# Tensile Properties of Natural Fiber Reinforced Polymer Composite – A Review

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***Abstract***- *There has been a growing interest in utilizing fibers as reinforcement to produce composite materials. Scientists prefer natural fiber as a reinforced material to make polymer composites. Natural fiber have recently become attractive to researchers, engineers and scientists as an alternative reinforcement for fiber due to their low cost, fairly good mechanical properties, high specific strength, non-abrasive, eco-friendly and bio-degradability characteristics. Mechanical properties of fiber-reinforced polymer composites are studied by many researchers and few of them are discussed in this article. Various fiber treatments, which are carried out to improve the fiber–matrix adhesion to get improved mechanical properties, are also discussed in this article.*

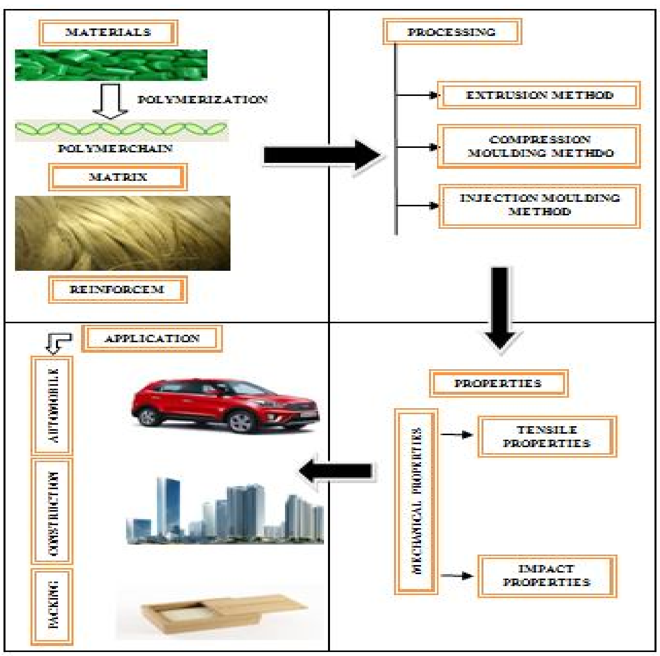


Figure 1.Graphical Abstract

***Keywords***- Natural fibers, polymer composites, polymer matrix, tensile properties

## I. INTRODUCTION

Now a day, we find that polymers have replaced many of the conventional metals/materials in various applications. This is possible because of the advantages of polymers over conventional materials. The most important advantages of using polymers are the ease of processing, productivity, and cost reduction. In most of these applications, the properties of polymers are modified using fillers and fibers to suit the high strength/high modulus requirements. These modified polymer composites are finding applications in diverse fields from appliances to spacecrafts.

Polymer composite material is made by combining two or more materials to give a unique combination of improved properties, such that each component retains its physical identity. A composite material is generally composed of reinforcement (fibers, particles, etc.) embedded in a matrix (polymers, metals, ceramics, etc). The matrix holds the reinforcement while the reinforced material improves the overall mechanical properties of the matrix. .

In fiber-reinforced polymer composite, reinforcement may either include natural fibers or synthetic fibers in polymer matrix. Natural fibers have become better replacement of synthetic fibers due to their advantages over synthetic fiber. Natural fibers show advantages such as low cost, low density, availability in abundance, environmental friendly, nontoxicity, high flexibility, renewability, bio-degradability, relative non abrasiveness, high specific strength and modulus, and ease of processing.

### Natural Fibers

The- idea of Natural fiber composites and their study has attracted attention of researchers since the early 1980's. Composites of primarily glass and natural reinforced composites, are found in countless consumer products including: boats, skis, agricultural machinery and cars [1,2,3]. A major goal of natural fiber composites is to alleviate the need to use expensive glass fiber ($3.25/kg) which has a relatively high density (2.5 g/cm³) and is dependent on nonrenewable sources [1,3].

