intended life of the product without failure. A material if it corrodes under certain conditions, then, it is neither stable nor reliable for those conditions.

1.2.3 Safety

A material must safely perform its function; otherwise, the failure of the product made out of it may be catastrophic in airplanes and high pressure systems. As another example, materials that give off sparks when struck are safety hazards in a coal mine.

1.2.4 Physical Attributes

The size and weight are the attributes of the physical functionalities with respect to its natural behaviour with other sources.

1.2.5 Environmental Conditions

This is the surrounding area where the performance can be achieved to the optimum level. The parameters which affects the environment are chemicals and corrosion.

1.2.6 Availability

The availability of the materials for different applications may lead to improve the functionalities of the materials.

1.2.7 Disposability and recyclability

These are the newest of the constraints and increasingly important factors in materials selection. Example – nuclear materials.

1.2.8 Economic Factors

The cost is one of the main factors than the other factors. If it becomes apparent that this limit will be exceeded, the design will be changed to after materials requirements. This fact of limiting cost is as true in the aerospace field as in consumer products fields. The only difference is that the limiting cost of aerospace system is considerably higher than for consumer products.

The total original cost of a material for a given application is made up of two components: the cost of materials and the cost of processing the materials into the finished part or product.

1.3 TYPES OF MATERIALS

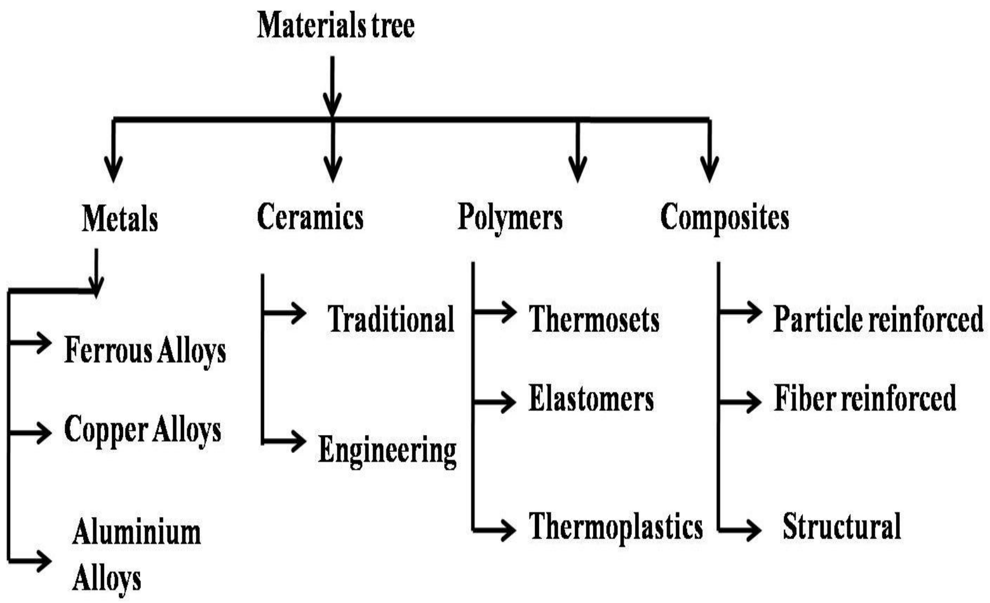


Figure 1.1 Classifications of materials tree

Figure 1.1 shows the classifications of materials tree. As depicted in Figure 1.1, the material tree is classified into four types as given in the following.

- Metals
- Ceramics

- Polymers
- Composites

A metal occupies 24% of the mass of the planet. The strength, melting points and ductility are the properties of metals. Thermal and conductivity is another two important properties of the metals. Metals are classified as ferrous alloys, copper alloys and aluminum alloys.

The name ceramics is derived from “Potter’s Clay”-a Greek word. In ceramics, hydraulic cement is used and metallic oxides are used as high temperature ceramic refractoriness. The properties of the ceramics are given in the following points as stated below.

Ceramics are generally hard and having toughness properties. They are having a high melting temperature. They have highly resistant to oxidation and its temperature is directly proportional to its strength.

1.4 COMPOSITES

Two dissimilar materials are combined to form composites. Fiberglass reinforced plastic is the best example for composite materials. This composite material can be used in may household applications.

