# A Review on Advance Material with Jute Fiber-Polyester Reinforced Composites

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**Abstract**

Natural fibers have been used to reinforce materials for over 3,000 years. More recently they have been employed in combination with plastics. Many types of natural fibers have been investigated for use in plastics including Flax, hemp, jute, straw, wood fiber, rice husks, wheat, barley, oats, rye, cane (sugar and bamboo), grass reeds, kenaf, ramie, oil palm empty fruit bunch, sisal, coir, water hyacinth, pennywort, kapok, paper-mulberry, banana fiber, pineapple leaf fiber and papyrus. Natural fibers have the advantage that they are renewable resources and have marketing appeal. The Asian markets have been using natural fibers for many years e.g., jute is a common reinforcement in India. Natural fibers are increasingly used in automotive and packaging materials. Pakistan is an agricultural country and it is the main stay of Pakistan's economy. Thousands of tons of different crops are produced but most of their wastes do not have any useful utilization. Agricultural wastes include wheat husk, rice husk, and their straw, hemp fiber and shells of various dry fruits. These agricultural wastes can be used to prepare fiber reinforced polymer composites for commercial use. This report examines the different types of fibers available and the current status of research. Many references to the latest work on properties, processing and application have been cited in this review.

**Key Words:** Matrix, Binder, Composites.

## I. Introduction

Composites are materials that comprise strong load carrying material (known as reinforcement) imbedded in weaker material (known as matrix). Reinforcement provides strength and rigidity, helping to support structural load. The matrix or binder (organic or inorganic) maintains the position and orientation of the reinforcement. Significantly, constituents of the composites retain their individual, physical and chemical properties; yet together they produce a combination of qualities which individual constituents would be incapable of producing alone. Wood is natural three-dimensional polymeric composite and consists primarily of cellulose, hemi-cellulose and lignin. In addition, wood is an original and natural composite. The biological world offers other examples of composites in bone and teeth, which are essentially composed of hard inorganic crystals in a matrix of tough organic collagen. Historical examples of composites are abundant in literature. Significant examples include the use of reinforcing mud walls in houses with bamboo shoots, glued laminated wood by Egyptians (1500 BC) and laminated metals in the forging of swords (1800 AD). In the 20th century, modern composites were used in 1930s, where glass fibers reinforced resins. Boats and aircrafts were built out of these glass composites, commonly called fiberglass. Since the 1970s, the application of composites has widely increased due to development of new fibers such as carbon, boron, aramids, and new composite systems with matrices made of metal and ceramics.

## II. Types of Composites

For the sake of simplicity, however, composites can be grouped into categories based on the nature of the matrix each type possesses. Methods of fabrication also vary according to physical and chemical properties of the matrices and reinforcing fibers.

### Polymer Matrix Composites (PMCs)

The most common advanced composites are polymer matrix composites. These composites consist of a polymer thermoplastic or thermosetting reinforced by natural fiber. These materials can be fashioned into a variety of shapes and sizes. They provide great strength and stiffness along with resistance to corrosion. The reason for these being most common is their low cost, high strength and simple manufacturing principles.

### Metal Matrix Composites (MMCs)

Metal matrix composites, as the name implies, have a metal matrix. Examples of matrices in such composites include aluminum, magnesium and titanium. The typical fiber includes carbon and silicon carbide. Metals are mainly reinforced to suit the needs of design. For example, the elastic stiffness and strength of metals can be increased, while large co-efficient of thermal expansion, and thermal and electrical conductivities of metals can be reduced by the addition of fibers such as silicon carbide.

### Ceramic Matrix Composites (CMCs)

Ceramic matrix composites have ceramic matrix such as alumina, calcium, aluminosilicates reinforced by silicon carbide. The advantages of CMC include high strength, hardness, high service temperature limits for ceramics, chemical inertness and low density. Naturally resistant to high temperature, ceramic materials have a tendency to become brittle and to fracture. Composites successfully made with ceramic matrices are reinforced with silicon carbide fibers. These composites offer the same high temperature tolerance of super alloys but without such a high density. The brittle nature of ceramics makes composite fabrication difficult. Usually most CMC production procedures involve starting materials in powder form. There are four classes of ceramics matrices: glass (easy to fabricate because of low softening temperatures, include borosilicate and aluminosilicates), conventional ceramics (silicon carbide, silicon nitride, aluminum oxide and zirconium oxide are fully crystalline), cement and concreted carbon components.