Table 1: Natural and Synthetic Fibers (Selected tensile properties)

| Fiber | Density (g/cm$_3$) | Tensile Strength (Mpa | Specific Tensile Strength (Mpa) | Elastic Modulus (Gpa | Specific Elastic Modulus (GPa) |
|---|---|---|---|---|---|
| Cotton | 1.5-1.6 | 400 | 250-267 | 5.5-12.6 | 3.5-8.1 |
| Kena | 1.45 | 930 | 641 | 53 | 36.5 |
| Sisal | 1.5 | 511-635 | 341-423 | 9.4-22 | 6.3-14.7 |
| E-glass | 2.5 | 2,000-3,500 | 800-1,400 | 70 | 28 |
| Carbon | 1.4 | 4,000 | 2,857 | 230-240 | 164-171 |


Figure2. Variety of natural fiber produced by plant

The use of natural fiber composites have already been incorporated by car manufactures for improvement of interior and exterior parts. This serves a two-fold goal of the automobile companies; to lower the overall weight of the vehicle thus increasing fuel efficiency and to increase the sustainability of their manufacturing process. Many companies such as Daimler Chrysler, Toyota and Mercedes Benz have already accomplished this and are looking to expand the uses of natural fiber composites[1]. Natural fibers with a density of 1.15-1.50 $g/cm^3$ are significantly lighter than E-glass with 2.4 $g/cm^3$ as indicated in Table 1.

Two major factors are there which limit the large scale production of natural fibers composites. First, the strength of natural fiber (Table 1) composites is very low compared to E-glass. This is often a result of the incompatibility between the fiber and the polymer matrix. Though when comparing specific strengths, natural fibers are not much less than glass fiber composites. The second is water absorption. Natural fibers absorb water from the air and direct contact from the environment. This absorption deforms the surface of the composites by swelling and creating voids. The result of these deformations is lower strength and an increase in mass. Additionally, with water absorption rates as high as 20 wt% the light weight advantage is often nullified.

To overcome these two limiting factors related with the natural fiber composites i.e. the incompatibility of the fibers and poor resistance to moisture, the choice of type of natural fiber is very important. This review presents the reported work on natural fiber reinforced composites with special reference to the type of fibers and matrix polymers.

The natural fibers such as cellulose fiber,[4–8] wood fiber,[9–12] flax,[13–18] hemp,[19–21] silk,[22–25] jute,[26–28] sisal,[29–31] kenaf,[32,33] cotton[34] and so on are being used to reinforce polymers by many researchers. Some advantages of natural fibers are low abrasion resistance, low density, high toughness, acceptable specific strength properties, good thermal properties, enhanced energy recovery, biodegradability and so on.[35–41] Natural fibers produce composites that offer advantages like environmental friendliness, renewability of the fibers, good sound abatement capability and improved fuel efficiency.[42-46]

Natural fibers are abundant and renewable bio-based materials. The properties (low density, abundant, and high specific strength) of natural fibers make them better replacement of synthetic fiber for environmental concern. The most used synthetic fibers in composites are glass,[49–52] carbon,[53–55] and aramid.[56,57] Among the synthetic fibers, glass fibers are widely used due to their low-cost (compared to carbon and aramid) and better physicomechanical properties.[58]

The natural fibers have been used as reinforcement by different researchers include jute [59, 60] banana[60,61] sisal[61,62] etc. A systematic classification of reinforcement material which is natural fibers is given in Figure 3. The two main sources of natural fibers are plants and animals. The main component of animal-based fibers is protein: examples include wool, silk, mohair, alpaca, angora, and so on. The major components of plant fibers are cellulose, microfibrils, hemicellulose, and lignin: examples include cotton, jute, flax, ramie, sisal, hemp, and so on. Form the literature survey it has been observed that a lot of work is done on plant based natural fiber. Animal based natural fibers, reinforcement is not reported much.