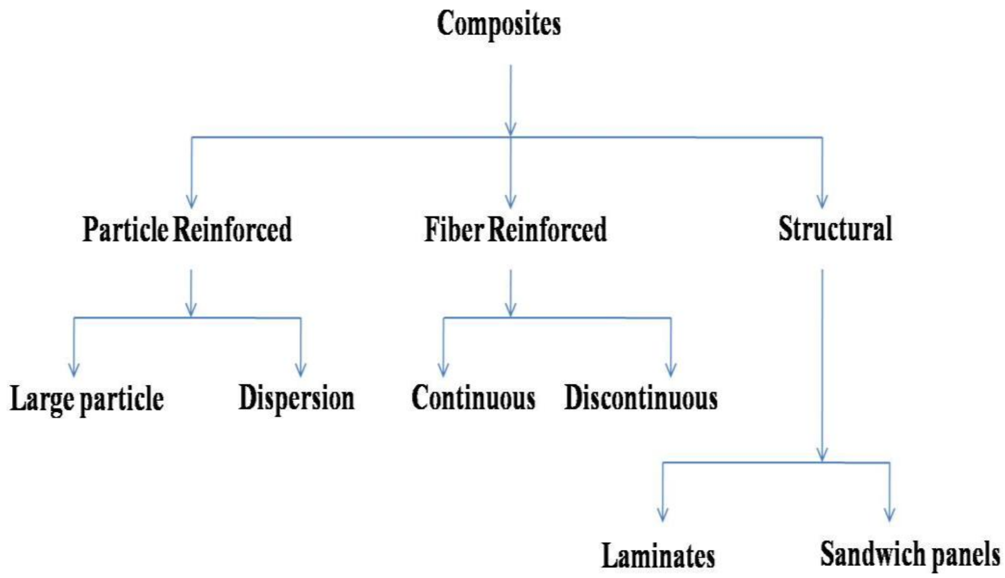


Figure 1.2 Classifications of composite materials

Composites can be classified into particle reinforced, fiber reinforced and structural as depicted in Figure 1.2. Further, particle reinforced composite can be classified into large particle and dispersion materials. The fiber reinforced composites can be divided into continuous and discontinuous materials. The structural composite material can be classified into laminates and sandwich panels.

1.4.1 Particle Reinforced Composites

Their particle dimensions are approximately equal in all directions. The large particle composite materials cannot be treated on the atomic a molecular level. Concrete is the subfamily of the large particle composite materials. The particles are small for the effective reinforcement in all directions. The mechanical properties of these reinforced materials can be improved by increasing the particle contents.

The dispersion composite materials are hard due to their uniform dispersion volume levels at all directions. This dispersed phase can be metallic or non-metallic.

1.4.2 Fiber Reinforced Composites

The fiber in case of a dispersed phase is called as fiber reinforced composites. They are high strength and high modules parameters. The strength behaviour of the fiber can be improved by reducing the length of the fibers. The mechanical characteristics of the fiber reinforced composites are based on the degree or the phase of the fibers. The fiber reinforced composites can be divided into continuous and discontinuous materials (Monteiro et al. 1998).