**Carbon-carbon composites (CCMs)**

CCMs use carbon fibers in a carbon matrix. Carbon-carbon composites are used in very high temperature environments of up to 6000°F, and are twenty times stronger and thirty times lighter than graphite fibers.

## III. Constituents of composites

1. Matrices
2. Reinforcing Fibers

**Matrices**

The role of matrix in a fiber-reinforced composite is to transfer stress between the fibers, to provide a barrier against an adverse environment and to protect the surface of the fibers from mechanical abrasion. The matrix plays a major role in the tensile load carrying capacity of a composite structure. The binding agent or matrix in the composite is of critical importance. Four major types of matrices have been reported: Polymeric, Metallic, Ceramic and Carbon. Most of the composites used in the industry today are based on polymer matrices. Polymer resins have been divided broadly into two categories:

1. Thermosetting
2. Thermoplastics

**Thermosetting**

Thermoset is a hard and stiff cross linked material that does not soften or become moldable when heated. Thermosets are stiff and do not stretch the way that elastomers and thermoplastics do. Several types of polymers have been used as matrices for natural fiber composites. Most commonly used thermoset polymers are epoxy resins and other resins (Unsaturated polyester resins) Vinyl Ester, Phenolic Epoxy, Novolac and Polyamide. Unsaturated polyesters [6] are extremely versatile in properties and applications and have been a popular thermoset used as the polymer matrix in composites. They are widely produced industrially as they possess many advantages compared to other thermosetting resins including room temperature cure capability, good mechanical properties and transparency. The reinforcement of polyesters with cellulosic fibers has been widely reported. Polyester-jute, Polyester-sisal, polyester-coir, polyester-banana-cotton, polyester-straw, polyester-pineapple leaf, and polyester- cotton-kapok, are some of the promising systems.

**Thermoplastics**

Thermoplastics are polymers that require heat to make them processable. After cooling, such materials retain their shape. In addition, these polymers may be reheated and reformed, often without significant changes in their properties. The thermoplastics which have been used as matrix for natural fiber reinforced composites are as follows:

1. High density polyethene (HDPE)
2. Low density polyethene (LDPE)
3. Chlorinated polyethylene (CPE)
4. Polypropylene (PP)
5. Normal polystyrene (PS)
6. Poly (Vinyl chloride) PVC)
7. Mixtures of polymers
8. Recycled Thermoplastics

Only those thermoplastics are useable for natural fiber reinforced composites, who's processing temperature (temperature at which fiber is incorporated into polymer matrix) does not exceed 230°C. These are, most of all, polyolefinnes, like polyethylene and polypropylene. Technical thermoplastics, like polyamides, polyesters and polycarbonates require processing temperatures > 250°C and are therefore not useable for such composite processing without fiber degradation.

## IV. Reinforcing fibers

The three most common types of reinforcing fibers include fiberglass, carbon and Aramid.

**Carbon fibers**

Carbon fibers are used for reinforcing certain matrix materials to form composites. Carbon fibers are unidirectional reinforcements and can be arranged in such a way in the composite that it is stronger in the direction, which must bear loads. The physical properties of carbon fiber reinforced composite materials depend considerably on the nature of the matrix, the fiber alignment, the volume fraction of the fiber and matrix, and on the molding conditions. Several types of matrix materials such as glass and ceramics, metal and plastics have been used as matrices for reinforcement by carbon fiber. Carbon fiber composites, particularly those with polymer matrices, have become the dominant advanced composite materials for aerospace, automobile, sporting goods and other applications due to their high strength, high modulus, low density, and reasonable cost for application requiring high temperature resistance as in the case of spacecrafts.

**Glass fibers**

Glass fibers are the most common of all reinforcing fibers for polymeric (plastic) matrix composites (PMCs). The principal advantages of glass fiber are low cost, high tensile strength, high chemical resistance and excellent insulating properties. The two types of glass fibers commonly used in the fiber reinforced plastics industries are E-glass and S-glass. Another type known as C-glass is used in chemical applications requiring greater corrosion resistance to acids than is provided by E-glass.