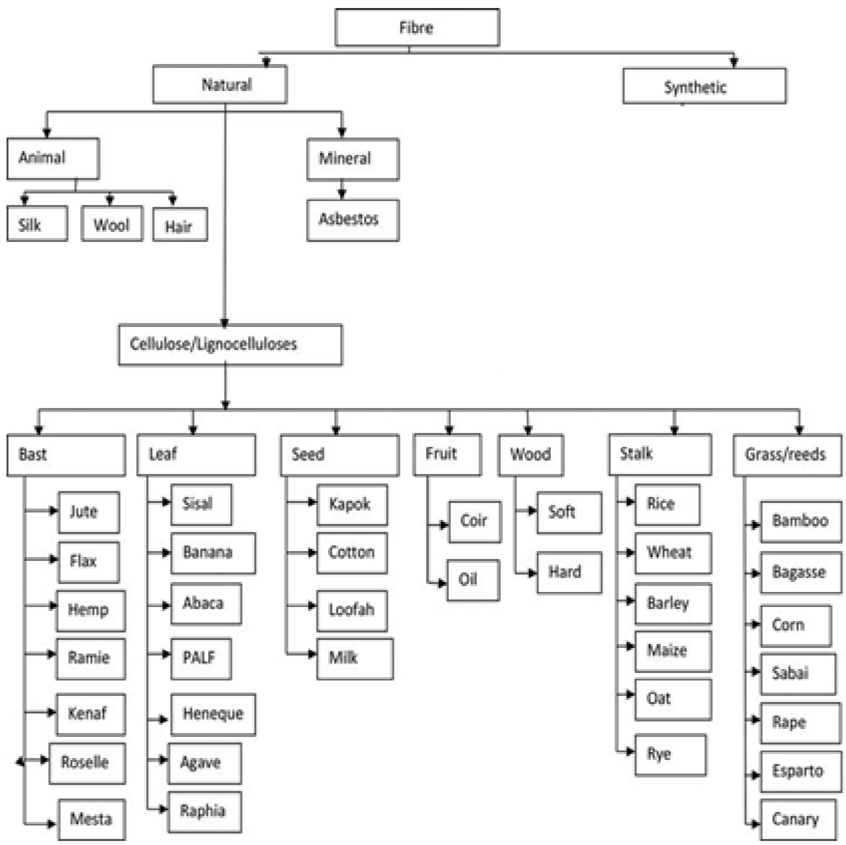


Figure 3: Classification of Natural Fiber

## II. NATURAL FIBER COMPOSITES REPORTED WORK

A large number of reports are available on the natural fiber composites. Table 2 summarizes the reported work on natural fiber composites. As can be seen from the table, the majority of the work is on wood flour, with a few reports on other fibers such as jute and sisal.

The major issues in development of composites are thermal stability of natural fibers and the moisture content of the fibers that can vary between 5 and 10%. This can lead to dimensional variations in composites and also affects the mechanical properties of the composites. Natural fibers (lignocellulosics) are also degraded by biological organisms since they can recognize the carbohydrate polymers in the cell wall. Lignocellulosics exposed outdoors undergo photochemical degradation caused by ultraviolet light. Resistance to biodegradation and UV radiation can be improved by bonding chemicals to the cell wall polymers or by adding polymer to the cell matrix.

The aspect ratio of the fibers, properties of the fibers and the fiber–matrix interface govern the properties of the composites. The surface adhesion between the fiber and the polymer plays an important role in the transmission of stress from matrix to the fiber and thus contributes toward the performance of the composite. Another important aspect is the thermal stability of these fibers. These fibers are lignocellulosic . The cell walls of the fibers undergo pyrolysis with increasing processing temperature and contribute to char formation. These charred layers help to insulate the lignocellulosic from further thermal degradation. Since most of the polymers are processed at high temperatures, the thermal stability of the fibers at processing temperatures is important. Thus the key issues in development of natural reinforced composites are (i) thermal stability of the fibers (ii) surface adhesion characteristics of the fibers and (iii) dispersion of the fibers in the case of polymer composites.