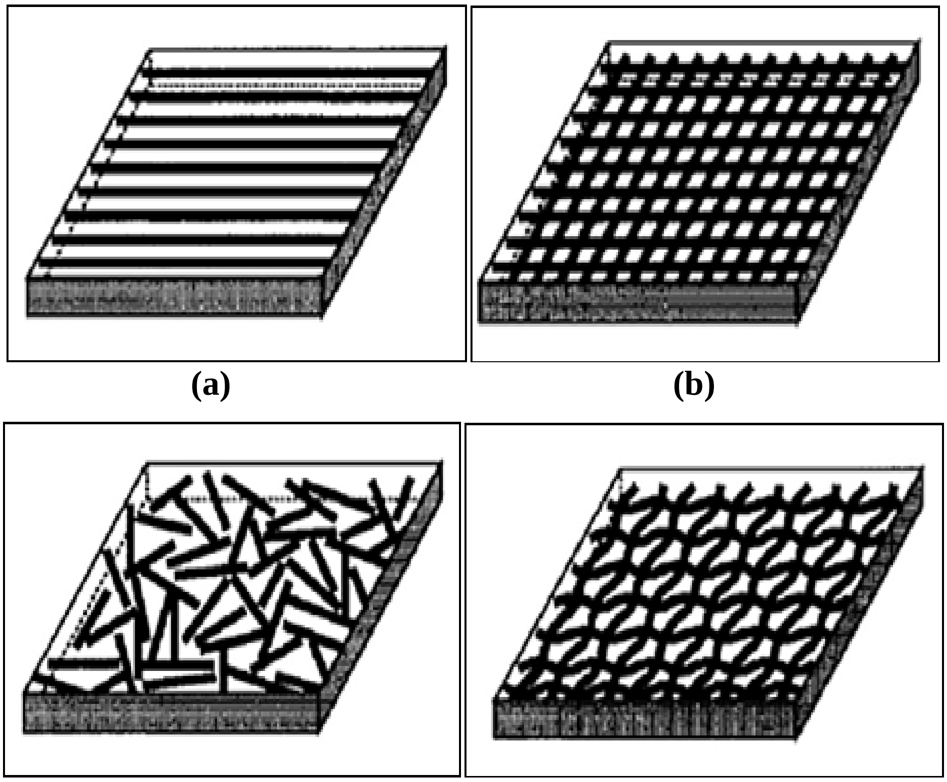
Wang et al. (2017) investigated and prepared two-layer reinforced carbon fiber (CF), i.e., Ag nanoparticles (Ag NPs)/graphene oxide (GO) reinforced CF (named as CF/Ag/GO) by using an electrochemical deposition and electrophoretic deposition (EPD). Interfacial shear strength, tensile strength, surface roughness and surface energy of the modified fiber increased depends upon nanosheets deposition. Eichhorn et al. (2001) was studied the mechanical properties of natural cellulose fibres and composite materials with different treatments.

Okubo et al. (2004) observed the mechanical properties of oil palm fiber with glass fiber and phenol formaldehyde as resin. The investigation revealed that maximum mechanical performance occurs at 40 weight% loading. Abdellaoui et al. (2015) analysed the tensile, flexural and impact properties of laminated composite based on natural jute fibres and epoxy resin.

Sukru Yetgin et al. (2008) was analysed the mechanical properties of adobes with addition of the fiber contents and also increased the strength. Pujari et al. (2014) was investigated that the natural fibers were an alternative resource to synthetic fibers, as reinforcement for polymeric materials for the manufacture is cheap, renewable and environment friendly. Natural fibers offer both cost savings and reduction in density when compared to glass fibers

The strain in the fiber and load are same in case of continuous fiber reinforcement materials. During low stress, both fibers and its matrix are similar in its natural behaviour. Further, the fibres in reinforced form can be classified into the following types of sub fibers as stated below and same is illustrated in Figure 1.3.

- Unidirectional fibers;
- Bi-directional fibers;
- Discontinuous fibers;
- Woven fibers;



(a) (b) (c) (d)

(Source: Tawfik et al. (2016))

Figure 1.3 Types of reinforced fibers as composite materials (a) Unidirectional (b) Bi-directional (c) Discontinuous fiber and (d) Woven

1.4.3 Structural Composites

It is the combination of homogeneous and composite materials. In general, the following composites are used as structural composite materials, which are mostly used in many industrial and household applications as stated below.

- Laminar composite materials
- Sandwich panels.

Laminated Composite Materials are stacked and having high strength, direction on each respective layer. This material can be composed by combining two dimensional sheets and both are aligned in a linear manner.

Sandwich Panels are constructed with by combining two strong outer sheets which are separated by lower stiffness materials. Most of the used sandwich panels, are aluminum alloys and titanium.

1.5 APPLICATIONS OF NATURAL FIBER COMPOSITES

The durability of natural fibers is higher than the other kind of fibers. The following are the applications of fiber composites with respect to its usage.

- Storage devices: post-boxes, grain storage silos, bio-gas containers, etc.
- Furniture: chair, table, shower, bath units, etc.
- Electric devices: electrical appliances, pipes, etc.
- Everyday applications: lamp shades, suitcases, helmets, etc.
- Low density: which may lead to a weight reduction of 10 to 30%
- Reduced fogging behaviour .
- Price advantages both for the fibers and the applied technologies.

Composites that use synthetic fibers are called Synthetic Fiber Reinforced Polymer Composites (SFRPC). They are high strength, which can be used in many automobile industries for their ruggedness and durability properties. They cannot be recycled is the major disadvantage of these materials. They are also not able to bio-degradable.