**Kevlar fibers**

Kevlar belongs to a group of highly crystalline aramid (aromatic amide) fibers that have the lowest specific gravity and the highest tensile strength to weight ratio among the current reinforcing fibers. They are being used as reinforcement in many marine and aerospace applications.

**Boron fiber**

The most prominent feature of boron fiber is their extremely high tensile modulus. Boron fibers offer excellent resistance to buckling, which in turn contributes to high compressive strength for boron fiber reinforced composites.

**Natural Fibers**

The use of natural fiber for the reinforcement of the composites has received increasing attention both by the academic sector and the industry. Natural fibers have many significant advantages over synthetic fibers. Currently, many types of natural fibers have been investigated for use in plastics including flax, hemp, jute straw, wood, rice husk, wheat, barley, oats, rye, cane (sugar and bamboo), grass, reeds, kenaf, ramie, oil palm empty fruit bunch, sisal, coir, water, hyacinth, pennywort, kapok, paper mulberry, raphia, banana fiber, pineapple leaf fiber and papyrus. Thermoplastics reinforced with special wood fillers are enjoying rapid growth due to their many advantages; lightweight reasonable strength and stiffness. Some plant proteins are interesting renewable materials, because of their thermoplastic properties. Wheat gluten is unique among cereal and other plant proteins in its ability to form a cohesive blend with viscoelastic properties once plasticized. For these reasons, wheat gluten has been utilized to process edible or biodegradable films or packing materials. Hemp is a bast lingo-cellulosic fiber, comes from the plant *Cannabis sativa* and has been used as reinforcement in biodegradable composites. Composites based on biologically degradable polyester amide and plant fiber (flax and cottons) with good mechanical properties, such as sufficient water resistance and biodegradability, have also been investigated.

Kenaf, *Hibiscus cannabinus*, a member of hibiscus family is also a biodegradable and environmentally friendly crop. It has been found to be an important source of fiber for composites and other industrial applications. The mechanical properties of composites manufactured from polyester resin with Kenaf fiber that blows to a height of at least 10 meter. Traditionally, hemp has been used to make ropes but these days its fiber is used to make items such as clothing, toys and shoes. The fiber is fully biodegradable, is non-toxic and may be recycled.

Flax fibers are potentially outstanding reinforcing fillers in thermoplastic bio composites. These bio composites could have a great potential in lowering the usage of petroleum based plastics. Automotive, building and appliance industries are increasing the utilization of flax fibers day by day due to cost saving, non-abrasiveness and the green movement. Bio composites containing thermoplastics and modified flax fiber have mechanical properties comparable with those of glass fiber-based thermoplastic (LLDPE/ HDPE) composites includes the mechanical properties of flax/polypropylene composites, manufactured both with batch kneading and an extrusion process, and compared with the properties of natural fiber mat thermoplastic composites. Yang *et al.* have studied the effect of compatibilizing agents on the mechanical properties and morphology of thermoplastic polymer composites filled with rice husk flour. As the filler loading increases, the composites made without any compatibilizing agent show decreased tensile strength and more brittleness, but greatly improved mechanical properties by incorporation of the compatibilizing agent. The poor interfacial binding between the filler and the polymer matrix causes the composites to have decreased tensile strength, but the tensile strength and modulus improve with the addition of compatibilizing agent. Wheat straw has been used for making composites, panel boards and anion exchangers where the straw is used in powder form rather than in the fibrous form. A limited number of studies have reported the use of wheat straw fibers for production of composites. Panthapulakkal *et al.* has processed and characterized wheat straw fibers to evaluate their potential as reinforcing material for thermoplastic composites. Jute is also one of the most common agro fibers used as a reinforcing component for thermoplastics and thermosetting matrices. Bamboo is an abundant natural source in Asia and South America and has been used to develop bamboo reinforced thermosetting plastic (epoxy and polyester). Thwe *et al.* have investigated the effect of environmental aging on the mechanical properties of bamboo-glass fiber reinforced polymer matrix hybrid composite. Okubo *et al.* have fabricated bamboo fiber eco-composites for ecological purposes with the conventional hot press method. They studied their static strength and internal state after their fabrication, and concluded that high weight content of bamboo fiber enabled the bamboo composites to increase their strength in the most effective way, when the bamboo fiber was modified into the cotton shape.

