2

Review of Literature

The Literature reviewed for the study is expressed under the following headings

2.1 Natural Fibre and its Classification

Environmental challenges are growing every day, and this has led the researchers to focus their explorations on eco-friendly, green, and biocomposite materials. The fibres are both natural and artificial, but the latter destroys the environment due to their non-biodegradable and polluting nature. This has led to the use of natural fibre-based composites. Natural fibres are being used as reinforcements along with the polymer matrix for composite manufacturing. For thousands of years, plant fibres have been a kind of renewable source that has been renewed by nature within their variation in properties and characteristics (Ramesh *et al.*, 2017). The degradable biomaterials are used to reduce environmental pollution (Sun *et al.*, 2017). Natural fibres are advantageous because of their high performance in their mechanical properties, easy availability, renewability, recyclability, carbon dioxide neutrality, non-toxicity, low energy consumption, and low cost (Morales *et al.*, 2017). These fibres are also potential alternative materials for the composite industry, owing to their flexibility, eco-friendly nature, low cost, renewability, and local availability (Stevens and Mussig 2010).

The fibres are classified according to their origin and are divided into natural fibres and synthetic fibres. Natural fibre is extracted from plant, animal, and mineral sources (Ahmad *et al.*, 2019). The increase in awareness of environmental damage caused by synthetic materials has led to the development of eco-friendly materials. Natural fibres are sustainable materials that are easily available in nature and have several advantages, such as low cost, lightweight, renewability, biodegradability, and sustainability (Thyavihalli *et al.*, 2019).

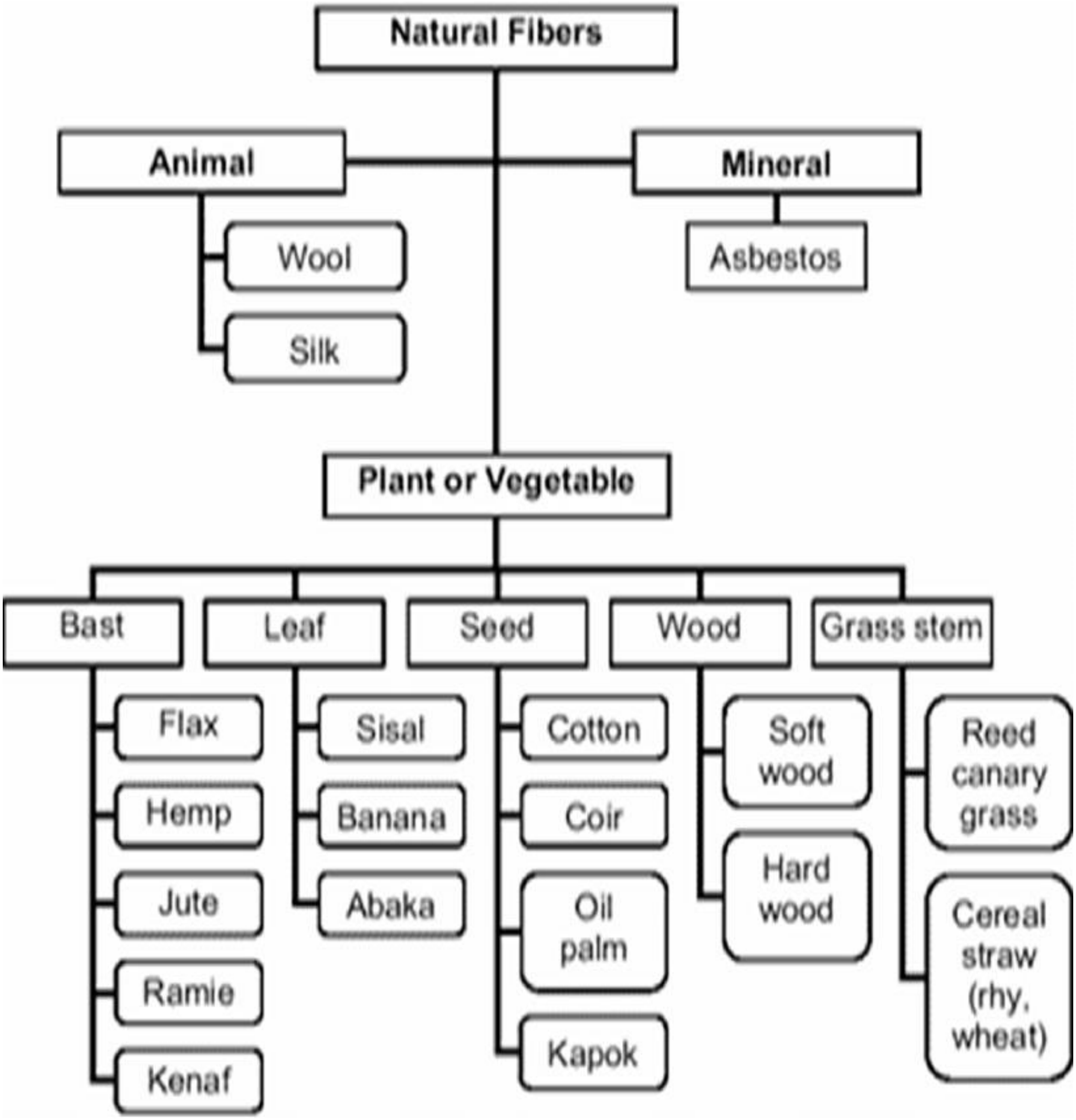
Fibres are classified into natural and synthetic fibres. Natural fibres include animal, cellulose, and mineral fibres. Animal fibre: silk, wool, hair; Mineral fibre: asbestos; Cellulose fibre: bast fibre: jute, flax, hemp, ramie, kenaf, Roselle, Mesta; Leaf fibre: sisal, banana, abaca, palf, henequen, agave, Raphia; Seed fibre: kapok, cotton, loofa, milkweed;

Fruit fibre: coir and oil palm; Wood: soft wood, hard wood; Stalk fibre: rice, wheat, barley, and maize; Grass/reeds: bamboo and bagasse. Synthetic fibre includes organic and inorganic fibre. Organic fibres including aramid/kelver, polythene, aromatic polyester; Inorganic fibres: glass, carbon, boron, and silica carbide (Saba *et al.,* 2014). Natural fibres like oil palm, sisal, flax, and jute are getting attention from researchers and academicians to be utilised in polymer composites due to their eco-friendly nature and sustainability (Mohammed *et al.,* 2015). In recent years, more renewable plant resources have been discovered and used due to the scarcity of non-renewable resources (Campilho, 2016). Though the strength of natural fibre is not as great as that of glass, some of the specific properties are comparable (Simmon, 2010).

