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Experimental Study of Physical, Mechanical and Morphological Properties of Natural Fibre (Grewia Optiva) Reinforced Hybrid Composite

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ABSTRACT

Natural composite materials are of interest to researchers because of their low density, an exceptionally high specific mechanical strength, and the fact that they are generally available, renewable, degradable, and environmentally friendly. Reinforcement using natural cellulose fibers in a matrix combines these materials together. In the present study, samples were prepared using fibers treated with sodium hydroxide at different volume percentages, while carbon fiber and epoxy were used as fillers for the matrix prepared by the hand lay-up method. The mechanical properties being investigated include tensile strength, impact strength, water absorption, and SEM for hybrid natural fiber composites. The effect of fiber surface treatment at varied volume percentages of NaOH was noticed for the different orientations of fiber in the hybrid composite. Surface treatment of the fiber improved tensile strength compared with the pure epoxy maximum. Mechanical properties exhibited higher values with 6% NaOH-treated fiber, and on further increase in the volume percentage of NaOH, the values of mechanical properties decreased. The water absorption tests carried out on the composite exhibit very low absorption of water.

CHAPTER-1

1. INTRODUCTION

1.1 Overview of composites

Research of natural composite materials has been focused recently on development of natural cellulose fibres, in conjunction with a base material, as reinforcements. By using NaOH-modified fibres, untwisted carbon fibre or epoxy resin matrix as the filler and hand lay- up method to produce test pieces, a sample was created for this study.The point of natural fibre hybrid composite is to look at its mechanical properties, including SEM, soaking of water, toughness and tensile strength. By contrast, when the ratio of surface treated fibre at variable volume% of NaOH is held constant, effect on parameters for the hybrid composite is significant. The treated fibre had better tensile strength than did a pure epoxy. The maximum value of all mechanical properties was found at 6% NaOH treated fibre,and the volume % higher these mechanical property values,you can see that weakens it. The water absorption test of the composite demonstrated exceedingly minute absorption of water.

1.2 COMPOSITE

"Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material," **said Jartiz**. They are cohesive structures produced by combining physically two or more suitable materials, differing in composition and properties and sometimes forms as well. It is not infrequent for composite materials to contain a bulk phase, which is continuous and known as the matrix, together with one dispersed The second non-continuous phase is called the reinforcement, which name must be because that component is typically both more robust than matrix material. The role of individual components has been characterised as:

Matrix phase

The basic phase, having a continuous feature, is termed matrix. Matrix is generally more ductile and less rigid phase. The matrix serves two essential goals viz., holding the dispersed phase in situ and deformed to distribution of the stresses among the component the scattered material under an applied load.

Dispersed (reinforcing) phase

The second phase (next round) is embedded in the matrix type of a discontinuous form. This subsequent phase is termed scattered phase. Dispersed phase is frequently stronger than the matrix, so it is sometimes termed reinforcing phase.

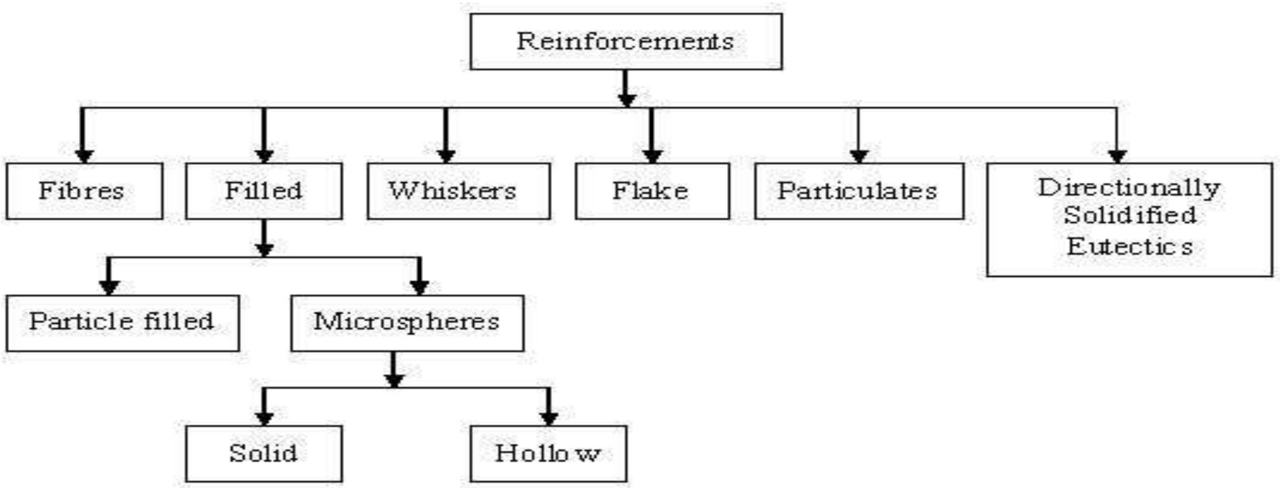


Fig.1 (a) Types of reinforcement

1.3 Types of Composites

However, for convenience, composites can be categorized into groups based on the type of matrix that each type comprises. The physical and chemical characteristics of the matrices and reinforcing fibres also affect the production methods.

(a) Metal matrix composites (MMCs)

Metal matrix composites (MMCs) are materials having a metallic matrix—aluminium, magnesium, or titanium—reinforced with dispersed ceramic particles, whiskers, or fibres to produce increased mechanical characteristics. The metal matrix, commonly an alloy of aluminium, magnesium, or titanium, acts as the continuous phase, while reinforcements such as silicon carbide or alumina contribute hardness, stiffness, wear resistance, and thermal stability. MMCs are divided by reinforcement morphology into particulate-, whisker-, short- fibre-, and continuous-fibre-reinforced systems, each having a unique combination of strength, ductility, and anisotropy. Among them, silicon carbide–reinforced aluminium composites (SiC/Al) are the most researched and commercially utilised owing to their high strength-to-weight ratio and cost-effective manufacturing. Ceramic phases give stiffness and strength advantages of up to 100% over unreinforced alloys, together with superior wear resistance under abrasive contacts. MMCs also provide adjustable thermal conductivity (up to 200 W/m·K) and regulated coefficients of thermal expansion, suitable for electrical and thermal management applications and vibration damping. Additionally, they demonstrate better fatigue life, creep resistance, and toughness via effective load transfer and fracture deflection at the reinforcement–matrix interface. Production covers solid-state routes—powder metallurgy and foil diffusion bonding—for low-porosity microstructures, to liquid-state techniques—stir casting, squeeze casting, and pressure infiltration—for high-volume, particulate composites. Semi-solid powder processing offers larger reinforcement loadings, whereas in situ fabrication creates reinforcements during eutectic solidification to strengthen surfaces. Moreover, additive manufacturing methods like as powder-bed fusion and directed energy deposition are developing for creating complex-shaped MMC components with customised reinforcing distributions. MMCs find uses in aerospace (brake rotors, turbine components), automotive (engine blocks, brake discs), electronics (heat sinks, substrates), and biomedical implants, leveraging on their lightweight strength and thermal performance. Despite these benefits, adoption is mitigated by high reinforcing costs, machining problems owing to abrasive phases, and manufacturing-induced residual stresses.

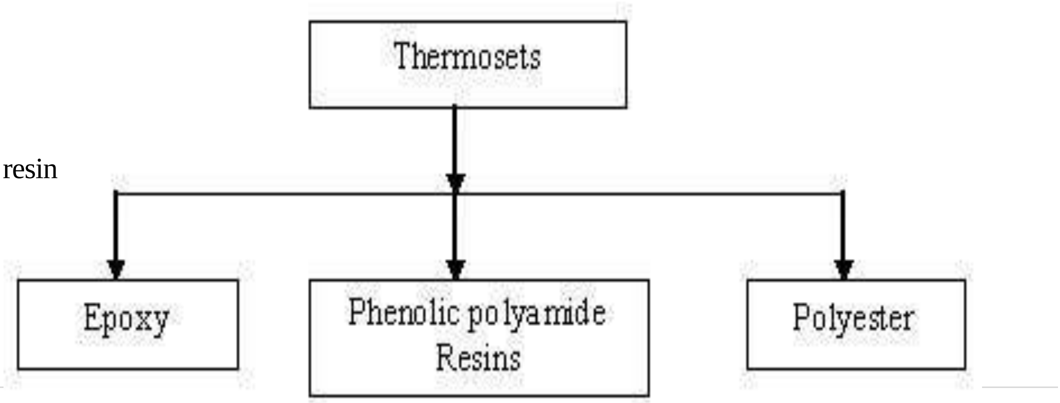
(b) Ceramic matrix composites (CMCs)