## V. Mechanical properties of natural fibers

The mechanical properties and physical properties of natural fibers vary considerably depending on the chemical and structural composition, fiber type and growth conditions. Mechanical properties of plant fibers are much lower when compared to those of the most widely used competing reinforcing glass fibers. However, because of their low density, the specific properties (property-to-density ratio), strength, and stiffness of plant fibers are comparable to the values of glass fibers.

**Advantages of natural fiber**

Natural fibers, as reinforcement, have recently attracted the attention of researchers because of their advantages over other established materials. They are environmentally friendly, fully biodegradable, abundantly available, renewable and cheap and have low density. Plant fibers are light compared to glass, carbon and aramid fibers. The biodegradability of plant fibers can contribute to a healthy ecosystem while their low cost and high performance fulfils the economic interest of industry. When natural fiber-reinforced plastics are subjected, at the end of their life cycle, to combustion process or landfill, the released amount of $CO_2$ of the fibers is neutral with respect to the assimilated amount during their growth. The abrasive nature of fiber is much lower which leads to advantages in regard to technical process and recycling process of the composite materials in general. Natural fiber-reinforced plastics, by using biodegradable polymers as matrices, are the most environmental friendly materials, which can be composed at the end of their life cycle. Natural fiber composites are used in place of glass mostly in non-structural applications. A number of automotive components previously made with glass fiber composites are now being manufactured using environmentally friendly composites. Although natural fibers and their composites are environmental friendly and renewable (unlike traditional sources of energy, i.e., coal, oil and gas), these have several bottlenecks. These have: poor wettability, incompatibility with some polymeric matrices and high moisture absorption. Composite materials made with the use of unmodified plant fibers frequently exhibit unsatisfactory mechanical properties. To overcome this, in many cases, a surface treatment or compatibilizing agents need to be used prior to composite fabrication. The properties can be improved both by physical treatments (cold plasma treatment, corona treatment) and chemical treatments (maleicanhydride organosilanes, isocyanates, sodium hydroxide permanganate and peroxide). Mechanical properties of natural fibers are much lower than those of glass fibers but their specific properties, especially stiffness, are comparable to the glass fibers.

**Chemical modification of natural fibers**

One of the major problems associated with the use of natural fibers in composites is their high moisture sensitivity leading to severe reduction of mechanical properties and delamination. The reduction in mechanical properties may be due to poor interfacial bonding between resin matrices and fibers. It is therefore necessary to modify the fiber surface to render it more hydrophobic and also more compatible with resin matrices. An effective method of chemical modification of natural fibers is graft copolymerization. The resulting co-polymer displays the characteristic properties of both fibrous cellulose and grafted polymer. One of the most explored chemical modifications is the acetylation-esterification of cellulose-OH, by reaction with acetic anhydride. This reaction reduces hydrophilicity and swelling of lignocellulosics and their composites. The effect of chemical treatment of natural fibres with sodium alginate and sodium hydroxide has also been reported for coir, banana and sisal fibres by Mani *et al.*. This modification results in an increase in adhesive bonding and thus improves ultimate tensile strength up to 30%. Mitra *et al.*, have reported that treatment of jute with polycondensates such as phenol-formaldehyde, melamine-formaldehyde and cashew nut shell with liquid-formaldehyde improves the wettability of jute fibres and reduces water regain properties. Samal and Ray have studied the chemical modification of pineapple leaf fibers using alkali treatment, diazo coupling with aniline and cross-linking with formaldehyde. These chemical treatments result in significant improvements in mechanical properties, chemical resistance and reduced moisture regain. Finally, Joseph *et al.*, have investigated the influence of chemical treatment with sodium hydroxide, isocyanate and peroxide on the properties of sisal/polyethylene composites. The observed enhancement in properties of the composites and attributed this to the strong bonding between sisal and polyethylene matrix. In an effort to improve the mechanical properties of recycled HDPE/wood fiber composites, Selke *et al.* investigated the use of several additives with possible effect on the fibre/matrix adhesion or fibre dispersion into the matrix. They found that maleic anhydridemodified polypropylene appears especially promising, since its use at a concentration of 5% in composites with 30% wood fibre results in an increase in tensile strength and elongation at break. Similar results have been obtained by Dalvag *et al.*, who have reported that the composite’s elastic modulus remains unchanged. Zadorecki and Flodin have found that some coupling agents, namely trichloro-striazine and di-methylol melamine can produce covalent bonds between cellulosic materials and polymer matrices, leading to modifi ed performance and reduced sensitivity to water. This approach has been further explored by Maldas and Kokta, who used phthalic anhydride as coupling agent for wood fiber/polystyrene composites. In addition to the chemical affinity of the benzene rings of phthalic anhydride with those of polystyrene, the anhydride group can directly attack the –OH group of cellulose. Furthermore, Razi *et al.* found that the treatment of wood with sodium hydroxide followed by drying with vinyltrimethoxysilance is superior, for obtaining maximum bonding strength at the wood/polymer interface that yields improved mechanical properties.