Table 2. Reported work on Natural fiber Composites

| **Fiber** | **Matrix Polymer** | **References** |
|---|---|---|
| Wood flour/fiber | PE | 5–12 |
| | PP | 13–28 |
| | PVC | 29–31 |
| | PS | 32–34 |
| | Polyurethane | 35 |
| Jute | PP | 36–40 |
| | SBR, nitrile rubber | 50, 51 |
| | Epoxy | 41, 42 |
| | Polyester | 43–49 |
| | Phenol–formaldehyde | 52 |
| Sisal | PE | 53–55 |
| | Polyester epoxy | 56, 57, 58 |
| Abaca | Epoxy | 72 |
| Pineapple | PE, polyester | 67–69 |
| Sunhemp | Polyester,PP | 76 |
| Oil palm | Rubber | 80 |
| Kenaf | PE, PP | 63–66 |
| Coir | Natural rubber | 75 |
| Banana | Polyester | 73–74 |
| Flax | PP | 70–71 |
| | | |
| Wheat straw | PP | 70 |
| Bamboo | Epoxy | 78 |

**Fabrication of Fiber Reinforced Polymer composites**

Polymer Composites are mainly fabricated by three different methods. They are extrusion,[100] injection[81] or by compression molding[82,83] methods. Figure 3 shows these three types of equipment.