The ceramic matrix composites (CMCs) constitute a type of advanced material that consists of a ceramic matrix like alumina, calcium aluminate, or alumino-silicate that has been reinforced with high-performance fibers like silicon carbide. These composites were designed not only to counteract the brittleness and poor fracture toughness characteristic of conventional ceramics but also to retain their wanted qualities. CMCs are characterized by exceptional mechanical strength, hardness, and thermal stability, making them suitable for applications requiring high temperature resistance, chemical inertness, and lightweight performance. The principal advantage of ceramic matrices is their ability generally to withstand high temperatures, but monolithic ceramics suffer extreme brittleness and catastrophic failure. Reinforcement with a material such as silicon carbide fibers allows CMCs to attain enhanced fracture toughness, damage tolerance, and thermal shock behavior. This makes them an excellent fit for extreme service applications like aircraft engines, gas turbines, heat shields, and high-efficiency braking systems. In contrast to conventional superalloys that sacrifice low density for high-temperature performance, CMCs provide the same heat resistance for much lower weight. CMCs are typically difficult to synthesize due to the fragile nature of the ceramic materials, and most methods begin with the matrix and reinforcement components in powder form. The powders are processed by slurry infiltration, chemical vapor infiltration, or hot pressing. Ceramic matrices in CMCs may be broadly categorized into four classes: glass-ceramics (like borosilicate and alumino-silicates, recognized for ease of fabrication due to low softening temperatures), conventional ceramics (including silicon carbide, silicon nitride, aluminum oxide, and zirconium oxide, all fully crystalline), cement-based ceramics, and carbon- containing ceramics. The control of matrix and reinforcement materials permits engineers to customize the composite according to specified mechanical, thermal, and environmental parameters. Therefore, CMCs continue to contribute significantly in the present-day high- performance structural applications.

(c) Polymer Matrix Composites (PMC)

Most widely used matrix materials are polymers. This can be traced to two sets of reasons. The first is that generally, the mechanical properties of polymers are deficient for many structural applications. In particular, these are strength and stiffness with respect to metals and ceramics. Such shortcomings are compensated with polymers by hardening other substances. Secondly, polymer matrix composites need not require processes that involve high pressures and high temperatures. Machines-very simple ones-are required for making composite polymers. Hence, there was a rapid development of polymer composites, and these became soon-to-market structural applications. Other reasons are the broad composites which in mass property superiority over those of component polymers. Also, they have higher elastic modulus than most polymers.

Fig.1 (b): Thermoset resin



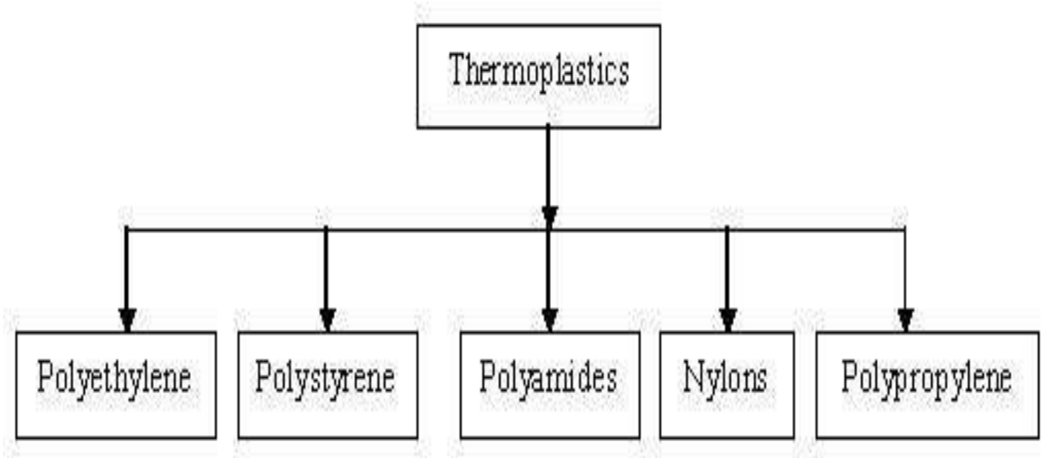


Fig.1: (c) Thermoplastic resin

1.3.1 Based on reinforcing material structure

Classification of composites: three main categories

❖ Particle-reinforced (large-particle and dispersion-strengthened)

- Fibre-reinforced (continuous (aligned) and short fibres (aligned or random)
- Structural (laminates and sandwich panels)

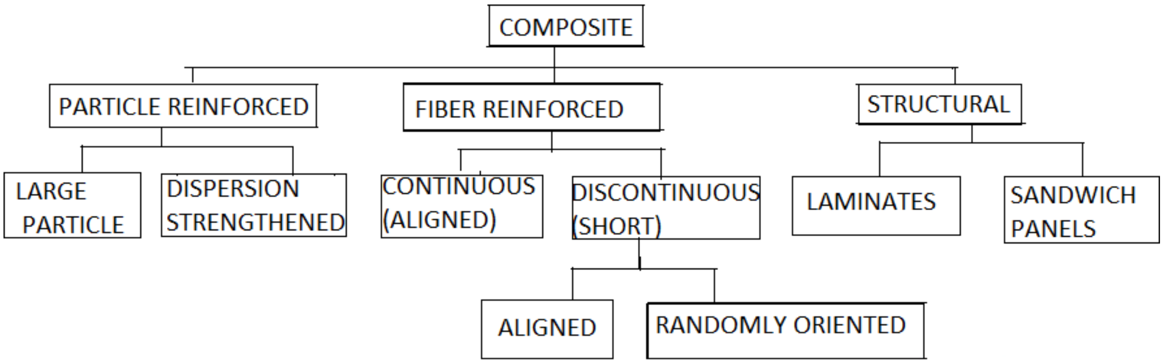


Fig.1: (d) Reinforced based composite

- **Particle reinforced composite**

Particle reinforced composites are materials made of a matrix—usually a metal, polymer, or ceramic—reinforced by a secondary phase in the form of discrete particles that are evenly spread throughout the matrix. These composites are among the most cost-effective and extensively utilised forms of composite materials because to their relatively easy production procedures and the abundant availability of raw ingredients. The major objective of the particulate phase is to increase the mechanical characteristics of the matrix, such as strength, stiffness, wear resistance, and occasionally thermal stability. Based on particle size, particle reinforced composites are usually categorised into two categories: those reinforced with big

particles (often larger than 1 millimetre), and those with tiny or fine particles (commonly in the nanometer to sub-micron range). Larger particles mainly work to limit deformation and offer load-bearing capacity, whereas smaller particles contribute to strengthening via methods such as grain refinement or impeding dislocation motion. Common examples include concrete (cement matrix with gravel or sand particles), metal matrix composites with ceramic particles like silicon carbide, and polymer composites with fillers like carbon black or silica. These materials are extensively utilised in construction, automotive components, wear-resistant surfaces, and electronic packaging because to their advantageous mix of performance, cost, and simplicity of manufacture.

- Composites with random orientation of particles.
- Composites with preferred orientation of particles.

These materials' dispersed phase is made up of parallel-arranged, two-dimensional flat platelets, or flakes.

- **Fibrous reinforced composite**

Short fibre reinforced composites:

Short fibre reinforced composites are a form of fibrous composite material in which a matrix— typically a polymer, metal, or ceramic—is reinforced with a dispersed phase of short, discontinuous fibres. These fibres normally have a length that is less than 100 times their diameter, separating them from continuous fibre composites. The short fibres are randomly orientated or occasionally aligned to a certain degree during processing, depending on the manufacturing technology utilised. These composites are meant to increase mechanical qualities such as tensile strength, stiffness, impact resistance, and fatigue behavior relative to the unreinforced matrix material. The reinforcement helps to transmit stress more efficiently and slows fracture formation, resulting to increased durability and performance. Commonly utilised fibre materials include glass fibres, carbon fibres, aramid fibres, and natural fibres, whereas thermosetting and thermoplastic polymers are typically employed as matrix materials. Short fibre composites are considerably simpler and cheaper to create than continuous fibre composites, making them commonly employed in automobile components, consumer items,electrical housings, and sports goods. Although they do not give the same degree of mechanical performance as long fibre or continuous fibre composites, they provide a fair compromise between cost, manufacturability, and better material qualities, particularly in complicated or injection-molded items.
. They are classified as

- Composites with random orientation of fibres.

Short fibre reinforced composites are a type of fibrous composite material in which short, discontinuous fibres are used to reinforce the matrix, which is often a polymer, metal, or ceramic. These fibres, which are dispersed throughout the matrix to improve its mechanical properties, typically have a length of less than 100 times their diameter. The orientation of the fibres determines one of the main classifications of these composites.