The chemical properties vary between all natural fibres. Cellulose is more common in sisal, hemicellulose in bamboo, and Lignin in piassava fibre. The density of the natural fibres is low as compared to the synthetic fibre. Because of this property, natural fibres are mostly used in many fields and considered an alternative to synthetic fibres (Naidu *et al.*, 2017).

Plant fibres are important types of natural fibres that mainly comprise cellulose, hemicellulose, pectin, and lignin. Prominent natural fibres are cotton, jute, flax, ramie, sisal, and hemp (Sonkar and Singh 2019). Utilizing natural polymer and bio fibres bio degradable composites can be produced. Natural fibre reinforced composite materials are expanding quickly with majority of applications due to industrial use. Examples of these materials are green composites made with banana, coir, pineapple leaf and sisal fibre (Gurajala *et al.*, 2023). These are used in the automotive sector and possess several benefits, such as weight and price reduction, recyclability, renewability, and being environmentally friendly. (Siakeng *et al.,* 2019). Each fibre has its own property and is used for various purposes. Coconut fibre is used to make furniture in cars, while cotton is used for noise cancellation. Wood fibre is used as furniture and accessories in vehicles, while flax and hemp are used in the refining of seatback linings and floor panels (Holbery and Houston, 2006). These natural fibres obtained from the different portions of the plant, like the leaf, bast, fruit, and seed, have unique properties.

Geo-polymers are aluminosilicate inorganic polymers formed by the polymerisation of aluminosilicate with alkaline solutions. Geo-polymer has several desirable attributes, which include good mechanical properties and durability (Duxson *et al.,* 2007).



(source : Ekundayo and Adejuyigbe 2019)

Figure.i Classification of Natural Fibres

2.1.1 Leaf Fibres

Leaf fibres are the coarse and hard fibres that are extracted from the leaf portion of the plant by hand scraping after beating, retting, or mechanical extraction. Due to their relatively high strength, these fibres are typically used for the production of ropes, fabrics, carpets, and mats (Kumar *et al.,* 2017b). Sisal is a xerophytic, monocarp, semi-perennial fibre-producing plant. The leaves are thick, fleshy, and often covered with a waxy layer, which are the typical characteristics of xerophytic plants (Sarkar and Jha 2017). These fibres are being used in civil construction as reinforcement in thermoplastics and elastomers (Melo *et al.*, 2019). It contains cellulose, lignin, hemicellulose, and moisture (Naveen *et al.*, 2016). It is a strong, stable, and versatile material and has been recognised as an important source of fibre for composite making (Saha *et al.,* 2016). In recent years, there has been an increasing interest in finding new applications for sisal-fibre-reinforced composites (Ali *et al.,* 2016). As it finds its use in carpets or in blends with wool and acrylic for a softer hand (Pickering *et al.,* 2016).

Among the different natural fibres, pineapple leaf fibres show good mechanical properties. They are multicellular and ligno-cellulosic fibres and are used for automobiles, textiles, and construction. These fibres are treated and surface modified for making conveyor belt cord, airbags, and advanced composites too (Paridah *et al.,* 2004). The plant *Agave americana* is a monocotyledon normally grown in tropical, subtropical, and temperate regions of the world. *Agave Americana* is abundantly available in nature and is characterised by low density, tenacity, and moisture absorbency in comparison with other natural fibres (Hulle *et al.,* 2015). It is primarily known as a succulent plant. Plant-based fibres are widely available around the world and being studied due to their properties, including biodegradability, biocompatibility, higher strength, higher aspect ratio, low density, low cost, good availability, and reduced health hazards (Krishnadev *et al.*, 2020). These fibres run along the length of the plant's leaves and are part of the vascular system. These are bound to qualify as a potential source for technical textiles after fabrication as composites and nonwovens (Prabhakar, 2012).

2.1.2 Bast Fibres

Bast fibres are extracted from the phloem which is located at the stem of the fibrous plant. Epidermis, shives, woody core, and a combination of xylem must be removed in order to obtain the bast fibres (Lee *et al.,* 2020). Kenaf fibre is a cellulosic fibre that has both economic and ecological advantages as it can be grown in a varied environment and the growth of the plant is very promising (Akil *et al.,* 2011). These are mainly used for paper and rope production (Hamidon *et al., 2019).* Nowadays, these fibres are made into composites along with other materials (Nishino *et al.,* 2003). Banana fibre is composed of mainly carbohydrates and protein, which makes it a high-strength fibre, but it also has a high content of water uptake. Hemp is one of the plant species grown mainly in Europe and Asia. These fibres are used in rope, textiles, dandelion, and an assortment of materials, and in recent years, they have been used to fabricate different composites (Li *et al.,* 2006).

Abutilon indicum, a medicinal plant that belongs to the family 'Malvaceae', commonly known as Thuthi/Atibala or "Kanghi" in Hindi, is a native plant of South Asia. It is an erect, woody, and shrubby plant widely distributed in tropical countries (Sasikala and Meena 2018). The plant is found in India, Sri Lanka, topical regions of America and Malesia, sub-Himalayan tracts (Shekshavali and Roshan 2016), hills up to 1200 m, and in hotter parts of India (Raut and Bandawane, 2018)

Jute is a natural cellulose fibre and is also called the golden fibre." Jute is the second-most important vegetable fibre after cotton. It has high tensile strength with low extensibility, which helps to make the best-quality industrial yarn and fabric suitable for packaging (Zakaria *et al.,* 2016). The flax fibres are from the prehistoric period and are mainly used to produce linen (Ruan *et al.,* 2015). These are cellulosic plants but are more in crystalline form, making them stronger, crisper, and stiffer to handle. These fibres are used in furniture materials, textiles, bed sheets, linen, interior decoration, and accessories (Angelini and Tavarini, 2013). Ramie is one of the herbaceous perennial plants that have been extensively used as one of the textile fabrics for over a century. The fibres extracted from the stem are the strongest and longest of the natural bast fibres. These fibres have good absorbency and coarseness. It also has low elasticity and dye affinity (Nam and Netravali, 2006).