**Special types of composites based on natural fibers**

In general, the mechanical and physical properties of natural fiber reinforced plastics only conditionally reach the characteristic values of glass-fiber reinforced systems. By using hybrid composites, made of natural fibers and carbon fibers or natural fibers and glass fibers, the properties of natural fiber reinforced composites can be improved further for compression strength. Natural fiber composites have been evaluated with regard to their anti-ballistic characteristics. Flax, hemp and jute reinforced polypropylene composites, with or without mild steel backing or facing, have been studied under ballistic impact test conditions. Many researchers have investigated the response of composite materials to ballistic impact. Recently, D'Almeida *et al.* investigated ballistic impact damage of glass fiber reinforced epoxy composites, while Hasur *et al.* reported on the response of carbon/epoxy composites under high velocity impact. Lee *et al.* studied ballistic impact on armour grade spectra and aramid reinforced composites, whereas Chou *et al.* worked on damage of S2 glass reinforced plastic structural armour. Hine *et al.* studied the energy absorption of woven nylon and aramid composites and UHMWPE (ultra high molecular weight polyethylene). Cantwel and Villanueva investigated the failure of fiber metal laminate (FML) reinforced aluminum foam sandwich structures at high velocity impact. Research on ballistic impact has been focused only on the high performance fibers, metal and ceramics and now attempts have been made to study the behavior of national fiber composite under ballistic impact. Wambua *et al.* bridged the gap and investigated the response of flax, hemp, and jute fabric reinforced polypropylene composites to ballistic impact by fragment simulating projectiles.

**Textile Composites**

Textile composite materials are composed of fibres fibre, yarn or fabric system and matrix material that is bind and protect the fibres. The fibres are usually the load bearing members, while the polymeric matrix provides transverse integrity and transfers the load onto the fibres. Besides of the properties of two main components of fibre and matrix, the fibre/matrix interphase also plays a crucial role for the load transfer. It is not a distinct phase, as the interphase does not have a clear boundary. This region exits between bulk fibre and bulk matrix and may contain several different layers as in the case of sizing.

**Jute Composites**

Jute composite materials consist of jute fibres of high strength and modulus embedded in or bonded to a matrix with distinct interfaces (boundary) between them. In this form, both fibres and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone. In general, jute fibres are the principle load carrying member, while the surrounding matrix keeps them in the desired location and orientation, acts as a load transfer medium between them, and protects them from environmental damages due to elevated temperature and humidity.

**Why Jute Fibre?**

The most important types of natural fibres used in composite materials are flax, hemp, jute, kenaf, and sisal due to their properties and availability. Using jute fiber for composites has many advantages. Firstly is has wood like characteristics as it is a bast fibre. Jute has high specific properties, low density, less abrasive behavior to the processing equipment, good dimensional stability and harmlessness. Jute is renewable, versatile, nonabrasive, porous, hydroscopic, visco-elastic, biodegradable, combustible, and reactive. The fiber has a high aspect ratio, high strength to weight ratio, and has good insulation properties. Jute textile is a low cost eco-friendly product and is abundantly available, easy to transport. The biodegradable and low priced jute products merge with the soil after using providing nourishment to the soil. Being made of cellulose, on combustion, jute does not generate toxic gases. Some might consider part of these properties as disadvantages, such as biodegradable and combustible, but these features provide a means of predictable and programmable disposal not easily achieved with other resources.