They are classed as composites with random orientation of fibres, where the fibres are spread in all directions without a precise alignment. This random distribution gives isotropic or nearly isotropic mechanical characteristics, making the material behave identically in many directions. The use of short fibres helps boost the tensile strength, stiffness, impact resistance, and wear qualities of the base material. Common reinforcing fibres include glass, carbon, aramid, and natural fibres, whereas the matrix is commonly a thermoset or thermoplastic resin. Although short fibre composites can not equal the high performance of continuous fibre systems, they provide a reasonable mix between increased mechanical qualities and simplicity of manufacturing. Due of their cost-effectiveness and versatility, these materials are widely employed in automobile components, appliance housings, consumer products, and structural applications needing moderate strength with complicated geometries.

- Composites with preferred orientation of fibres.

Short fibre reinforced composites are fibrous composites in which a matrix material— commonly a polymer, metal, or ceramic—is reinforced with short, discontinuous fibres often having a length less than 100 times their diameter. These fibres boost the overall mechanical performance of the material by enhancing qualities such as tensile strength, stiffness, impact resistance, and fatigue life. Based on the orientation of the fibres inside the matrix, these composites are generally categorised into two categories: composites with random orientation of fibres and composites with desired orientation of fibres. In randomly oriented composites, fibres are spread in multiple directions, enabling consistent mechanical performance in all directions, making them suited for applications where loading is multidirectional. On the other hand, composites with chosen orientation of fibres have fibres aligned in certain orientations, commonly obtained by processing processes like extrusion or injection molding. This alignment leads in improved strength and stiffness along the path of the fibres, making them excellent for components susceptible to directional loads. Reinforcing materials such as glass, carbon, or aramid fibres are frequently employed, inserted inside thermoset or thermoplastic matrices. These composites achieve a compromise between cost-effectiveness and better performance, making them popular in automobile components, consumer items, electrical housings, and other industrial applications.

Long-fibre reinforced composites:

Long-fibre reinforced composites are high-performance materials in which a continuous phase, known as the matrix—typically a polymer, metal, or ceramic—is reinforced by long, continuous fibres that run through the whole length or considerable parts of the composite structure. These fibres, generally formed from materials such as carbon, glass, aramid (e.g., Kevlar), or basalt, serve as the major weight-bearing component inside the composite, while the matrix binds the fibres together, protects them from external damage, and allows load transmission between fibres. Unlike short-fibre composites, where reinforcement is discontinuous and randomly distributed, long-fibre reinforced composites provide considerably better mechanical qualities owing to the consistent alignment of fibres. This produces in higher tensile strength, stiffness, fatigue resistance, and impact tolerance, especially in the direction in which the fibres are orientated. Depending on the design requirements, these composites may be made into unidirectional, bidirectional (woven), or multidirectional fibre patterns, enabling engineers to accurately regulate the strength and stiffness of the final product. Manufacturing techniques such as pultrusion, filament winding, hand lay-up, resin transfer molding (RTM), and automated fibre placement are commonly used for producing long-fibre composites, although these processes often demand greater precision, labor, and cost compared to those for short-fibre composites. Despite the additional production complexity, the performance gains make long-fibre composites appropriate for structurally demanding applications. They are frequently utilised in aircraft constructions (fuselages, wings, and control surfaces), automotive components (chassis parts, body panels), maritime applications (boat hulls and masts), wind turbine blades, sports goods (bicycle frames, tennis rackets), and even prostheses. Their high strength-to-weight and stiffness-to-weight ratios are particularly helpful when lightweight and robust materials are necessary. Moreover, long-fibre composites provide enhanced dimensional stability and may be manufactured to withstand corrosion, wear, and environmental deterioration during lengthy service lifetimes. In recent years, improvements in automation and material science have significantly enhanced the cost- efficiency and durability of these composites, boosting their application across numerous sectors. Although challenges such as high material costs, complex fabrication techniques, and recyclability concerns remain, the long-term benefits in performance, durability, and weight savings continue to drive widespread adoption and innovation in the use of long-fibre reinforced composites in modern engineering applications.

- Unidirectional orientation of fibres.

Unidirectional orientation of fibres refers to a fibre arrangement in composite materials where all the reinforcing fibres are orientated in a single, parallel direction. This arrangement is one of the most effective reinforcing techniques when mechanical loads are predicted to operate largely along the fibre axis. along such composites, the fibres produce greatest strength and stiffness along the direction of their alignment, delivering exceptional tensile and flexural qualities. The matrix—usually a polymer, metal, or ceramic—surrounds the fibres and supports them by transmitting loads between fibres and providing environmental protection. However, whereas unidirectional fibre composites excel in one direction, they tend to be weak in directions perpendicular to the fibres, where the matrix predominantly bears the load. This anisotropic behavior must be studied carefully during design. Common uses of unidirectional fibre composites include aircraft structures, wind turbine blades, high- performance sports goods, and automotive components where directional strength is important. Manufacturing processes such as manual lay-up, pultrusion, or filament winding are routinely employed to make unidirectional composites. Although they provide excellent mechanical efficiency, their performance is strongly reliant on appropriate fibre alignment, resin impregnation, and bonding quality. Engineers

commonly mix unidirectional layers in multiple orientations to form balanced, multidirectional laminates for better overall strength.

➢ Bidirectional orientation of fibres (woven).

Bidirectional orientation of fibres, generally referred to as woven fibre reinforcement, contains threads orientated in two perpendicular directions—typically warp (longitudinal) and weft (transverse)—creating a fabric-like structure inside the composite material. This weaving pattern enables the composite to contain strength and stiffness in both directions, delivering better balanced mechanical qualities compared to unidirectional fibre composites. The interlaced structure boosts dimensional stability, improves impact resistance, and minimises the danger of delamination under multi-axial stress situations. While braided composites often do not approach the maximum strength of unidirectional composites in a single direction, their isotropic-like performance over two planes makes them excellent for structural components subjected to diverse loading situations. The matrix, generally a polymer resin, combines with the woven cloth to produce a stiff and durable composite. This form of reinforcement is frequently utilised in aircraft panels, automobile body components, boat hulls, and protective gear, where resistance to impact, abrasion, and fatigue is crucial. Additionally, woven textiles may be created in several weave patterns—plain, twill, or satin—each impacting the drapability, surface smoothness, and mechanical reaction of the finished composite. The bidirectional fibre architecture therefore offers a feasible compromise between strength, manufacturability, and structural performance in advanced composite applications.

❖ **laminate composite**

The laminate composite is one of the kinds of fiber-reinforced composites which are made up of different layers or plies of fibers oriented differently. Thus, individual layers of the laminate normally consist of fibers oriented in one specific direction-unidirectional, bidirectional, or even at specific angles-to ensure optimum performance of the composite under any kind of loading. These are therefore combined and oriented in a way such that the laminate can achieve the desired balance of strength, stiffness, and durability required for the application. Laminate composites are commonly called multilayer composites because of the multiple layers

composing them, which in turn give engineers more freedom over the properties of the material.

A laminate composite is the arrangement of layers glued into each other by means of a matrix material ranging from polymers, metals, ceramics, etc., in which the layers of fibres are further glued and stress is also transferred. The soil matrix protects the fibres from moisture, heat, and chemicals. This is the reason laminate composites have been made with multiple layers with different fibre orientations that opt to prove their performance with very high success in multi-axial loading conditions when the stresses are applied in different directions. Examples include cross-ply angling where fibres in the adjacent layers are oriented at specific angles to improve strength and stiffness in more than one direction, such as 0°/90° or ±45° orientations.

The most crucial benefit of laminate composites is the ability to impart high tensile and compressive strength, reduce weights in comparison with traditional materials such as metals or solid ceramics, and poor fatigue resistance. As a result, they begin to fit very high- performance applications, such as from aerospace structures (wings, fuselages, tail sections) to automotive components (chassis, body panels), and from sporting goods (bicycle frames, helmets) to even medical implants (bone plates, prosthetics). Also, by being design flexible, laminate composites allow for further process optimization for a particular mechanical, thermal, or environmental property-related to wear, corrosion, or even high temperatures.

The above-mentioned facts can prove laminate composites to be highly tufted, the number of layers, fibre orientations, and matrix materials u can be varied according to required performance criteria. Like all other laminate composites, they also reveal some problems, having issues with inter-laminar shear stresses, then manufacturing complexity, and in fact, precise control of layer alignment is necessary during production. Still, laminate composites are very serious material in modern engineering today and are also among very key materials in industries where strength to weight ratio matters and performance under complex loading conditions has to be emphasized.