2.1.3 Seed Fibres

The fibres sourced from the outer part of the seeds are called seed fibres, and these fibres are used as ropes, mats, fabrics, and carpets (Kumar *et al.,* 2017b). Cotton, which belongs to the sub-tribe Hibisceae and family Malvaceae, is an important agricultural crop and a commonly used natural fibre for the production of cloth (Elmogahzy and Farag, 2018) The cotton fibre is extensively used in textile industries, and recently attempts have been made to develop composites for industrial applications (Cheung *et al.,* 2009). Kapok *(Ceiba Patendra) fibre is* cultivated in Malaysia for its seeds; the fibres obtained from it are used as fillers for pillows and mattresses (Koay *et al.,*2015). This fibre is cellulosic, light-weight, and hydrophobic (Prachayawarakorn *et al.,* 2013). Conventionally, kapok fibre is used as buoyancy material, oil-absorbing material, reinforcement material, adsorption material, and biofuel (Tye *et al.,* 2012).

2.1.4 Fruit Fibres

Among the different natural fibres, coir fibres are the thickest. These are strong fibres and have attracted scientific and commercial importance for their specific characteristics and availability (Sen and Reddy, 2011). Coconut fibre has higher lignin and lower cellulose and hemicelluloses and exhibits valuable properties, such as resilience, strength, damping, resistance to weathering, and high elongation at break (Muensri *et al.,* 2011). Coconut husk from the coir fibre industry is used in the manufacture of building boards, roofing sheets, insulation boards, building panels, lightweight aggregate, composite reinforcements, cement boards, and geo-textiles.

The *arecanut* plant belongs to the species *Areca Catechu Linnaeus in* the family *Palmaceae.* Among all the natural fibres, *Arecanut* fibre, a type of nut shell fibre, is more promising because it is inexpensive, derived from a very high-potential perennial crop, abundantly available in the Garo hills of Meghalaya, and has limited applications (Mishra and Das, 2019). Areca sheath fibre finds applications in both structural and non-structural product preparation in the packaging, automobile, and construction fields (Ashok *et al.,* 2018). Also, these fibres are used for making value-added items like fluffy cushions and thick boards (Islam *et al.,* 2018). But *Areca* fibre needs to be treated before being used for composites to reduce moisture absorption (Padmaraja *et al.,* 2013).

The date Palm fibres are potential cellulosic fibre sources which are extracted from lea branches and are used as reinforcements for thermoplastic and thermosetting polymers. Some researchers have found their application in the automobile industry (Alawar *et al.,* 2009). Palm fibre-reinforced composites treated with chemical treatment enhanced tensile strength and elastic modulus, which was due to improved adhesion between the fibre and matrix (Abdal-hay *et al.,* 2012). Sugar palm fibre-reinforced composites treated with chemical treatments have increased impact properties (Bachtiar *et al.,* 2009). Various underutilised and nonconventional fibres fulfil the properties required for composites.

2.1.5 Grass Fibres

Bamboo fibre is also known as natural grass fibre due to the alignment of fibres in the longitudinal directions. Bamboo has been traditionally used for making houses, bridges, and traditional boats and is commonly used for its properties such as light weight, low cost, high strength, and stiffness. The fibres extracted from bamboo are also used as reinforcement for making advanced composites in various industries (Deshpande *et al.*, 2000). Bamboo fibre composites are fabricated using various methods, such as hot press, cold press, injection moulding, and other moulding techniques (Zakikhani *et al.*, 2014). The specific compressive strength of Bamboo PLA composite is enormous, which could find its use in aerospace engineering. This combination can be a good alternative to E-glass or epoxy composites, wood materials, or aluminium alloys. Their high mechanical properties have potential in the energy or automotive industries as well (Morales *et al.*, 2017).

2.2 Properties of Ecofriendly and Manmade Fibres

Natural fibres are biodegradable, renewable, widely available, and have a neutral CO_2 emission. Their properties include great mechanical strength, modulus, and moisture absorption, along with low density, elongation, and elasticity. These fibres involve relatively low production and processing costs, which puts them in a position of important economic focus in developing countries (Osorio *et al.*, 2019). The materials, namely jute, sisal, flax, kenaf, and hemp, are used in various industrial applications due to their outstanding mechanical features, low cost, high strength, eco-friendliness, and biodegradability (Alkbir *et al.*, 2016). Chemical properties of natural fibres have their own significance, as cellulose present offers superior mechanical properties (Sajith *et al.*, 2017); hemicellulose is very hydrophilic, reducing water sorption and enhancing thermal stability; the lumen is a hollow central cavity in a fibre cell, and is responsible for density reduction, increasing thermal insulation, and noise reduction properties (Reddy and Yang, 2005). Nowadays, natural fibre composites have gained increasing interest due to their eco-friendly properties (Prakash *et al.*, 2014).

Although natural fibres are cheap compared to artificial fibres, there is a possibility of biodegradation in the long run (Ramesh *et al.*, 2017). The use of natural fibres in civil engineering applications is limited, mainly due to their tendency to degrade under different environmental conditions (Sameer, 2014). Despite their relative advantages, geotextiles based on natural fibre find limited use in many engineering projects because of their relatively low tensile strengths and their susceptibility to biological, chemical, and physical degradation (Saha *et al.,* 2016). Man-made fibres can be defined as fibres manufactured by industrial processes (Bansal and Raichurkar, 2016). Polyester is a fibre composed of linear macromolecules having a chain length of 85–5 percent, a diol, and terephthalic acid. Polyester, commonly known as polyethylene terephthalate (PET), has become the world's major man-made fibre (Bansal and Raichurkar, 2016). Due to their superior mechanical properties, ability to be recycled, low cost, and ease of processing, PET fibres are extensively used in various textile and technical applications (Ciera *et al.,* 2014). Polythene terephthalate fibres are highly transparent and colourless, but thicker sections are usually opaque and off-white (Dinesh and Rao, 2017). PET has undesirable properties such as pilling, static, and a lack of dyeability associated with its hydrophobic nature (Kumar *et al*, 2020b).