1.6 NATURAL FIBER REINFORCED POLYMER COMPOSITES

Natural Fiber Reinforced Polyester (NFRP) is one kind of glass made fiber as used as natural fibers in many industrial manufactured products production. They are low environmental impact with other materials and used as eco-friendly products as stated in Nilza et al. (2007).

Srinivas And Naidu et al. (2017) analyzed the behaviour of the natural fibers with respect to its mechanical properties with other resources. The environmental attentiveness was also concerned. The Tensile and flexural strengths of the natural fiber were depended on the fiber weight ratio. If, fiber load was increased both strengths also increased up to optimized level.

Rajesh et al. (2017) analyzed the buckling and free vibration behaviour of natural fiber fabric composite beam under axial compression experimentally. They observed free vibration results reveal that natural frequency reduced with increase in axial compression load in the pre-buckled region while it increases significantly in the post-buckled region.

Khanlou & woodfiled et al. (2017) studied and mapped out a window of suitable temperatures and consolidation times for compression moulding of a bio-composite using kinetic data and available models from the literature for thermal penetration, melt-fibre impregnation and thermo-chemical degradation of both fiber and matrix. They optimized manufacturing time of bio-composite fabrication and increased mechanical strength.

Maache M Bezazi et al. (2017) investigated a new lignocellulosic fiber extracted from Juncus Effusus L (JE). They fabricated with fiber reinforced polymer composite and it analyzed FTIR spectrum, XRD, thermogravimetric method compared with other polymer matrix composite materials. They observed it an alternative for conventional synthetic fibers such as glass fibers used in composite structures.

Girisha et al. (2012) developed a mechanism for analyzing the properties and behaviour of the materials which are used in may industrial manufacturing organization. The authors reported their mechanical behaviour using SEM images.

The improvements in properties, especially stiffness, can be obtained using chemical treatments of the fibers (Joffe et al. 2003 and Dash et al. 1999) analyzed the mechanical behaviour of the materials for improving the properties using various hot curing methods.

Dick et al. (2009) demonstrated the possibility of expressing each of the model parameters as a function of single variable that is stress ratio, maximum stress level, or a material-dependent constant. The study examined the fatigue properties of glass-filled polycarbonate when subjected to cyclic flexure loading. The results were then used to evaluate the prediction accuracy of an existing residual strength degradation model (the YL model). Kathrine et al. (2008) investigated the connection, if any, between the distribution of lignin and pectin and the loading of Pb and Zn on coir (mesocarp fibres from Cocos nucifera L.). The coir consisted mainly of xylem and a fibre sheath.

Rozman et al. (2001) analyzed the behaviour of the tensile and flexural strength for improving the strength of the materials. The composite materials such as maleated polypropylene and 3-(trimethoxysilyl) - propymethacrylate materials were used as the higher end behaviour of the composite properties. Mizanur Rahman et al. (2007) were observed that the alkali treatment of coir fiber reduced the hydrophilicity of the fiber and significant increased the tensile properties.

Glass fibers were used as the enhancing materials of the natural fibers which had psychical strength which enhanced the strength of the natural fibers after imposing the glass materials. Panthapulakkal & Sain et al. (2007) analyzed the characteristics of the thermal behaviour of the natural fibers which had hemp/glass fiber–PP composites. Sakthivel et al (2013) was investigated that the mechanical properties of natural fiber (Banana, Coir, Sisal) polymer composites and its automobile applications.

Christy Fernandez (2003) analyzed the coir fiber field which can be used in advanced fiber industries. The author's also analyzed coir amalgamated which were used in many automobile industries. The interior and exterior components were designed by this methodology proposed in this research work due to the improvement in mechanical behaviour of the strength. The stability and durability of the coir fibers are also improved by coir amalgamated mechanism.

The renewable natural resources are otherwise called as natural fibers. They are having high strength for many important applications where light weight is required. The advantages of Natural Fiber Reinforced Polymer composites (NFRPC) are higher than the advantages of glass fibers as stated in Joshi et al. (2001). The major defect with natural fibers is that presence of moisture. The water absorption capacity of the natural fibers results in moisture content which in turn influences the mechanical and physical properties. Hence, researchers are studying the water absorption behaviour of NFRP and its influence on mechanical properties.