1.4 Natural Fibre Reinforced Composites

Novel structural materials that use matrix materials such as polymers reinforced with fibers, natural fibers, or glass-fibers, among others, have been developed in the quest for better mechanical properties. Unlike the conventional fiber reinforced composites that are most often made by using synthetic fibers such as glass, carbon, or aramid with thermoset or thermoplastic resins, it is these kinds of composites that are often considered to be the new family of materials. Because of their high specific strength, stiffness, and adaptability, fiber-reinforced polymer composites have been widely used in various industries for several years. But the attention has been drawn towards natural fiber composites due to the adverse environmental effects of synthetic fibers that result from energy-intensive methods of manufacture, lack of biodegradability, and non-availability of recycling facilities.

Natural fibers in these composites are obtainable from certain plant sources such as jute, hemp, flax, bamboo, and sisal; animal sources such as wool and silk; and mineral sources such as asbestos, though the latter is limited in usage because of health reasons. These fibers are more regarded as environmentally friendly since they can decompose, are renewable, and require much lesser energy to produce than their synthetic counterparts. The other final and significant aspect of natural fibers is that they offer, at least under some conditions, a balance between mechanical properties and environmental sustainability, thereby making them most favorable toward use in different sectors, including automotive, construction, consumer products, and packaging.

They are lightweight that much lower the total weight of the finished product. This is one of the major advantages of using natural fibres in composites-they are excellent for applications where weight elimination is significant. They have high impact resistance and insulation properties, which also suit them for components of vehicle interiors, furniture, and construction materials. In addition, natural fiber composites are usually cheaper than the conventional synthetic fiber composites.

Yet, they are most probably related to restraits in the use of these composites-natural fiber reinforced composites. Natural fibers are susceptible to moisture and environmental conditions such as humidity and that can affect their longevity as well as mechanical performance. These can also not always give the same strength or stiffness that may otherwise be expected with synthetic fibers and hence can restrict their application in areas that need really high performance like aerospace and military. Some part of the research is concentrating on enhancing performance of these composites as a result of fiber changes or the resin matrix modifying them for optimizing their traits.

Yet, notwithstanding all these, the growing demand for sustainable materials has manipulated the new improvements in natural fiber composites, and there are further studies redirecting attention toward improving their performance, durability, and cost. With progress in these materials, natural fiber reinforced composites will continue to occupy an increasing share of importance.

Advantages of Natural Fibres

- **Environmentally friendly:** Natural fibres rank as environmentally friendly alternatives to synthetic fibres since they are renewable and obtained from plant, animal, or mineral sources. The manufacturing stage of natural fibres often consumes less energy than those of synthetics, thus lowering their environmental footprint.

- **Fully biodegradable:** In contrast to synthetic fibres, those made by nature decompose in the environment, thus reducing the problem of long-term disposal and pollution. Such attributes make them appropriate for use in different industries.

- **Non-toxic**: Natural fibres do not emit toxic chemicals in the course of their production and use, thus being relatively safer for human health and the environment, unlike some synthetic fibres that may emit toxins after a while.

- **Easy to handle**: Compared to synthetic fibres, natural fibres are easier to handle because of their inherent softness. Less need arises for special equipment and processes in their manufacture.

- **Non-abrasive in processing and use:** Generally, natural fibres are not abrasive in comparison to synthetic fibres and hence reduce frictional wear to machines during production. Furthermore, they ensure no abrasive action on surfaces or machinery during their use in end products.

- **Low density/light weight:** Low density characterizes natural fibre-based composite materials as composites that are light in weight. This low density of materials is beneficial to industries like automotive and aerospace, where weight reduction is very important for performance and fuel economy.

- **Source of income for rural/agrarian communities**: The growing, harvesting, and processing of natural fibres offer a means of livelihood to the rural farmers, especially in developing countries. This supports the rural economy and promotes sustainable agricultural practices.

- **Renewable, abundant, and** continuous supply of raw materials: Several natural fibres, such as hemp, jute, and flax, are being produced abundantly and yearly or treated as per their season rapidly in order to ensure a continuous supply of raw materials for industries using them.

- **Cheap:** In general, natural fibres are found to be cheaper than synthetic fibres due to their ready availability and relatively uncomplicated method of production. Hence, they can be economically implemented for a variety of composite applications.

- **Free from health hazards (causing no skin irritation):** Natural fibres do not pose health risks like partial dermal irritation and respiratory problems, making it safe for workers during production and for consumers while using products made from natural fibres.

• **High toughness**: Many natural fibres have high toughness and impact resistance desirable in applications requiring durable material. They form a natural compliment to composite products, mainly because of their toughness.

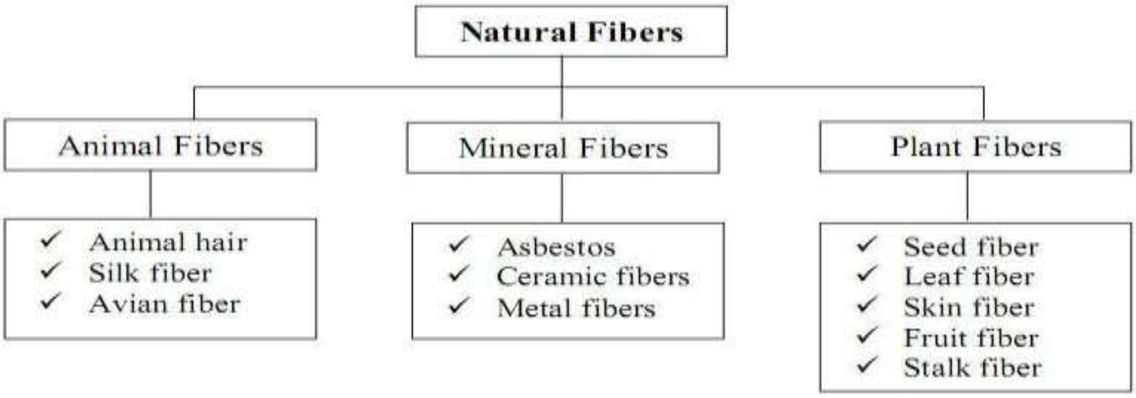


Fig.1: (e) Classification of natural fibre

1.5 Plant fibre

The basic component of all plant fibers comprises cellulose that occurs in cotton along with jute and flax and bhimal and sisal and hemp. Cellulose fibers serve as the main ingredient for making fabric and paper. Fibre sourced from plant leaves constitutes what is known as seed fibre. It includes agave along with sisal. The outer layer of plant stems surrounding the stem constitutes the skin fibre. Strengthening resistance stands higher for these fibres in comparison to the other available fibre types. These fibres find applications in producing paper and packaging items as well as textiles and yarn with high durability. Flax together with jute bananas hemp and soybeans represent several examples of fibres from this group. Natural plant fibers reaching their mature stage are known as fruit fibres with coconut (coir) fibres derived from fruit structures of the plant. For instance, barley, rice, wheat, and other crop straws, as well as bamboo and grass. The second type of fibre originates from tree wood. The usage of natural fibre composites in human society extends through many historical centuries. Building wall techniques were already known to the ancient Egyptians who used straw-strengthened clay as construction material. The combined properties of heat-resistance and non-conductive nature enabled researchers to create electrical applications using phenol- or melamine- formaldehyde resins with wood or cotton fibre reinforcement at the early 20th century. Natural fibre composites find their primary usage within building constructions and automotive applications with additional applications that require stability under hot conditions taking the secondary priority.

The Natural Fibre composites can be very cost effective material for following

Applications:

• The building and construction sector: partition boards, partition panels, window and door frames, walls, floors, roof tiles, and movable or prefabricated structures that may be utilized during natural disasters like earthquakes, floods, and cyclones.

• Storage devices: post-boxes, grain storage silos, bio-gas containers, etc.

- Furniture, such as tables, chairs, showers, and bathtubs.

- Electrical equipment, such as pipelines and appliances.
- Commonplace uses include helmets, bags, lampshades, and more.

- Transportation: aircraft, the interior of cars and trains, boats, etc.

1.6 Hybrid composite material

Hybrid materials are composites comprised of two component of organic and inorganic chemicals at molecular level or nanoscale level. Hybrid composite materials are highly useful in engineering where cheap cost, ease of manufacturing, and strength to weight ratio are required. A mixture of properties that are not achievable in composite materials, such as compressive strength, impact strength, and tensile modulus, are provided by hybrid composites. Hybrid composites are frequently utilized when a variety of fibre types' qualities need to be combined or when both longitudinal and lateral mechanical performances are needed.