2.3 Fibre Surface Modification Types and Their Importance

To achieve a strong fibre-matrix interfacial adhesion there is an absolute need for the fibres to be treated either by using physical or chemical methods. The uses of physical and chemical methods optimize the interface between the fibre and the matrix. These modification methods are of different efficiencies for the adhesion between matrix and fibre (Kayode 2015). So, to modify their physical, chemical, and morphological properties, these fibres should be given appropriate treatments. It improves the strength and bonding between matrix and fibre, which leads to improved mechanical properties (Shireesha *et al.,* 2019).

2.3.1 Need for Surface Modification

The natural fibres are highly sensitive to moisture content, resulting in delamination between the matrix and fibre, thereby reducing the mechanical properties of the composite structures (Yang *et al.,* 1996). This is due to the fact that the presence of non-cellulosic components such as pectin, lignin, and hemicelluloses in them makes them polar and hydrophilic, making them water absorptive (Saheb and Jog, 1999). Differences in the performance of natural fibres are due to environmental conditions that include sun, rain, soil conditions, and the amount of water the plant receives during its growth (Atiqah *et al.*, 2019). However, the problems regarding the utilisation of natural fibres in the composite can be solved by physical and chemical modifications. Various treatments namely physical, chemical, and biological, would improve the surface roughness, thereby improving adhesion properties between the fibre and the matrix, leading to an increase in strength or other essential properties of composites.

2.3.2 Physical Treatment

Modification of natural fibres is essential in transforming the fibre surface properties to improve their properties like stability, high moisture absorption, and adhesion with different matrices in composite manufacturing (Franco and González 2005). The physical treatment methods involve corona discharge, plasma, ionised air, ultraviolet radiation, electron radiation, and thermal treatment (Ahmad *et al.,* 2019). Plasma treatment is a physical technique that has been successfully utilised to modify the surface of various natural fibres, significantly improving their mechanical properties (Oliveira *et al.*, 2012). Ultraviolet radiation increases the wettability of the fibres, resulting in improved mechanical properties of the composite structures (Khan *et al.*, 2004).

2.3.3 Chemical Treatment

The development of newer fibres has led to the replacement of materials like glass and carb-n-reinforced composites with natural fibre-reinforced composites. The hydrophilic nature of natural fibres makes them incompatible with thermoplastics, which results in poor mechanical properties in the composites. Therefore, the modification of natural fibres is required to make them less hydrophilic (Sepe *et al.,* 2018). The chemical treatment improves the interfacial adhesion between the fibre surface and the polymer matrix. Various types of chemical treatments on natural fibres include alkaline treatment, silane treatment, acetylation treatment, peroxide treatment, benzoylation treatment, potassium permanganate treatment, and stearic acid treatment (Kalia *et al.,* 2009).

The silanes used are amino, methyl, and lkyl glycidoxy silanes and glycidoxy silanes that increase the hydrophobicity of natural fibres and the strength of natural fibre composites (Rachini *et al.*, 2012). Fibre surface modifications are carried out using various chemicals such as alkali, acetic anhydrate, potassium permanganate, peroxides, silane, and benzoylchloride (Mukesh and Godara, 2019). Chemical treatments are considered when modifying the fibre structure's properties (Srinivasa and Bharath, 2011). Chemical treatments can significantly improve the mechanical properties of natural fibres by modifying their crystalline structure as well as by removing weak components like hemicelluloses and lignin from the fibre's structure (Shahidi *et al.*, 2013). These can also improve the fibre/matrix interfacial interactions through the formation of strong chemical bonding, which results in a significant improvement in the mechanical performance of composites (Cruz and Fangueiro, 2016).

Alkalization

Alkalization is an effective process to improve fibre-matrix interaction, thermal stability, and heat resistance (Zin *et al.,* 2018). The surface-treated fibres, when reinforced into composites, hold higher degradation temperatures, resulting in improved thermal stability (Margabandu and Senthilkumar 2020). The natural fibre consists of lignin, pectin, waxy materials, and natural oils, which cover the outside layer of the fibre cell wall (Liu *et al.,* 2004). The chemical treatment alters the structure of the natural fibres. Sodium Hydroxide (NaOH), is the most commonly used reagent for this process. The alkali reagent is used to alter the structure of the cellulose in the plant fibres by cleaning the surface, and the process is called alkalization. The alkali treated fibres have better fibre adhesion, leading to an increase in interfacial energy and thus enhancing the thermal and mechanical properties of composites (Mwaikambo and Ansell, 2002). The alkali treatment changes the colour of the bleached fibres and also imparts crimp to the fibre (Ki *et al.,* 2003). Sodium hydroxide treatment on the fibre would remove impurities like pectin, facts, and lignin from the fibre, resulting in an improvement in adhesion between fibre and matrix, which also increases the mechanical properties of fabricated structures (Venkatesha *et al.,* 2016). This treatment improves the tensile strength of composites over untreated fibre-reinforced composites (Suardana *et al.,* 2011). Alkali treatment is the commonly used treatment for natural fibre for obtaining good fibre matrix adhesion and the thermal and mechanical properties of composites (Hashim *et al.,* 2017). It leads to an increase in the effective surface area between the fibre and the matrix by removing impurities, hemicellulose, and lignin from the surface of fibres (Wang *et al.,* 2015). This treatment is one of the simple and effective surface modification techniques widely used for treating natural fibre for composite reinforcement for improvement of the tensile and flexural properties (Naveen *et al.,* 2016). Alkaline processing directly influences the cellulosic fibril, the degree of polymerisation, and the extraction of lignin and hemicellulosic compounds (Ravi *et al.,* 2018).

Benzoylation

Benzoylation is the most frequently used chemical treatment done with benzoyl chloride, which includes benzoyl and contributes to the decrease in the hydrophilic nature of natural fibres. This in turn improves bonding with the hydrophobic polymer matrix, thereby increasing the strength of composites (Gupta *et al.,* 2018). Benzoylation is an important transformation in organic synthesis. Benzoyl chloride is most often used in fibre treatment for increasing the hydrophilic nature of the fibres (Ali *et al.,* 2016). This treatment increases the fibre matrix bonding, which in turn increases the strength of the composites (Chand and Fahim, 2021). Benzoyl chloride is the most commonly used chemical for treating fibres. It increases the strength and decreases the water absorption, thereby improving the fibre matrix bonding (Murali and Chandra, 2014).