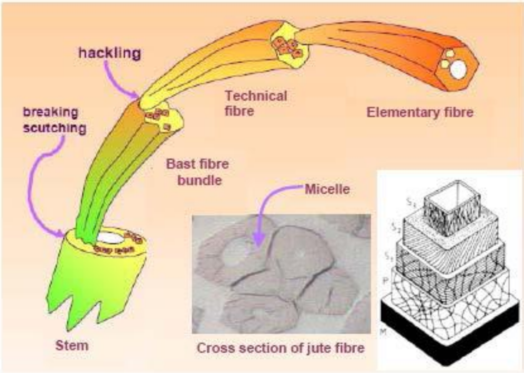


**Fig. Jute Fiber Cross Section**

**Strength of Jute as Reinforcing Material for Composite**

- Jute is bio-degradable and replenishes earth nutrients.
- Jute possess no threat to the environment because it neither emits toxic gases nor harmful chemicals
- Jute will not cause the problems like the synthetic material in waste management cycles through emitting hazardous gases during incineration of landfill sites.
- Jute makes durable and strong composite, handling of which is easier.
- Abundant availability of jute fibre.

**Weakness of Jute as Reinforcing Material for Composite**

- Moist condition, usually more than 60% of moisture can reduce the tensile strength of the Jute Fibre.
- Acidic contact or atmosphere can reduce the luster as well as tensile strength.
- Pectin and lignin bonds inherited in Raw Jute can rot or deteriorate the quality of the Jute Fibre.

However, this weakness can be overcome by proper retting, washing, drying process and modification of jute fibre.

**Technical applications of natural fiber reinforced composites**

Natural fibers are replacing synthetic fibers as reinforcement in various matrices. The composites so prepared can effectively be used as substitute for wood and also in various other technical fields, e.g. automotive parts. Seventy years ago, nearly all resources for the production of commodities and many technical products were materials derived from natural textiles. Textiles, ropes, canvas and also paper, were made of local natural fibers, such as flax and hemp. Some of these are still used today. As early as 1908, the first composite materials were applied for the fabrication of large quantities of sheets, tubes and pipes for electronic purposes (paper or cotton to reinforce sheets, made of phenol or melamine-formaldehyde resins). For example in 1996, aero plane seats and fuel tanks were made of natural fibers with small content of polymeric binders. The last decade has seen a multiplicity of applications of natural fiber composites due to their impressive properties such as biodegradability and high specific properties. Currently, a revolution in the use of natural fibers, as reinforcements in technical application, is taking place mainly in the automobile and packaging industries (e.g., egg boxes). In the automotive industry, textile waste has been used for years to reinforce plastics used in cars, especially in the Trabant. The use of natural fibers within composite applications is being pursued extensively throughout the world. Consequently, natural fiber composite materials are being used for making many components in the automotive sector. These materials are based largely on polypropylene or polyester matrices, incorporating fibers such as flax, hemp, and jute. Thus in the future cars may be molded from cashew nut oil and hemp. Even golf clubs may be built around jute fibers, and tennis racket may be stiffened with coconut hair. Bicycle frames may derive their strength from any one of the 2000 other suitable plants. The high-tech revolution in use of natural fibers could end in replacement of synthetic materials. The diverse range of products now being produced, utilizing natural fibers and bio based resins derived from soybeans, is giving life to a new generation of bio based composites for a number of applications. These include not only automotive vehicles (including trucking) but also hurricane-resistant housing and structures, especially in the United States. The construction sector and the leisure industry are some of the other areas where these novel materials are finding a market. In Germany, car manufactures are aiming to make every component of their vehicles either recyclable or biodegradable.

## VI. Future Outlook

In order to be environment friendly, automotive engineers have now developed a concept car, the Eco Car. It is expected to be the sustainable vehicle for the future, running on biofuels. It uses natural fiber composite panels where biodegradable resins have been incorporated as the matrix material. It has been recently predicted that the most important technologies of the future that incorporate natural fiber composite materials will be natural fibers for injection moulded products (32%) followed by natural fibers with a bio plastic matrix (19%) and modified fibers for use in advanced applications (19%).

## VII. Conclusion

Natural fibers, when used as reinforcement, compete with such technical fibers as glass fiber. The advantages of technical fibers are good mechanical properties; which vary only little, while their disadvantage is difficulty in recycling. Several natural fiber composites reach the mechanical properties of glass fiber composites, and they are already applied, e.g., in automobile and furniture industries. Till date, the most important natural fibers are Jute, flax and coir. Natural Fibers are renewable raw materials and they are recyclable.

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