1.7 Surface treatment of fibres

Cellulosic in nature, the fibres obtained from the Grewia optiva plant typically consist of 58– 75% cellulose, 10–12% hemicelluloses, and 7–12% lignin, respectively. Serious problems have been found if we use raw fibre directly without any chemical treatment. The sample composed of this untreated fibre has a higher capacity to absorb water, which has a significant effect on the mechanical properties of composites. Here, we discuss numerous chemical remedies that are used by different researchers. Grewia optiva fibres' surface adhesion capabilities with their matrix may be improved by a variety of surface treatments, including graft copolymerization, mercerization, benzoylation, and silane techniques. The impact of these surface treatments on the mechanical properties of the generated composites are also examined.

Mercerization

Both thermoset and thermoplastic composites commonly use the NaOH treatment of natural fibres. The outside surface of natural fibres is coated in waxy substances. This surface has a low surface tension and is not suitable for creating a strong connection with a polymer matrix.

By treating the fibres with a chemical that makes them hydrophobic, bond strength can be increased. Mercerization is another word for the alkali treatment of natural fibres. It is a popular technique for creating fibres of superior grade. When native cellulose fibres are inflated in caustic soda and the alkali is then removed by washing, the process is known as "mercerization," which turns native cellulose or cellulose one into cellulose two. It is known that alkali treatment hydrolyzes the amorphous portion of cellulose found in fibres, resulting in a higher concentration of crystalline cellulose in the final product. Raw Grewia optiva fibre was mercerized by steeping it in a 10% (w/v) NaOH solution for four hours at room temperature [18]. Reaction serves as an illustration of the reaction's scheme.

∑Grewia optiva fibre –OH+NaOH⟶ ∑Grewia optiva fibre –O^-Na^++ H_2O

1.8 Manufacturing Processes of Composite Material

The process of creating a composite material involves combining fibre reinforcement with a polymeric resin system. Since the fibres' orientation greatly affects the composite's ultimate properties, it is imperative that the manufacturing process align the fibres in the right direction. A successful manufacturing process will have consistent dimensional tolerances, a greater, homogeneous fibre volume percentage, and the ability to inexpensively create large quantities of components.

The composite manufacturing techniques can be classified into two categories:

A. Open mould process

a) Lay-up process by Hands

b) Process of spraying up

c) Auto clave process (Vacuum-bag)

d) Filament winding process

B. Closed mould process

a) Compression moulding

b) Injection moulding

c) Sheet moulding compound (SMC) process

d) Continuous pultrusion process

CHAPTER-2

2. LITERATURE SURVEY

Natural fibre composites are common in industries because they provide superior mechanical qualities and hence apply in different applications. However, due to increasing concerns in recent years regarding the environmental effect and energy consumption associated with creation, use, and disposal of such synthetic fibres, research is underway for alternative, more promising, and sustainable materials. Grewia optiva and other similar natural fibres are becoming popular and ideal alternatives to synthetic fibres for reinforcing polymer matrix composites (PMCs). However, this transition to natural fibres is further supported by economic advantages associated with production and processing. In the past decade, many review papers have emphasized the vast potential of natural fibres in composite applications - notably towards lowering environmental footprints in materials used in the automotive, construction, and consumer products stretch.

To fully realise the potential of Grewia optiva fibre as a reinforcing material, however, numerous challenges have to be overcome. The surface properties of natural fibres represent one of the most critical issues. These fibres generally contain diverse associated waxes, impurities, hemicellulose and pectin, and lignin deposits on their surfaces. These circumstances restrict their potential to connect effectively with the polymer matrix, which results in diminished overall strength and performance of the composite material. Different surface treatments, including graft copolymerization mercerization silane, treatment, and

benzoylation, have been adopted to get past this constraint. Such treatments remove impurities and change the fiber structure, enhancing surface properties, giving birth to rougher surfaces favourable to adhesion between the fiber and the matrix. Therefore, the mechanical characteristics of the treated fibers are much greater than those of the untreated fibers.
Such treatments improve the surface properties of natural fibers as well as create rougher surfaces that promote adhesion between the fiber and the matrix. As a result, treated fibers have been superior to untreated fibers in terms of mechanical properties.

One among the surface treatments is mercerization or alkali treatment, which is the widely applied one and cost-effective for natural fibers' surface alteration. During the process, fibers are immersed into an alkaline solution, which allows the fibers to swell and highlight their opening. This procedure also enhances the fiber-matrix bonding and

improves some mechanical properties of the composite material like tensile, compressive, and flexural strength. Studies indicate that the mechanical properties of natural fiber-based composites are highly improved using mercerization.

CHAPTER-3

3. MATERIAL CHARATERIZATION

3.1 Materials

Bhimal fibre (Grewia optiva), as illustrated in Fig. 3.1(b), was employed as the principal material for composite construction. The extraction procedure of Bhimal fibre begins with the collecting of fibre from the stems of the Bhimal tree, depicted in Fig. 3.1(a). This fibre extraction was done starting the first week of November when the branches of the Bhimal tree were hacked down. After hacking the branches, the sticks were first piled under a shade of a tree to enable drying under controlled environment. The use of shade drying ensures that the fibre keeps its natural features and does not get affected by exposure to direct sunlight which may degrade the quality of the fibre.

After the branches dried up in the shadow, we kept on with the procedure up to the arrival of the spring season, the first week in April, when we gathered all the dried sticks. At this time, the sticks were laid in the sunshine to facilitate proper drying. The last stage in the drying technique of sticks clearly sedimented powder suspended in oil was essential because it assures that moisture content is entirely eliminated, which is vital for separating fibres from the sticks as well as for further processing in expected future operations.

The twenty kilogram sticks were dried and assembled into bundles. The bundles were carried to the nearby creek to be subjected to the retting procedure. In order to achieve this, an artificial water pool was formed by damming the running stream with stones around the border. This works as an efficient way to control the flow of water, which is supportive for the retting process. Each bundle of sticks was strategically submerged by placing a stone over the bundle to ensure it was completely engulfed. This soaking procedure of retting the bundles for several months or up to three month was done and finished around June along with the extraction of fibres.

The limbs were subsequently subjected to a post-retting procedure during which they began bark stripping, removing the outer bark in manageable strips. After being transformed into

newly pure constituents, the strips underwent a mild wash in running water to remove any remaining impurities. Constant washing provided the degree of purification required to ensure these constituents would be free of contaminants affecting the quality of the fibre. After removing the outer pulp, the inner bark was stripped and the remnants were meticulously pulled free to yield the valuable fibres.

The fibres were subsequently subjected to solar drying, which ensured maximum moisture removal, a crucial requirement for the composite manufacturing usability of the fibres. During the second part of the study, the separated Bhimal fibres underwent treatment with varying concentrations of sodium hydroxide (NaOH). To enhance the fibres' surface properties and improve bonding with the matrix material, the fibres were treated with NaOH at 6 %, 8 %, and 10 % concentrations. Surface modification is an essential phase of fibre treatment as it can have a significant impact on the mechanical performance of the composite materials. Once the fibers had undergone treatment, they were formed into mats following two methods: unidirectional and bidirectional. These mats, both treated and untreated, were ready to be tested and further evaluated to determine how treatment influences the mechanical properties of the composite.

For the matrix material, epoxy E-21 (HS code 3709), hardener (MEKP) and carbon fibre (0.2 mm) was procured from Amtech Esters Private Limited, New Delhi. The incorporation of Bhimal fibre with different matrix materials was aimed at producing bio-composites with improved mechanical properties. The unidirectional and bidirectional fibre mats treated with different concentrations of NaOH were used to make composite materials so that their utilization in the field of composites could be accessed. Steps for fibre extraction, fibre treatment, and preparing composite materials are explained in detail to achieve the desired property of bio-composite materials. Utilizing Bhimal fibre, which is light and tough, for making bio-composites is hoped to be a good substitute for synthetic fibre composites, particularly for the eco-friendly industries and for reducing environmental pollution.

Fig.3.1: The images of (a) Bhimal plant, (b) Extracted fibre, (c) fibre treatment and (d) bidirectional mat

3.2 Composite fabrication

The traditional hand layup procedure was used to create the Bhimal fibre composites. When the composite was being made, 2% of the weight was made up of bhimal fibre. A 300 x 210 x 20 mm3 mild steel mold was utilized. Using a stirrer, the epoxy E21 resin and methylethyl- ketone-peroxide (MEKP), which was utilized as a hardener, were combined. After that, the wooden mold was filled with Mylar sheets. As seen in fig. 3.2 (a), the silicon was sprayed onto the Mylar sheet, which serves as a releasing agent. After that, the epoxy and hardener mixture was put over the mold, followed by carbon fibre and bhimal fibre mat.To get the required thickness, the same process was carried out again. The mixture was filled with the leftover mixture. The composite plates were then cut using a wire hacksaw blade in accordance with ASTM standards for water absorption, mechanical, and SEM tests after the composite mold had been cured for 24 hours, as seen in fig. 3.2 (b). The detailed composition of the composite is shown in Table 3.2.