Acetylation

An acetyl group during acetylation reacts with hydrophilic hydroxyl groups of natural fibre to generate esterification that reduces this nature by absorbing moisture from the fibre (Teli and Valia 2013). After acetylation, the dimensional stability is improved as well as the dispersion of fibre into polymeric matrices, thus increasing the hydrophobic nature of the fibre due to the substitution of hydroxyl groups with acetyl groups (Ahmad *et al.,* 2019). Acylation of natural fibres is an esterification method that is divided into acetylation and valorisation and causes plasticization of cellulosic fibres. Polymer hydroxyl groups of the cell wall with acetyl groups modify the properties of these polymers so that they become hydrophobic, which could stabilise the cell wall against moisture, thereby improving its dimensional stability (Ku *et al.,* 2011). It reduces the susceptibility of natural fibres to moisture absorption, improves dimensional stability, and increases resistance to environmental degradation (Oladele *et al.,* 2020).

Biological Treatment

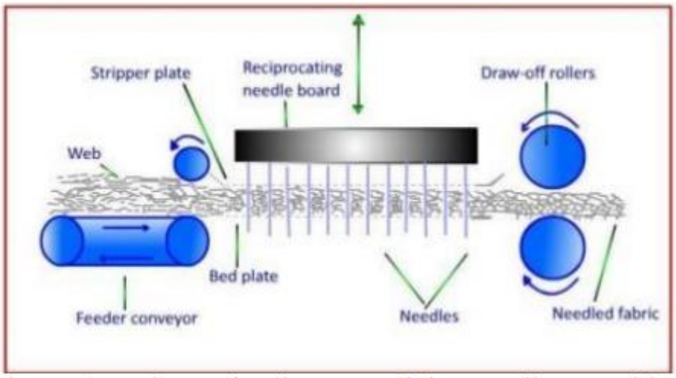
The recently used enzymes for biological treatment are for surface modification of fibres (Kumar *et al,* 2021). It is an eco-friendly method used for fibre surface modification as it does not discharge harsh substances into the environment due to the milder conditions of use (Setara *et al.,* 2016). Enzyme treatment is progressively popular, with benefits related to environmental friendliness (Ahmad *et al.,* 2015). Enzyme treatment is a biological modification of fibres that requires low energy input and is environmental friendly. This biological treatment is becoming an important technology due to its advantages with respect to environmentally friendly impacts. The enzymes act as accelerators for changing substrates into targeted products **(**Padzil *et al.,* 2020). Enzyme utilised in the textile field are amylases, cecatalase, catalase, and pectinase for purposes like removing starch, degrading excess oxide, bleaching textiles, and degrading polymers (Patel *et al.,* 2017). The reaction happens with lower activation energy, which is achieved by forming an intermediate catalyst substrate. The enzyme substrate molecule is converted into the product, and then the catalyst is also regenerated by itself (Talukder, 2017).

The use of enzymes is considered a gentler alternative to alkaline or acidic treatments. Enzyme pretreatment is a recent development in textile processing that has been found to improve the product qualities with respect to softness, elasticity, absorption, comfort, dimensional stability, and comfort (Ammayappan and Gupta, 2005). From research work, it is observed that the enzymatic treatment facilitates better fibre-matrix adhesion and improved mechanical properties of the composites (George *et al.,* 2014). Pectinases are the enzymes used for the degradation of the pectin material. Pectinases are mainly used for scouring. These have various enzymatic activities and reaction mechanisms and are divided into lyases and polygalacturonases. Various pectinases are commercially available and are used in the bioscouring process (Thakur and Mukherjee, 2018). Cellulases and pectinases are used to remove the cuticle from cotton fibres, which results in weight loss and absorbency properties (Younghua and Hardin 1998). Cellulases are enzymes used for their versatility on different materials and for different purposes (Celulaz and Plemenitenja, 2015).

2.4 Nonwoven Fabrication and Its Application

Nonwoven textiles are sophisticated and engineered materials since they are made from short and long fibres by bonding with various techniques such as mechanical, chemical, and thermal (Yilmaz *et al.,* 2020). *Both the* natural and the fibres, defined and blended, give the required characteristics, so the blending process is essential (Ghosh and Raihan, 2015). Blending different types of fibres is done to enhance the quality characteristics of yarn by incorporating desirable properties of constituent fibres and to reduce their cost. But the fibre blend ratio is an important factor that determines the properties of the resultant mixture (Saha *et al.,* 2016). The knowledge about the importance of blended products in the textile industry and the increasing costs of products prepared from individual fibres lead to the necessity for fibre blending to obtain the best quality products (Prakash, 2019). The blending may be done using Polyethylene terephthalate fibres (PET) along with natural fibres. The Properties of recycled Polyethylene Terephthalate (PET) fibres are fineness - 1.85 dtex, mean length - 20mm, tenacity - 26.92cN/tex and elongation at break 39.13 percentage (Teli and Ozdil 2015). The other properties of recycled PET fibres include diameter range - 25-30µm, water absorption - 3.3 %, vitreous temperature - 62^{o}C and fusion temperature - 252.8^{o}C (Pelisser *et al.,* 2012). In recent years, recycling has been as attractive issue for researchers considering sustainability of the wastes arising from different engineering applications. In this scope, r-PET fibers which are mechanically and chemically recycled from PET bottles can be reused in needle punched non-woven production technology (Sevencan and Vaizoglu 2007).

A nonwoven fabric is defined as a sheet or web structure bonded together by entangling filaments by various mechanical, thermal, or chemical processes. These are made directly from the fibres or from molten plastic or plastic film. The unique advantage of nonwoven fabric manufacture is that it is a continuously linked process, where in the first stage, raw materials (fibres) are converted into webs through the carding process, followed by the second stage of bonding into finished products (Cheema *et al.*, 2018). Multi-layer nonwoven composites, laminates, and three-dimensional nonwoven structures are commercially produced by combining materials with different chemical and physical properties, so that nonwovens can be used widely for industrial consumer goods, consumer goods, and health-care goods (Kalebek and Babaarslan, 2016). Thermal bonding, also known as cohesion bonding, constitutes one of the most commonly used manufacturing strategies (Islam *et al.*, 2019). This type of bonding is carried out by the application of heat to fuse the matrix web fibres and bond reinforced web and matrix web together (Raghvendra and Sravanthi, 2017).