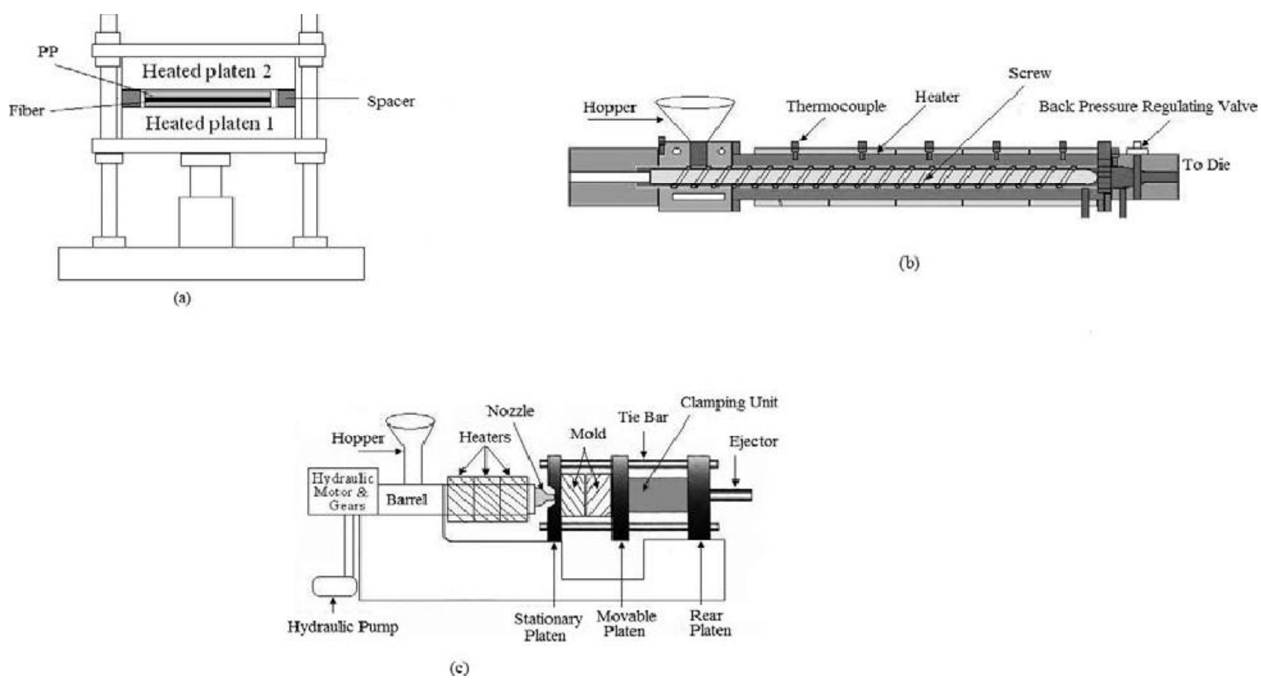


Figure 3. (a) Compression, (b) extrusion and (c) injection molding machines

The extrusion method is not used extensively for fabrication of Polymer Composites with unidirectional fibers, as this process can only result in short fiber length (few millimeters at most). In an extruder, a screw pushes the mixture of fiber and through a heated cylinder, changing Polymer bead from solid state to liquid and mixing with the fibers as it moves through the barrel. This is followed by the die which will give the mixture a constant cross-sectional area. Extrusion method is widely used to fabricate short Fiber Reinforced Polymer Composites. Many researchers fabricated polymer composites by the extrusion method. For example, Mora´n et al. fabricated flax/PP composite,[85] Hassan et al., betel nut short fiber/PP composite,[86] van den Oever et al., jute/PP[87] and Fu et al., glass fiber/PP and carbon fiber/PP[88] using extrusion method.

Injection molding refers to a process that generally involves forcing or injecting a plastic material into a closed mold of desired shape. The molding compound is fed into injection chamber through the feed hopper. In the injection chamber, the molding compound is heated and therefore it changes into liquid form. It is forced into the injection mold by the plunger. This method is normally used for high-volume and low cost component manufacturing. Both thermoplastic and thermoset are subjected to injection molding. A thermoplastic material is first melted and then forced through an orifice into the mold which is kept relatively cool. The material solidifies in the mold from which it can then be removed. But in thermoset injection molding, high temperature is required for solidification. Therefore, a reaction material is forced into a generally warm mold in which the material further polymerizes into a solid part. This method is suitable for high-volume and low-cost component manufacturing. But the method is limited to short fibers. Many researchers fabricated Fiber Reinforced Polymer Composites by injection molding method.

For example, abaca/PP, jute/PP and flax/PP composites were fabricated by Bledzki et al., using injection molding method.[89] Similarly, Arzondo et al. fabricated sisal/ PP,[90]Karmaker et al., jute/PP[91] Bledzki et al., wood fiber/PP,[92] Suhara et al., hempglass/ PP[93] and Abraham et al., nylon/PP[94] composites using injection molding method.

Compression molding is one of the oldest manufacturing techniques that use large pressure to compress the polymeric material which is placed between two matched steel dies. The recent development of high strength, fast cure, sheet molding compounds and advancement in press technology has made this process very popular for mass production of composite parts. In comparison with the injection molding process, it generally provides better physical and mechanical properties. This process utilizes large tonnage presses, wherein the curing occurs between two matched steel dies under pressure and high temperature. Compression molding basically involves the pressing of a deformable materials charged between the two heated mold and its transformation into a solid product under the effect of the elevated mold temperature. After placing the laminate to be cured, the cavity is closed. The molds are heated to a high temperature which causes the reduction in charge viscosity. With increasing mold pressure, the charge flows toward the cavity extremities, forcing air out of the cavity. High pressure helps to eliminate the problem of development of voids. The primary advantage of the compression molding is its ability to produce large number of parts with little dimensional variations. Various shapes, sizes and complexity can be achieved by compression molding. This process has high tooling cost and not cost effective for low volume production. It is very important to control the cure time. Otherwise cracking, blistering or warping may occur. Compression molding processes[95] is the process used for the fabrication of unidirectional FRPCs. Shubhra et al.[96] fabricated unidirectional silk/PP composite using compression molding method. Similarly, Avik et al. fabricated Ca-alginate fiber/PP composite,[97] Khan et al., phosphate glass/PP[98]composite, Khan et al., jute/PP[99] composites in the same way using compression composites in the same way using compression process.

## III. TENSILE PROPERTIES OF NATURAL FIBER COMPOSITES

Mechanical properties of natural fiber are an important parameter on which mechanical properties of composite depend. Table 3 shows the mechanical properties of few natural fibers along with references.