Fig.3.2 The images of (a) spraying releasing agent, and (b) composite mould

Table 3.1 Detailed composition of Natural fibre reinforced hybrid composite

S no.		**Fibre**		**Weight**			
		Before Treatment	After Treatment	Epoxy (g)	Hardener (g)	Carbon fibre(g)	Total (g)
1	Untreated 0°	-	10.15	425	50	15	500

2	Untreated 90°	-	10.24	424	50	16	500
3	Untreated Bidirectional	-	10	423	50	17	500
4	Treated (6% NaOH) 0°	10.35	9	424	50	17	500
5	Treated (6% NaOH) 90°	9.45	8.95	427	50	14	500
6	Treated (6% NaOH) Bidirectional	9.92	9.5	426	50	14	500
7	Treated (8% NaOH) 0°	10.30	9.79	425	50	15	500
8	Treated (8% NaOH) 90°	9.13	8.25	426	50	16	500
9	Treated (8% NaOH) Bidirectional	13.22	11.36	423	50	17	500
10	Treated 10% NaOH 0°	11.07	10.81	421	50	16	500
11	Treated 10% NaOH 90°	11.5	10.32	426	50	17	500
12	Treated 10% NaOH bidirectional	14.17	13.30	421	50	16	500
13	Epoxy	-	-	450	50	-	500

CHAPTER 4

4. CHARATERIZATION OF COMPOSITE MATERIAL

4.1 Physical test

4.1.1 Water absorption test

The samples for moisture absorption measurements followed ASTM D 570 specifications and were thus 50mm diameter disks as seen in Figure 4.1(a). Their weight was taken before immersion in normal water. After 24 hours of immersion, the specimens were taken out of the wet chamber and all surface moisture was wiped using a clean dry towel or tissue paper, as shown in figure 4.1(b). The specimens were immediately weighed again on an electronic digital scale to the nearest 0.001 mg, within a minute after taking them out of the environment room. Weight checks were routinely done on the specimens at 24, 48, and 72 hours during exposure. Moisture absorption was determined using the weight difference. The water absorption tests samples are shown in Figure 4.1. The following formula was used to establish the % weight increase at different times for the specimen:

$$W\% = (W_W - W_d)/ W_d \times 100$$

Where W_W refers to the weight of the specimen at a given time of immersion and W_d represents the dry weight of the specimen.

Fig 4.1: The images of (a) water absorption samples, and (b) water absorption test

4.2 Mechanical Test

4.2.1 Tensile Test

Using a computerized Universal Testing Machine HEICO (HL-590), tensile tests were performed on the dog-bone-shaped specimen in accordance with ASTM D 3039 standards. Figure displays the pictures of the tensile specimen. For the test, a uniaxial force was applied to both ends of the composite specimens. The cross section area (9×13) was used for the experiments. Every sample was subjected to the tests.

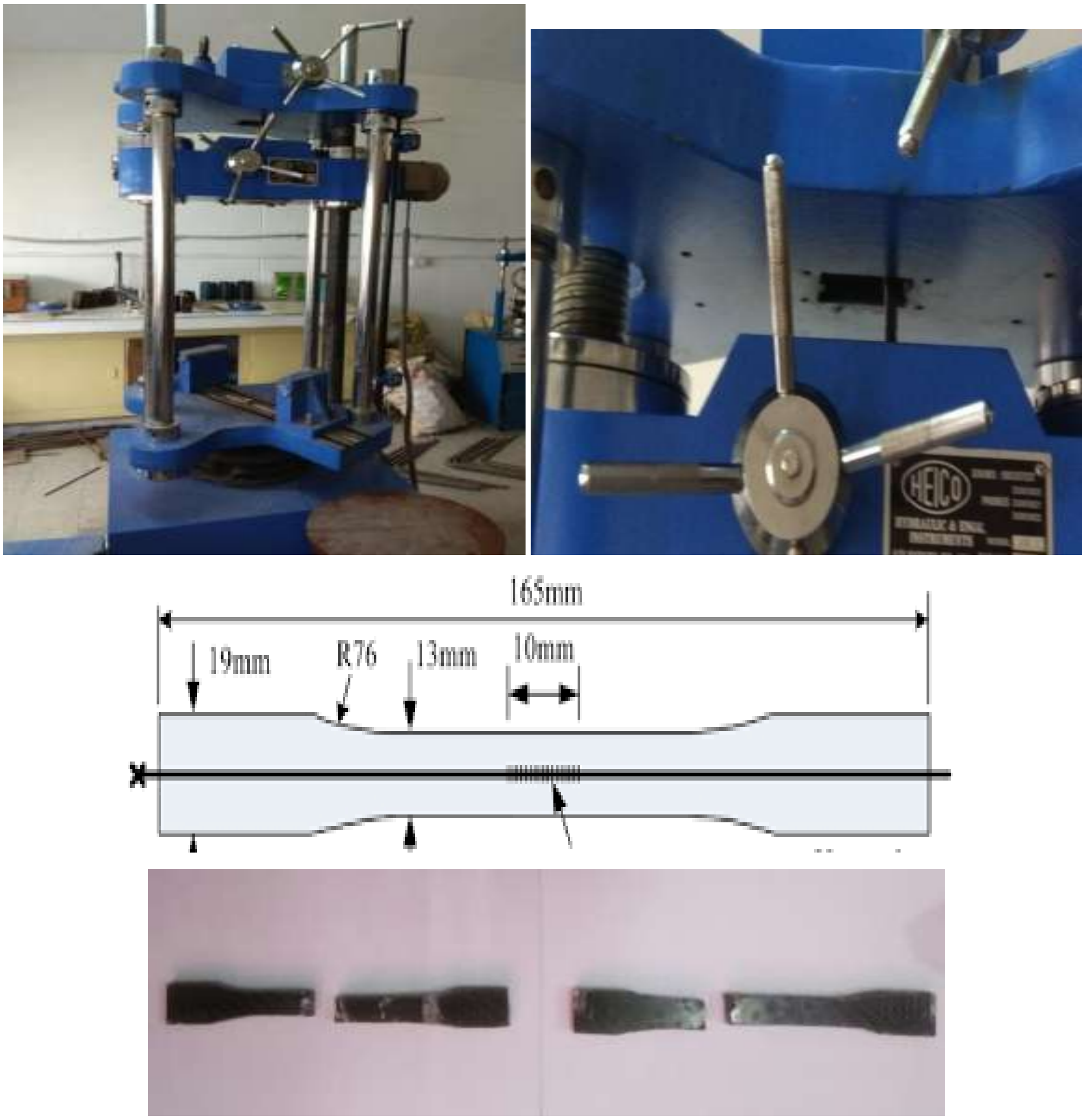


Fig 4.2: The images of (a) UTM (HEICO), (b) Dimension of standard specimen,

(c) specimen after testing

4.2.2 Impact test

As seen in Figure 4.3(a), a Veekay (Model-I 91) impact tester was used to conduct the Charpy impact test. In compliance with ASTM E23 requirements, specimens measuring 55×10×10 mm3 and having a notch depth of 2 mm and a 45˚ angle were examined. The impact energy that the samples have absorbed is shown by the tester in joules. Every composite was put through the test.

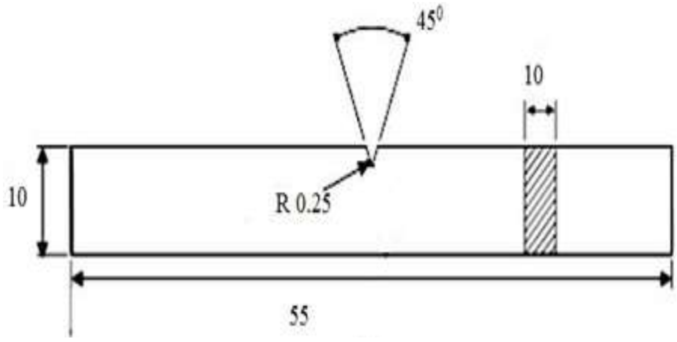


Fig 4.3: The images of (a) Impact testing machine, (b) dimension of standard specimen and (c) specimen after testing

CHAPTER 5

5. RESULT AND DISCUSSION

5.1 Physical Test

5.1.1 Water Absorption test

The water absorption was performed on hybrid composite. Table no.5.1 shows the water absorption readings. Initially during 24 hours, there was slight increase (0.1%) in weight of specimen but after 48 and 72 hours there was no further increase in weight of specimen. From results we can conclude that it absorbs very less amount of water.