(Source : Savitha *et al.*, 2021)
Figure ii Needle punching process

2.5 Composites and Their Application

Composites are materials that comprise a strong material that can sustain a very large load, known as reinforcement, and are imposed on a weak material called a matrix. In simple words, the matrix is a base on which a strong material is imposed. The matrix also plays an important role in maintaining the position and orientation of the reinforcement (Das, 2018). The short and discontinuous fibre composites known as whiskers are responsible for the biggest share of successful applications. But for long fibres, by altering the alignment and the direction of fibre orientation, the material properties are enhanced. Composites are prepared by various methods, namely hand layup, spray up, vacuumed bag moulding, pressure bag moulding, thermal expansion moulding, autoclave moulding, press moulding, transfer moulding, pultrusion moulding, filament winding, casting, centrifugal casting, continuous casting, slip forming, wet layup, compression moulding, and thermoplastic moulding (Bhoopathi *et al.*, 2018). The mechanical properties of polymeric composites have a strong dependence on the interface adhesion between the fibre and the polymer matrix (John and Thomas, 2008).

The composites are reinforcing materials that are incorporated into two or more reinforcing and filling materials that are present in a single matrix (Fu *et al.*, 2002). A composite material is prepared by mixing two or more different elements in order to make a material with superior properties from its potential materials (Mathur *et al.,* 2017). One constituent is called the reinforcing phase, and the one in which the reinforcement is embedded is called the matrix (Sundar, 2020). The composite materials possess a unique combination of properties such as a high strength-to-weight ratio, toughness, functional superiority, weathering and fire resistance, electrical insulation, anti-friction properties, and low maintenance costs (Sai, 2016). Composites are great materials for automotive and aeronautical applications due to their high mechanical qualities and low weight (Todor *et al.,* 2018b).

In addition to fibre matrix interfacial bond strength, the mechanical properties of a natural-fibre reinforced composite depend on other parameters like fibre strength, modulus, length, and fibre orientation. Also, processing conditions and techniques influence the mechanical properties of fibre-reinforced composites (Boopathi *e*t al., 2022). One of the main scientific challenges for composite engineers is manufacturing stronger, tougher, lighter structural materials supporting modern technologies and design concepts for complex-shaped structures like aircraft, automotive structures, and huge wind turbine blade structures (Gururaja and Hari, 2012).

2.5.1 Hybrid Composites

Hybrid composites are compound substances that are fabricated by combining two or more different kinds of fibres within the same matrix, as given by various researchers (Thwe and Liao 2003). Hybrid composites are more developed than other fibre-reinforced composites and have enormous usage, as the positive attributes of one kind of fibre could complement the lacking properties of the other fibre present in the hybrid composites. This leads to the development of better performance and more cost-effective products (Bakar *et al.,* 2013*)*. The progress of hybrid composites leads to an improvement in the performance of finished materials due to the process of combining two or more types of reinforcements in a single matrix. Improved performance in composite materials is obtained by reinforcing two or more fibres with a single polymeric matrix, resulting in the manufacture of advanced materials called hybrid composites with a good diversity of material properties (Prabhakaran *et al.,* 2012).

The combination of sisal and oil palm fibres is an excellent variety of hybrid composite, as sisal fibre has good tensile strength and oil palm fibres have high toughness (Jacob *et al.,* 2007). Hybrid composites are more reliable for various applications, besides being more environmental friendly (Nurazzi *et al.,* 2021). The hybrid composite products will be cost-effective materials for the production of automobile body panels, interiors, storage devices, buildings, and industrial panels (Karthi *et al.,* 2020). These are used for manufacturing the primary structures in commercial, industrial, aerospace, marine, and recreational structures, with their high range of benefits, namely great fatigue, corrosion resistance, and excellent impact resistance, finding their application in the aerospace industry (Mohammad *et al.,* 2018). The various hybrid composite applications are in Aerospace Applications - Fuselage, Wings, Control surfaces, Fan blades, Tail cones, Interiors, Wind Turbines - Wind blades, Nacelles, Spinners, Constructions - Bathtub, Doors and Windows, Roofing and Cladding, Pultruded profiles, Swimming pools and Marine - Hull, Decks, Fly bridges, Mast, Rudders and Centre boards (Subramani *et al.,* 2017). The mixture of natural and synthetic hybrid composites will assist in improving various properties such as strength, temperature resistance, and moisture absorption rate (Mohammad *et al.,* 2018). The usage of hybrid natural fibre composites is promising to satisfy the needs of sports products to bridge the requirements of people to create a greener environment (Nurazzi *et al.,* 2021).

2.5.2 Matrix and Reinforcements

The composites are made of two materials: one is the matrix, or binder, which surrounds and binds together the fibres of fragments of the other material, called the reinforcement (Deborah, 2003). Polymer matrices can be divided into two types: one is synthetic petrochemica-based called synthetic matrix polyester, polypropylene (PP), polythene (PE), and epoxy, and the other is natural or bio-based called biodegradable matrix (Lotfi *et al.,* 2019). Polymer matrix composites are made up of natural or synthetic matrix materials, namely thermoplastic or thermosetting plastic, with one or more reinforcements such as carbon fibres, glass fibres, or natural fibres (Faruk *et al.,* 2010; Sharma *et al.,* 2020). The thermoset polymers are highly cross-linked polymers with good properties such as high flexibility for tailoring desired ultimate properties, great strength, and modulus. (Ticoalu *et al.,*2010). Thermoset resins are mostly composed of phenolics, polyesters, melamines, silicones, epoxies, and polyurethanes. The form of thermoset resins cannot be altered or remelted, but the application of heat or UV radiation can initiate the cross-linking reaction (Fan and Weclawski, 2017). Epoxy resin is a valuable product in a variety of sectors because of its strong adhesive properties. It also gives resistance to heat and chemicals and is appealing in structural composite applications (Fiore and Valenza, 2013). The epoxy resin is extensively used in advanced composites for aerospace applications due to its excellent high-temperature properties (Moureen *et al.,* 2004). Epoxy resins are widely used because of their high mechanical properties and high corrosion resistance (Muthukumar *et al.*, 2014).