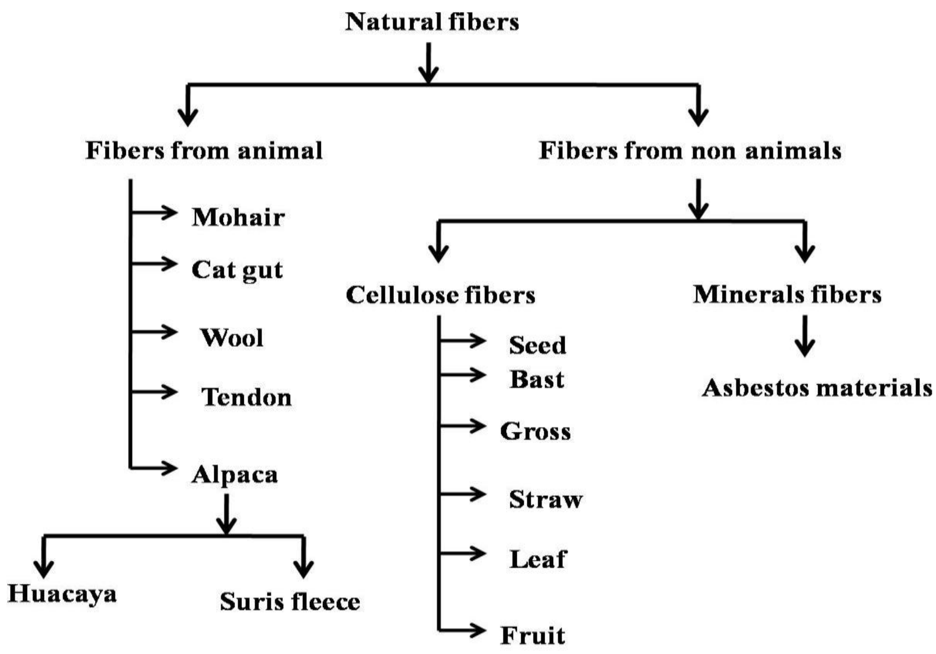


Figure 1.4 Classifications of natural fibers

As shown in Figure 1.4, the natural fibers are categorized into fibers from animal and fibers from non animals. Fibers from an animal can be Mohair, Catgut, Wool, Tendon and Alpaca.

Similarly, fibers from non animal can be classified as cellulose fibers and mineral fibers. The cellulose fibers can be from Seed, Bast, Gross, Straw, Leaf and Fruits.

The classifications of cellulose fibers are shown in Figure 1.5.

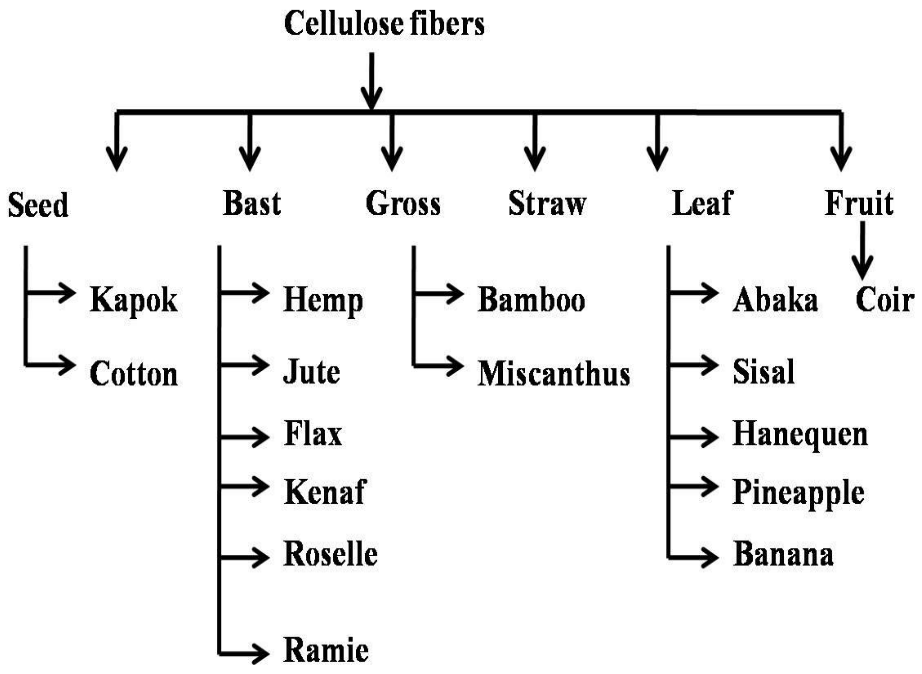


Figure 1.5 Classifications of cellulose fibers

Table 1.1 shows the various fibers and its type, common, family and scientific name. Table 1.2 shows the mechanical properties of natural fibers.