Table 5.1: Detailed reading of Water absorption test

S. no.		Treatment	Orientation	Initial weight	24 hours Wt.(gm)	48hours Wt.(gm)	72hou rs Wt.(gm)
1	Untreated	-	0°		19		
2	Untreated	-	90°		28	28	28
3	Untreated	-	Bidirectional		25	25	25
4	Treated	6%NaOH	0°		23	23	23
5	Treated	6%NaOH	90°		20	20	21
6	Treated	6%NaOH	Bidirectional		14	14	13
7	Treated	8%NaOH	0°		22	23	21
8	Treated	8%NaOH	90°		15	15	15
9	Treated	8%NaOH	Bidirectional		21	22	23
10	Treated	10%NaOH	0°		28	28	28
11	Treated	10%NaOH	90°		19	19	20
12	Treated	10%NaOH	Bidirectional		22	22	22
13	Epoxy	-					

5.2 Mechanical Test

5.2.1 Tensile Test

The tensile test was performed on the grewia optiva reinforced hybrid composite. Table no. 5.2 shows the maximum tensile stress at 6 vol% (45.79 N/mm^2). The bidirectional fibre orientation gives maximum tensile stress followed by 0° and 90° respectively at all concentrations. However the tensile stress increases with increase in vol% concentration of NaOH upto 6%

and decreases on further increase in vol% concentration of NaOH. The tensile stress of grewia optiva hybrid composite is higher as compared with tensile stress of pure epoxy (23.00 N/mm^2) [10].6% alkali treated Bidirectional gives the highest value of tensile strength which is 99% and untreated bidirectional shows 86% increment than pure epoxy. It shows treated fibres have more tensile strength as compared with untreated fibres. In the same way 8 vol% NaOH treated Bidirectional gives 39% increment and 10 vol% NaOH treated Bidirectional shows 33.81% increment in tensile strength.

TENSILE TEST READINGS: AREA = 9*13(mm^2)

Table 5.2: Detailed readings of Tensile test

S No.		Treatment	Orientation	Peak Load (N)	Displacement (mm)	Stress (N/mm^2)
1	Untreated	-	0˚	3.96	2.71	33.99
2	Untreated	-	90˚	3.82	2.13	31.24
3	Untreated	-	Bidirectional	5.00	3.22	42.73
4	Treated	6%NaOH	0˚	3.70	2.53	36.35
5	Treated	6%NaOH	90˚	3.90	1.33	32.27
6	Treated	6%NaOH	Bidirectional	5.35	4.09	45.79
7	Treated	8%NaOH	0˚	4.12	2.73	35.25
8	Treated	8%NaOH	90˚	3.79	4.25	32.42
9	Treated	8%NaOH	Bidirectional	3.74	2.46	31.97
10	Treated	10%NaOH	0˚	3.06	2.21	26.15
11	Treated	10%NaOH	90˚	2.33	0.9	24.49
12	Treated	10%NaOH	Bidirectional	3.57	0.81	30.56
13	Epoxy	-	-	-	-	23.00

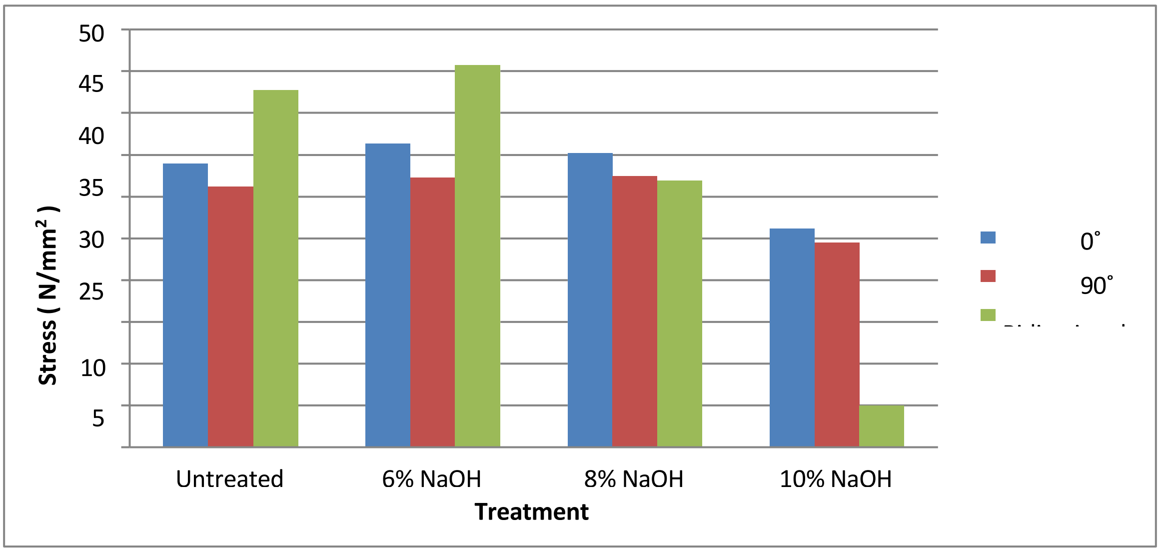


Fig 5.1: Effect of fibre treatment on Tensile Strength

5.2.2 Impact Test

Bhimal fibre (Grewia optiva), as illustrated in Fig. 3.1(b), was employed as the principal material for composite construction. The extraction procedure of Bhimal fibre begins with the collecting of fibre from the stems of the Bhimal tree, depicted in Fig. 3.1(a). This fibre extraction operation took performed during the first week of November, when the limbs of the Bhimal tree were chopped down. After the branches were cut, the sticks were originally put beneath the shadow of a tree to promote drying in a controlled setting. The use of shade drying ensures that the fibres keep their inherent qualities while limiting excessive exposure to direct sunshine, which may impair the quality of the fibre.

Once the branches were sufficiently dried beneath the shade, the procedure proceeded until the spring season, around the first week of April, when all the dried sticks were gathered. At this time, the sticks were put in the sunlight to ensure full drying. This last drying procedure was crucial for ensuring that the moisture content in the sticks was totally eliminated, which is required for the proper extraction of fibres and future processing.

The dried sticks which weighed 15 to 20 kilos each underwent bundling after they had dried. Following the drying process workers transported the bundles to a stream nearby to start the retting process. The running stream was dammed with border stones to create an artificial water pool. The water flow regulation system proves essential for retting processes. A stone was placed over each bundle of sticks to ensure complete submersion during their careful immersion in water. The retting method which involved soaking the bundles over several months lasted for approximately three months. The retting process concluded by June which meant the fibres were prepared for extraction.

The bark of each stick was gently removed in small pieces after completing the retting process. The strips underwent a careful rinsing process in running water to remove all remaining contaminants. Through continuous washing, the outer pulp of the bark underwent cleansing to ensure all residual contaminants were removed to maintain fibre quality. The removal of the outer pulp allowed the inner bark to be separated and extracted from which the precious fibres remained. The removed fibres underwent sun drying to completely eliminate moisture which ensures their suitability for composite fabrication.

The isolated Bhimal fibres received different sodium hydroxide (NaOH) doses during the second phase of the investigation. Researchers processed the fibres by applying sodium hydroxide solutions at 6%, 8%, and 10% concentrations to enhance their surface characteristics and strengthen the bonding to the matrix material. The processing of fibres includes surface treatment because it can significantly alter the mechanical properties of composite materials. The treated fibres were organized into mats displaying two specific orientations which were unidirectional and bidirectional. Researchers prepared fibre mats that had undergone treatment along with untreated ones to evaluate how treatment affected mechanical properties of composites.

The matrix material components including epoxy E-21 (HS code 3709), hardener MEKP and carbon fibre with 0.2 mm diameter came from Amtech Esters Private Limited in New Delhi. The primary objective of combining Bhimal fibre with multiple matrix materials was to create

bio-composites that demonstrated superior mechanical properties. The researchers tested the potential of unidirectional and bidirectional fibre mats with different NaOH treatments when inserted into composite materials. This procedural approach demonstrates why fibre extraction and treatment along with meticulous composite material preparation is essential.

By employing Bhimal fibre, which is both lightweight and strong, the research aims to build bio-composites that provide viable alternatives to typical synthetic fibre composites, especially in businesses focused on sustainability and environmental impact reduction.