Table 3 Mechanical Properties of Natural Fiber

| Fibers | Diameter (µm) | Density (g/cm$^3$) | TS (MPa) | TM (GPa) | Elongation (%) | Reference |
|---|---|---|---|---|---|---|
| Jute | 25–250 | 1.3–1.49 | 393–800 | 13–26 | 1.16–1.5 | [102] |
| Sisal | 50–200 | 1.34 | 610–710 | 9.4–22 | 2–3 | [103,104,113] |
| Cotton | - | 1.5–1.6 | 287–597 | 5.5–12.6 | 7.0–8. | [104] |
| kenaf | - | 1.45 | 930 | 53 | 1.6 | [104] |
| Wood (soft) | - | 1.5 | 600–1020 | 18–40 | 4.4 | [104,105] |
| Coir | 150–250 | 1.2 | 175 | 4–6 | 30 | [104,108] |
| Flex | 25 | 1.5 | 500–1500 | 27.6 | 2.7–3.2 | [104,100] |
| hemp | 25–600 | 1.47 | 690 | 70 | 2.0–4.0 | [104,100] |
| Pineapple | 50 | 1.526 | 170–1627 | 60–82 | 2.4 | [104,101] |
| Banana | 100–250 | 0.8 | 161.8 | 8.5 | 2.0 | [106] |
| coconut | — | 1.1 | 140–225 | 3–5 | 25–40 | [109,112] |
| Oil palm | 174 | 0.7–1.55 | 206 | 3.567 | 4 | [100,111] |
| Date palm | 100–1000 | — | 135 | 4.6 | 3.6 | [110,113] |
| Vetiver grass fiber | 1.50 | — | 247–723 | 12.0–49.8 | — | [112] |
| Nettle | 20 | — | 1594 | 87 | 2.11 | [114] |
| Bamboo | 88–125 | 800 | 441 | 35.9 | 1.3 | [107] |
| betel nut husk | 410 | 0.38 | 128.79 | 2.569 | 23.13 | [115] |

It can be seen from Table 3 that date palm having maximum diameter and vetiver grass having lowest diameter. Fiber diameter is one of the important parameter for deciding tensile properties of composites since the increase in fiber diameter after a certain value results in decreased strength of composites as found for many fibers like coir, banana, sisal, silk and jute. Since, with the increase in fiber diameter, fiber strength decreases, fibers with more diameters when reinforced with Polymer for composite fabrication will result in lower strength.

Maximum and minimum density is shown by bamboo and betel nut husk, respectively (Table 3). Maximum and minimum value of tensile strength (TS) is shown by nettle and date palm, respectively. Nettle and coconut show the maximum and minimum value of tensile modulus (TM) and percentage elongation, respectively. Thus choice of natural fiber for reinforcement in polymer, depends on mechanical properties of natural fibers which are acceptable compared to synthetic fibers.

The tensile properties of natural fiber reinforced composites depend on a number of other parameters also. These parameters are volume fraction of the fibers, fiber aspect ratio, fiber–matrix adhesion, stress transfer at the interface, and orientation. Most of the studies on natural fiber composites involve study of mechanical properties as a function of fiber content, effect of various treatments of fibers, and the use of external coupling agents.[116-120]

Tensile Strength (TS), Bending strength (BS),Impact strength (IS) and hardness are some mechanical properties that are considered very important for fiber reinforced polymer composites. TS is the maximum stress that a material can withstand without tearing apart. Tensile properties of natural fiber reinforced composites can be determined according to American Society for Testing and Materials (ASTM) D638, [121-122] TS of FRPCs is determined by the following equation:

$\sigma = F/A_f$, where, F is the force at failure, $A_f$ is the average cross-sectional area of filament.

BS also known as flexural strength is defined as a material’s ability to resist deformation under load. BS represents the highest stress experienced within the material at the moment of rupture. Two methods are used to determine the bending properties of material: three-point loading system and four-point loading system.

For a rectangular sample of FRPCs under load in a three-point bending setup, the BS is calculated by the following formula:

$\sigma = 3FL/2bd^2$, where F is the load (force), L is the length of the support span, b is width and d is thickness.