Table 1.1 Fibers and its type, common, family and scientific name

Type	General Name	Family Name	Scientific Name	Uses
Bast Fibers	Hemp	Cannabaceae	Cannabis sativa	Cordage, high-grade paper, fire hoses, sandals
	Jute	Tiliaceae	Corchorus capsularis	Cordage
	Flax	Linaceae	Linum usitatissimum	Cordage, high-grade paper
	Kenaf	Malvaceae	Hibiscus cannabinus	Tires, fire hoses, sandals
	Roselle	Malvaceae	Hibiscus sabdariffa	Bagging, seed oil
	Ramie	Urticaceae	Boehmeria Nivea	Cordage, bagging

Table 1.1 Continued

Leaf Fibers	Abaka	Musaceae	Musa textilis	Marine cordage, paper, mats
	Sisal	Agavaceae	Agave sisalana	Cordage, bagging, coarse fabrics
	Henequen	Agavaceae	Agave fourcroydes	Cordage, bagging, coarse fabrics
	Pineapple	Bromeliaceae	Ananas comosus	Cordage, coarse fabrics
	Banana	Musaceae	Musa mannii	Bagging, coarse fabrics
Fruit Fibers	Coir	Arecaceae	Cocos nucifera	Rugs, mats, brushes
Seed Fibers	Kapok	Bombacaceae	Ceiba pentandra	Upholstery padding, flotation devices
	Cotton	Malvaceae	Gossypium arboreum	Textiles, paper, seed oil
Gross fibers	Bamboo	Gramineae	Bambusoideae	Medicinal purposes, scaffolding
	Miscanthus	Poaceae	Miscanthus X giants	Feedstock production
Straw	Corn	crane	Zea mays	Corn cobs, oil
	Wheat	Graminae	Triticum	Bread flour

(Source: Ashik et al. 2015)

Table 1.2 Mechanical properties of natural fibers

Fiber	Density	Young's modulus (GPa)	Tensile strength (MPa)	Elongation at break (%)
Flax	1.54	27.5 – 85	345 – 2000	1 – 4
Ramie	1.5 – 1.56	27 – 128	400 – 1000	1.2 – 3.8
Hemp	1.47	17 – 70	368 – 800	1.6
Jute	1.44	10 – 30	393 – 773	1.5 – 1.8
Sisal	1.45 – 1.5	9 – 22	350 – 700	2 – 7
Coconut	1.15	4 – 6	131 – 175	15 – 40
Cotton	1.5 – 1.6	5.5 – 12.6	287 – 597	7 -8
Nettle	1.51	24.5 – 87	560 – 1600	2.1 – 2.5
Kenaf	1.2	14 – 53	240 – 930	1.6
Bamboo	0.6 – 1.1	11 – 17	140 – 230	-
Carbone	1.4	230 – 240	4000	1.4 – 1.8
Coir	1.2	30	175	4 – 6

(Source: Celino et al. (2014) Brancifort et al. (2009) and Murali Mohan Rao et al. (2007)

1.6.1 Fibers construction

Natural fibres are mainly composed of cellulose, hemicellulose, lignin, pectin and other extraneous materials and are characterised by a cellular structure. Each cell has one external wall and three side walls containing crystalline cellulose regions called microfibrils which are interconnected via the lignin and hemicellulose fragments. The individual cells are known as elementary fibres. The cell walls are defined by the concentration of constituent materials and the microfibrilar angle. The cellulose microfibrils are almost parallel to the elementary fibre in the inner part of the secondary cell wall (0-2°), helical in the outer part of the secondary cell wall (25-30°) and helical in the primary cell wall (70-90°). The lumen is hollow and allows the transport of moisture and nutrients within the plant by a capillary action which can also lead to the ready absorption and retention of internal moisture which is enhanced by the presence of lignin and hemicellulose. The primary cell wall is rich in lignin and pectin with decreasing volumes of lignin towards the inner part of the fibre**.**

1.6.2 Bonding between fiber and matrix

There can be a lack of interfacial adhesion between hydrophilic natural fibres and hydrophobic matrix solutions such as polyester. Chemical modification is widely considered to be necessary to improve the adhesion between hydrophilic natural fibre reinforcement and hydrophobic polymer matrix solutions. However, it has been shown that some treatments are toxic and potentially harmful to the environment.