Epoxy resin is widely used as a necessary insulating material in heavy machinery and as a dielectric material because it is affordable and has great qualities (Yin *et al*., 2011). When compared to petroleum-based composites, biopolymers are environmentally responsible and sustainable and have relatively low impact, tensile strength, and thermal stability. (Diez-Pascual, 2019). Epoxy resin is known in the marine industry for its incredible toughness and strength for bonding. It has a greater ability to flex and strain with the fibres without micro-fracturing and is good at resisting water absorption. It also bonds to all sorts of fibres very well and gives excellent results in repair ability (Guduru *et al.,* 2016). The classic variety of epoxy resin, manufactured through polymerisation, is used as a thermoset polymer for adhesives and composites and is two times stronger than concrete, which is seamless and waterproof too (Ray *et al.,* 2016). Thus, resin is extensively used in advanced composites for aerospace applications due to its excellent high-temperature properties (Moureen *et al.,* 2004). The most widely adopted epoxy resin (LY556) and industrial application hardener (HY951) are employed to fabricate the laminated sheets and hybrid combinations. Epoxy resins are widely used because of their high mechanical properties and high corrosion resistance (Muthukumar *et al.*, 2014).

For high-tech structural applications that need properties such as strength, stiffness, durability, and light weight, epoxy resins are found to be the standard for matrix in composites. The main consideration for material selection for most composite builders is cost, along with performance (Sinturel and Thomas 2014). The applications for epoxy-based materials are extensive and include coatings, adhesives, and composite materials where carbon fibre and fibreglass reinforcement are used (May 1988). The epoxy resins find their application for their superior properties in places where electrical and UV ray resistance are needed (Chen *et al.*, 2017). The Properties of Epoxy resin LY556 are that it has a viscosity of 250 c, a clear, pale yellow liquid, and a density of 1.15–1.20 gm/cm^3 at 250°C. The properties of Hardener HY951 are density: 0.95 g/cm^3, melting point: 120°C (lit), Boiling point: 266–267 °C, and water solubility (Wangikar *et al.*, 2020).

The flexible epoxy resin is used to increase the thermal resistance of natural fibres. (Thitithanasarn *et al.*, 2012). Epoxy is a kind of thermosetting matrix or resin that contains one or more epoxide groups, also known as oxirane or ethoxyline groups, and is recognised as the basic building block of epoxy polymers. It is widely used as a necessary insulating material in heavy machinery and as a dielectric material because it is affordable and has great qualities (Petersson *et al.* 2007).

These resins have an extensive record of use in repairing concrete and a variety of composite materials, and the structural flexibility of these resins enables the production of a wide range of goods with various levels of performance (Abdellaoui and Kacem, 2019).

These have great chemical resistance to water, a variety of solvents, acids, alkalies, and other chemicals because they include an extremely stable linkage (Senthil, 2010). The characteristics of epoxy enables it to be used in a wide range of applications, including adhesives, laminated circuit boards, structural fibre-reinforced composites, and electronic component encapsulations (Grause *et al.*, 2008).

The mechanical properties of composite materials depend on many factors, such as fibre length, shape, size, composition, orientation, and distribution, as well as volume fraction. Mechanical properties of the matrix, manufacturing techniques, and bonding between fibres and matrix also play an important role. Fibreglass has been used in reinforcing polymer matrix composites since the 1930s. Kenaf, sisal, banana, cane, bamboo, jute flax, pulp, cane, wood flour, oil palm, pineapple leaf, and coir are the main natural fibres used as composite reinforcement. (Xin X *et al.*, 2007). The reinforcement is stronger and stiffer than the matrix, giving composites better performance. The matrix holds the reinforcements because the reinforcements are discontinuous, and it also helps to transfer load among the reinforcements (Madhukiran *et al.,* 2013). Reinforcement is a method by which fibres or polymers' tribological properties are altered (Lomov *et al.,* 2006).

The most commonly used natural fibres for reinforcement are cotton, jute, sisal, hemp, banana fibre, and many more. It has been found that the tensile strength of the composites has improved due to the incorporation of natural fibres into polymers (Chandramohan and Marimuthu, 2011).

2.5.3 Properties of Natural Fibre Reinforced Composites

Since the 1990s, natural fibre composites have emerged as realistic alternatives to glass-reinforced composites in several applications. Natural fibre composites such as hemp-epoxy flax fibre (PP) and China reed fibre (PP) are particularly attractive in automotive applications because of their lower density and lower cost (Joshi *et al.,* 2013). The natural fibre composites are called "Green composites". Natural fibre-reinforced composites are emerging very rapidly as a potential substitute for metal or ceramic based materials for automotive, aerospace, marine, and electronic industrial applications. (Nithin, 2019). The natural fibre composites are not only biodegradable and renewable but also possess several other advantages, namely light weight, low cost, high specific strength, high modulus, reduced tool wear, and a safe manufacturing process (Asma, 2020). The fibre matrix interfacial bond strength and properties of a natural fibre-reinforced composite depend on different aspects such as fibre strength, modulus, fibre length, fibre orientation, and processing techniques (George *et al.,* 2001). A strong fibre-matrix interface bond is significant for high mechanical properties and for effective stress transfer from the matrix to the fibre, whereby maximum utilisation of the fibre strength in the composite is achieved. (Karnani *et al.,* 2006). Fibre-reinforced composites possess interesting properties like high specific strength and stiffness and good fatigue performance (Dhand *et al.,* 2015). The natural fibres provide a higher degree of design, higher strength, lower density, biodegradability, flexibility, prevention of health hazards, and lesser wear during machining (Oksman *et al.,* 2016). Composite materials have the advantage of combining a number of properties that are usually not found together in a single material (Arpitha *et al*., 2017).