IS of FRPCs is a measure of the ability of the composites to resist the fracture failure under stress applied at high speed and is directly related to the toughness of the composites. It is generally accepted that the toughness of a fiber composite is mainly dependent on the stress–strain behavior of fiber. Strong fibers with high failure strain impart high work of fracture on the composites. Fibers play an important role in the impact resistance of fiber reinforced polymer composites as they interact with the crack formation and act as stress transferring medium.

Both the matrix and fiber properties are important in improving mechanical properties of the composites. The tensile strength is more sensitive to the matrix properties, whereas the modulus is dependent on the fiber properties. To improve the tensile strength, a strong interface, low stress concentration, fiber orientation is required whereas fiber concentration, fiber wetting in the matrix phase, and high fiber aspect ratio determine tensile modulus.

The aspect ratio is very important for determining the fracture properties. In short-fiber-reinforced composites, there exists a critical fiber length that is required to develop its full stressed condition in the polymer matrix. Fiber lengths shorter than this critical length lead to failure due to debonding at the interface at lower load. On the other hand, for fiber lengths greater than the critical length, the fiber is stressed under applied load and thus results in a higher strength of the composite.

For, good impact strength, an optimum bonding level is necessary. The degree of adhesion, fiber pullout, and a mechanism to absorb energy are some of the parameters that can influence the impact strength of a short-fiber-filled composite. The properties mostly vary with composition as per the rule of mixtures and increase linearly with composition.

However, it has been observed that this linear dependence on percentage of fiber content does not hold at high percentage (80%) of the fiber, probably due to lack of wetting of the fiber surface by the polymer.

**Recent Developments**

A natural fiber composite with an outstanding combination of properties can be easily acheived today. Use of proper processing techniques, fiber treatments, and compatibilizers/coupling agents can lead to composites with optimum properties for a particular application.

Recently, there has been increasing interest in commercialization of natural fiber composites and their use, especially for interior paneling in the automobile industry. These composites with density around 0.9 g/cm$^3$, stiffness around 3000 MPa, impact strength of 25 kJ/m$^2$, and good sound absorption characteristics are being used by a number of leading companies.[112] Composites based on polyolefins are now commercially available. It is reported that these composites offer advantages of 20% reduction in processing temperature and 25% reduction in cycle time in addition to a weight reduction of about 30%.[112] The composites provide woodlike appearance without requiring the maintenance. The extruded profiles can be used as a wood substitute in various applications such as window systems and decking. These developments are confined to polymer composites based on PE, PP, PS, and PVC, for which the processing temperature is about 200$^0$C. The real challenge for the scientist is to improve the thermal stability of these fibers so that they can be used with engineering polymers and further the advantage of both the polymers and the fibers. Thus improved thermal stability of natural fibers and modification of fibers for better performance are still an indispensable task for the scientist. Such attempts can widen the applications of natural fiber composites.

## IV. CONCLUSION

Following conclusions can be drawn from aforementioned study:

Natural fiber are reinforced in polymer matrix in different form as randomly oriented, unidirectional, bidirectional, and woven mat form. These composites are prepared by various manufacturing techniques using various weight or volume fractions of fibers. compression molding techniques are very popular among those manufacturing techniques.

Mechanical properties of natural Fiber Reinforced Polymer composite are found to increase due to incorporation of either synthetic fiber or natural fiber having comparably high elongation.

Natural fibers have many advantages such as low cost, low density, eco-friendly, recyclable, and availability in abundance. Natural fibers can be used in place of synthetic fiber due to its acceptable mechanical properties.

There are a very less research papers on hybrid sisal and jute natural Fiber Reinforced Polymer composite. Mechanical properties and Characterization of this hybrid composite may be a good topic for researchers.

A very few papers are there on animal based natural fiber polymer composite. This can also be thought of thrust area for researcher, as animal based fiber are easily available, reproducible and give employment to the region where the animal belongs for example, sheep, horse, silkworm, pig etc.
Thus, further research and improvement should be conducted so that these fully degraded composites can easily be manipulated and can give benefit to all mankind and environmental issues.

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