The alkali treatement is used for changing the molecule behaviour of the fibers. The relation between fiber matrix is analyzed by using its covalent bond in all kind of fiber resources.

1.7 BAMBOO FIBER

Fibers which are obtained from bamboo plant are called as bamboo fibers. They are having a high moisture absorption with high numbers of micro gaps and holes. Apparel made from bamboo fiber is crowned as Air Conditioning Dress. The main application of the bamboo materials is medical applications and many industrial applications. In case of medical applications, many instruments and products are developed which can be used in curing diseases in patients, as a cost effective product. In the case of industry applications, the bamboo materials are used in making industrial products.

Bamboo fibers are very soft in nature and they have a very smooth structure on it. Bamboo materials can be used as best antibacterial materials which are anti fungal products. Many research results proved that bamboo materials can reduce the death ratio to below 70% by implementing the bamboo materials to many hospitals or primary health centers. The fabrics which are made from bamboo materials are sustain its natural behaviour after long usage.

1.7.1 Properties of Bamboo Fiber

The bamboo is in its size, lightness and strength an extreme product of nature. It is stable in nature and is used for structural and constructional applications owing to its light weight properties.

With respect to the above said characteristics of the bamboo fibers compared to other natural fibers, it is much better for reinforcement process related to various engineering sources.

Bamboo is able to resist more tensile than compression. Slim tubes are in this occasion superior, too. Inside the syllabicated outer skin one can find axial-parallel extremely elastically Fibers with a tensile strength up to 40kN/cm^2. As a comparison: extremely strong wood Fibers can resist a tension up to 5 kN/cm^2 and steel St37 can resist as highest possible a tension of 37 kN/cm^2.

1.7.2 Applications of Bamboo Fiber

The various applications of bamboo fibers are stated in the following.

- The building roads can be constructed using bamboo materials which increases the mechanical strength.
- Bamboo materials can be used in many medical applications. Kidney diseases can be cured and treated by implementing bamboo materials as one of the main components.
- Many houses, schools and industries can be constructed with the help of bamboo materials as main agent materials in construction.
- Bamboo materials can be used in constructing cloths and jewels.

- Bamboo materials can be used as Eco friendly and environmentally safe materials which are used in constructing the household appliances.
- Toys are constructed with the help of bamboo materials which increases the life of the constructed toys.
- Many musical instruments are developed using bamboo materials.

1.8 SISAL FIBER

Sisal fiber is one kind of natural fiber and it is obtained from the sisal plant. They are highly cultivated in India when compared with other countries. Its family name is Agave Sisalana. Sisal leaf in sisal contains long and straight fibers. These fibers from the sisal plant (Figure 1.6) can be removed using the process of decortications.

Figure 1.6 Illustration of sisal plant

Many industry need sisal fiber as its main component which requires three levels of grades as Grade 1, Grade 2 and Grade 3.

Grade 1

It is otherwise called as lower grade, which is used in many paper manufacturing companies, due to its availability of high volume cellulose components.

Grade 2

It is otherwise called as medium grade, which is used in manufacturing of ropes and agricultural products.

Grade 3

It is otherwise called as high grade fibers which are used in the carpet industry.

1.8.1 Properties Of Sisal Fiber

The mechanical property of sisal fiber is given in the following points.

The main advantage of sisal fiber is that the biogradability capacity of sisal fiber is higher than other fibers. The strength of the materials in terms of tensile, flexural and water absorption are high in the case of sisal fibers compared to other natural fiber sources. They are very hard and durable. They required minimum maintenance with low cost. They are having various colors in its nature. Sisal fibers are recycled and can be used again with other products. They are having good absorption strength properties and are anti static. They have high moisture resistance.

The chemical components of the sisal fiber are cellulose (65%), hemicelluloses (12%), lignin (9.9%) and waxes (2%).