Although glass fibres have some benefits, such as low cost and high strength, they are not biodegradable, whereas natural fibres are renewable, cheap, recyclable, biodegradable, and abundantly available. These fibre-reinforced composites also exhibit low density and reduce the extent of environmental pollution caused by synthetic fibres (George *et al.*, 2001). The percentage of natural fibres in mixed and composite materials is generally high and for this reason they are considered as sustainable solution. Existing life cycle assessment studies show that the substitution of conventional thermal and sound insulating materials with sustainable materials as significant effects (Asdrubali *et al.*, 2012). The physical disadvantages of the natural fibre-reinforced polymer composites are moisture absorption, restricted processing temperature, and variable quality, which limit their performance (Gallo *et al.*, 2013). The wide advantages of natural fibre-reinforced composites, such as their high stiffness-to-weight ratio, lightweight, and biodegradability, make them suitable for different applications in the building industry (Kakroodi *et al.*, 2013). The performance of a natural fibre composite depends on factors like mechanical composition, structure defects, cell dimensions, physical properties, chemical properties, and also the interaction of the fibre with the matrix (Dai and Fan, 2014). The mechanical properties of polymeric composites have a strong dependence on the interface adhesion between the fibre and the polymer matrix (John and Thomas, 2008). Composite materials have unique properties that have a high strength-to-weight ratio with the advantage of structural flexibility so that they can be formed into intricate designs (Amir *et al.*, 2019). The reduced weight compared to metallic structures, lower transportation and erection costs, and lower maintenance costs are the factors that make composites a material for enormous applications (Carrie, 2017). Many plant – based natural fibres such as jute, coir, sugar cane, banana and sisal are used in various matrices to create eco friendly composite material (Parikh 2023).

2.5.4 Application of Composites

Composite materials are generally costlier when compared to conventional materials, but their use is still becoming increasingly popular because of their significant properties (Sai, 2016)**.** Natural fibre-reinforced composites are emerging very rapidly as a potential substitute for metal- or ceramic-based materials in applications that also include the automotive, aerospace, marine, and electronic industries. (Nithin, 2019). In the United States, composite building materials made from straw are used for the inner door panel of the 1999 S-class Mercedes (Sanjay *et al.*, 2016)**.** The area of composites leads to the manufacturing of value-added products like anti-bacterial walls, sound-absorbing panels, sunlight-proof covers, fire retardancy, vibration damping, impact strength, gas barriers, and waterproof composites (Thyavihalli *et al.*, 2019). Due to their high specific strength and stiffness, low cost, biodegradability, and ease of material availability, natural fibre composites are now the most widely used materials for a variety of applications, including those in the aerospace, automotive, marine, and defence industries (Pickering *et al.*, 2016).

The applications of natural fibre-reinforced composites are growing rapidly in numerous engineering fields, and hence different kinds of natural fibres such as jute, hemp, kenaf, oil palm, and bamboo-reinforced polymer composites have received great importance in different automotive applications, structural components, packing, and construction (Sassoni *et al.*, 2014). Natural fibre-reinforced composites are a very affordable material used in building and construction areas (walls, ceilings, partitions, window and door frames), storage devices (bio-gas containers, post boxes), furniture (chairs and tables), electronic devices (outer casting of mobile phones, toys), and other applications (helmets and suitcases). (Dalbehera and Acharya, 2014). The widespread application of these composites is due to their low specific weight, relatively high strength, relatively low production cost, resistance to corrosion and fatigue, biodegradability, good mechanical properties, and availability from renewable sources as compared to synthetic fibres (Shinoj *et al.*, 2010).

The car manufacturing industry in Europe has done various research to increase the applications of these composites in the automotive industry, especially in the car interior, such as seat backs, parcel shelves, boot linens, front and rear door linens, truck linens, and door trim panels (Graupner *et al.*, 2009). High strength, energy absorption, and stiffness are obtained by composite materials, which are widely used in industries mainly due to their property of mass reduction (Savage, 2010). Fibre-reinforced polymers have been largely applied to the area of aerospace technology, but these construction materials have also been used in many technical applications to achieve the required strength (Maharshi and Shivdayal, 2021).

The potential applications of the developed material for aerospace are very restricted, but the high mechanical properties could fulfil the requirements of other industrial sectors such as energy or automotive (Mohanty *et al.*, 2000). Besides the auto industry, the application of natural fibre composites has also been found in the building and construction industry, sports, aerospace, and others (Shinoj *et al.,*2011). Fibre-reinforced composites are used in high-performance sports gear because of their light weight, high strength, and easy processing and forming characteristics. From football helmets and hockey sticks to kayaks and bobsleds, carbon fibre and fibre glass composite materials are used, which provide durable and lightweight equipment. Composites reduce the weight of the sports product without compromising strength, durability, or protection (Kaufmann, 2015). Wind energy is one of the most promising markets in the composite industry, as the use of composites in renewable energy plays a vital role through the manufacture of structures that help sustain sustainable energy sources (Jones *et al.,* 2022).

Noise is an unwanted and undesirable sound that affects the human ear and causes disturbances. Noise adversely affects human health and causes permanent hearing loss, mental illness, cardiovascular diseases, and sleeping disturbances. High noise levels can be controlled by the use of suitable sound-control materials, such as acoustic materials. The effectiveness of a material in sound absorption depends mainly on the frequency of the sound wave subjected to the material, basis weight, air permeability, fibre geometry, and fibre arrangement (Kumar *et al.,* 2020a). When the average sound absorption coefficient is greater than 0.20 in a material, it is called a sound absorption material, and it is said to be a high-efficiency sound absorption material when it is greater than 0.56 **(**Qian and Li, 2000**)**. The coir fibres treated with sodium hydroxide gained the highest sound absorption coefficient values across low and high frequency ranges, yielding coefficient averages of 0.9 Hz and above (Nasidi *et al.,* 2021). The acoustic properties of the produced materials depend on their structure and parameters. The sound absorption of felt formed from randomly oriented, tangled, and physically interlocked fibres depends mainly on the fibre packing density and fabric thickness **(**Kobiela-Mendrek *et al.,* 2022). The sound transmission loss of Kevlar and pineapple leaf fibre composites is the fraction of energy dissipated due to sound being transmitted through the material. The higher the transmission loss, the less sound passes through the composite panel (Jeyaguru *et al.,* 2022). It is important to use sound-absorbing materials for ceiling and side walls together. The nonwoven material can be used for the ceiling as a lay-in material as it has proven to be effective at sound attenuation (Su and Caliskan, 2007). The noise reduction coefficient (NRC) is a single number value ranging from 0.0 to 1.0 that describes the average sound performance of a material and is expressed as a percentage (0.65 means 65% of sound energy coming into contact with the specific material is absorbed). A material with a noise reduction coefficient of efficiency greater than or equal to 0.20 is a sound absorption material (Su *et al.*, 2009).