Table 5.3: Detailed Readings of Impact test

S. No.		Treatment	Orientation	Impact energy absorbed (Joules)
1	Untreated	-	0˚	4
2	Untreated	-	90˚	4.5
3	Untreated	-	Bidirectional	6
4	Treated	6%NaOH	0˚	6
5	Treated	6%NaOH	90˚	7
6	Treated	6%NaOH	Bidirectional	7.5
7	Treated	8%NaOH	0˚	4.5
8	Treated	8%NaOH	90˚	5
9	Treated	8%NaOH	Bidirectional	6
10	Treated	10%NaOH	0˚	3
11	Treated	10%NaOH	90˚	4
12	Treated	10%NaOH	Bidirectional	4.5

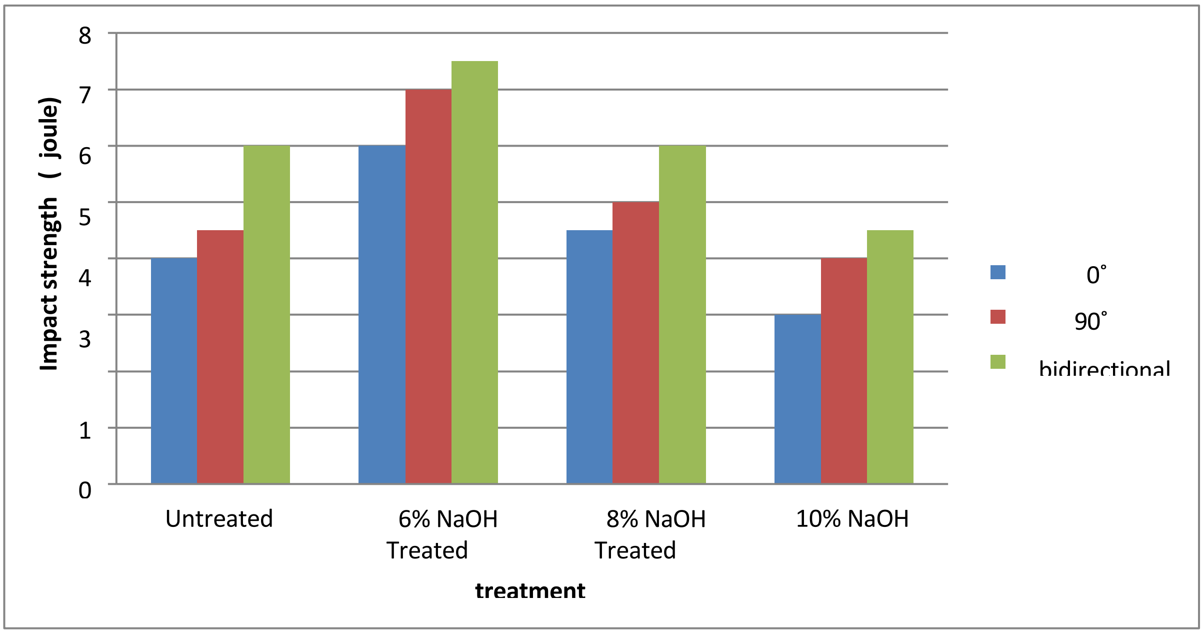


Fig 5.2: Effect of fibre treatment on Impact Strength

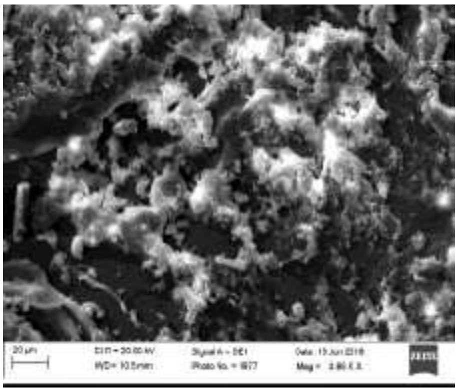
5.3 Morphological Test

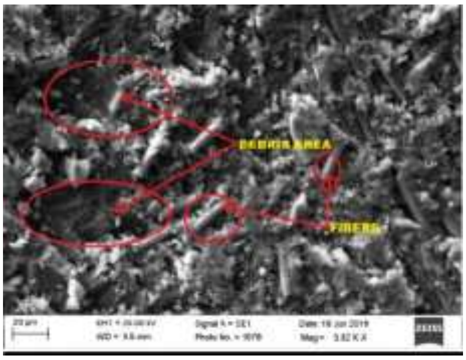
5.3.1 SEM (SCANNING ELECTRON MICROSCOPY) Test

The scanning electron microscope stands out as an advanced form of electron microscope which scans sample surfaces with a focused electron beam to create extremely detailed images. The atoms in the sample produce various signals when interacting with electrons which reveal key information about the sample's elemental composition and surface features. Researchers commonly apply this method to analyze material shapes and surface characteristics at a microscopic scale.

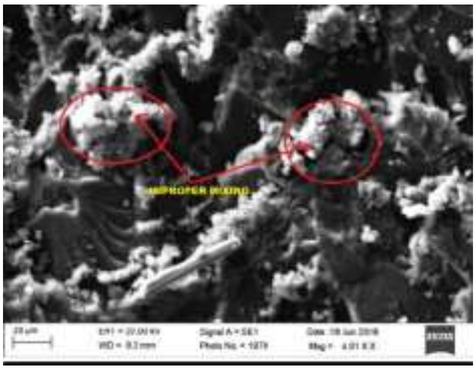
Scanning Electron Microscopy serves as a valuable tool for analyzing both structural integrity and component bonding in composite materials. SEM analysis is conducted on fabricated composite structures which consist of epoxy resin bonded with surface-treated Bhimal fibre at different NaOH concentrations alongside carbon fibre and hardener. The investigation of materials focuses on evaluating bonding quality alongside the detection of internal cracks and interface properties between fibre and resin matrix.

The **cross-sectional analysis** of the composites, as shown in **Figure 5.3**, allows for an in-depth examination of the internal structure of the materials. SEM imaging can reveal issues such as voids, fibre-matrix interfacial bonding, and internal cracks, which can significantly influence the mechanical performance of the composite. By monitoring these factors, researchers can identify potential areas for improvement in the fabrication process, enhancing the material's overall strength and durability.





(a) **(b)**



(c)

Fig.5.3: The images of fractured surface of tensile specimen

(a) 8% unidirectional (b) 6% bidirectional (c) 8% bidirectional

In 8% alkali treated unidirectional and 8% bidirectional composite debris area and D-bonding between fibres and resin is present as shown by figure 5.3(a, c) which is not desired.

In 6% alkali treated bidirectional composite fibre flakes are present in large amount which shows good bonding between fibres and resin so it should have good mechanical properties. In Figure 5.3(b) Because the fibre was homogenous throughout the matrix and the force was properly transmitted through the fibres, the 6% alkali-treated composite had the best tensile and impact strength of all the compositions tested.

CHAPTER-6.

CONCLUSION

In the present investigation, the author relied on Bhimal fibre (Grewia optiva) as the primary material for composite construction, as shown in Fig. 3.1(b). The extraction process of Bhimal fibre starts from collecting the fibre from the stem of Bhimal tree, as shown in fig. 3.1(a). The fibre extraction took place during the first week of November, at the time of sunrise when limbs were being cut from the Bhimal tree. The first branch was stacked under a tree and later dried in a controlled environment. This form of shade drying stops excessive exposure to direct sunlight which affects the quality of the fiber, while allowing the fibers to retain their natural qualities.

This was the first step into the next process; the stage continued until the Spring when all the sticks were collected early in April. The sticks were given light sun exposure to achieve total dryness. The entire extraction of water from the sticks was found extremely necessary for the complete removal of moisture thus favoring the very good extraction of fiber before other processing steps were undertaken.

During the drying phase, staff members collected bundles of sticks weighing between 15-20 kilos each. The field workers then took the bundles to a creek where retting was done. A water pool was built at the site through stone damming for managing the flow of running water. The developed system of regulation of the water flow is quite instrumental in the retting processes. The process required placing a rock on top of each bundle to completely submerge it underwater in the pool. Those bundles underwent what is referred to as retting, meaning soaking them for several months in this specific process for about three months. Logan checked a completed process of retting in June to start extraction of the fibers.

Each stick bark stripping began after with retting during which small precise bark portions were removed under control. Washing of strips with running water received great attention to remove remaining contaminants. Continuous washing with watering was done to wash the outer pulp from the bark until it became free from all contaminants that could potentially be harmful. Great care was taken to peel off the outer pulp in order to move to the next step of separating and pulling off the valuable fibers from the inner bark. Drying of the sundry fibers was needed before any fabrication of composite materials, as they had to get to the necessary moisture-less state.

The second phase in this research involved the subjecting of the isolated Bhimal fibres to various concentrations of sodium hydroxide (NaOH). The Bhimal fibres received treatment of NaOH with percentage concentrations of 6%, 8% and 10% to improve their surface properties and enhance the bonding with matrix materials. The surface treatment of fibres forms an importan part in fibre processing since it could greatly affect the mechanical properties of composite materials.

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