1.8.2 Applications of Sisal Fiber

Sisal fibers can be used in many applications from commercial to home daily applications as stated below.

The cargo section in shipping industries requires sisal fibers. Elevators require sisal products for higher lubrication and durable properties. They are used in many homes held products at craft manufacturing etc., Sisal fibers can also be used in the automobile industry with a variety of applications. Sisal materials can be used in textile product development as depicted in Figure 1.7.

Figure 1.7 Usage of sisal in textile products

1.9 FIBER PREPARATION USING BAMBOO/SISAL MATERIALS

A good wetting of the fibers with the matrix is obtained by interfacing bonding and the formation of a chemical bond between the fiber surface and the matrix. The treatment of fibers with mechanical behaviour of the materials are done with respect to various products and natural sources. Mwaikambo LY et al. (2002) developed a mechanism for analyzing the behaviour of the fibers using sodium hydroxide.

The sodium hydroxide opened up the cellulose structure allowing the hydroxyl groups to get ready for the reactions. During washing with sodium hydroxide, the wax, cuticle layer and part of lignin and hemi cellulose are removed. The link and reference between surface treatment process is analyzed for improving the behaviour of the natural fibers.

The fibers from different natural sources are immersed with alkali liquid for a period of one complete day. Then, NaOH solution can be applied on these materials to smooth the surface. Finally, these solution immersed fibers are dried for the whole day at room temperature.

The reinforcement materials are treated for the production of equipments in industry needs. The bamboo and sisal fiber are arranged in a mold 250*250*3mm. The resin was degassed before pouring and air bubbles are removed carefully in the roller.

Hybridization on tensile properties of sisal, bamboo fibers with epoxy resin were studied by Girisha et al. (2012). The technical analysis was made by authors in order to improve the mechanical behaviour of the materials. Studies were made to improve fiber quality or reducing the effect of the presence of fiber defects in the final material via improved processing or fiber treatment. The improvements in properties, especially stiffness, can be obtained using chemical treatments of the fibers (Hassan et al. (2000)). The strength and modulus of the longitudinal composites in tensile and flexural loading increased with fiber content as predicted in accordance with the rule of mixtures.

1.10 ORGANIZATION OF THE THESIS

The thesis has been organized as follows

Chapter 1: Introduction This chapter gives an introduction about NFRP composites, and explains the properties of bamboo and sisal fibers and its characteristics in detail.

Chapter 2: Literature Survey The natural fiber reinforced composites and its behaviour with its properties are discussed in this chapter. The conventional methodologies are also discussed.

Chapter 3: Study on Mechanical And Water Absorption Properties of Sisal/Bamboo Hybrid Composites

In this chapter, the mechanical and water absorption behaviour of sisal and bamboo incorporated hybrid composites materials are studied. Initially, the optimum fiber length and weight percentage are determined. To improve the tensile, flexural, impact properties, sisal fiber is hybridized with untreated bamboo fiber. Morphological analysis is carried out to observe fracture behaviour and fiber pullout of the samples using scanning electron microscope. A detailed report about this is given in this chapter.

Chapter 4: Study on Mechanical and Water Absorption Properties of Alkali Treated Sisal/Bamboo Hybrid Composites In this chapter, the effects of fiber treatment and concentration on the mechanical properties of short bamboo/sisal reinforced polyester hybrid composite are investigated. The mechanical properties of composites with treated fibers are compared with untreated fiber composites. The fractured surface of the treated fiber composite specimen is studied using Scanning Electron Microscopy (SEM).

Chapter 5: Mechanical Properties of NFRP Hybrid Composite: Modeling and Optimization In this chapter, emphasis is given for predicting and optimizing the mechanical properties of short bamboo/sisal fiber reinforced hybrid polyester composite using Neuro-fuzzy modeling and Genetic algorithm (GA) method. The better tensile property with optimum fabrication parameters are obtained by the single objective optimization method of GA. The mechanical properties of the natural fiber hybrid polyester composite can be predicted within the ranges of fabrication parameters using Neuro-Fuzzy modeling.

Chapter 6: Conclusion And Future Works This chapter concludes this research work and states the future scope of this research.

1.11 SUMMARY

In this chapter, a brief introduction about NFRP composites, and their classifications, advantages and its applications of natural fibers are stated and discussed. The properties of bamboo and sisal fibers are explained in detail. The organization of the thesis is also highlighted.