RNI: MAHENG/2016/68030 **Vol. 4 Issue 6 Nov.-Dec. (2019): Page No.21-32** **ISSN: 2456-5342 (print)**

MAHATMA GANDHI MISSION MGMUNIVERSITY MGM's JAWAHARLAL NEHRU ENGINEERING COLLEGE

VISTA INTERNATIONAL JOURNAL ON ENERGY, ENVIRONMENT & ENGINEERING

VISTA

Polymer composite with improved mechanical properties using natural fiber

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ABSTRACT

There has been a growing interest in utilizing fibers as reinforcement to produce composite materials. Growing environmental awareness throughout the world has triggered a major shift towards designing materials compatible with the environment. 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 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.

Keywords: *Natural fibers, polymer composites, polymer matrix, tensile/ mechanical properties*

1. Introduction:

Now a days, 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, biodegradability, relative non abrasiveness, high specific strength and modulus, and ease of processing.

1.1 Natural Fibers

The idea of Natural fiber (Fig.1) 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 [1-3]. 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].

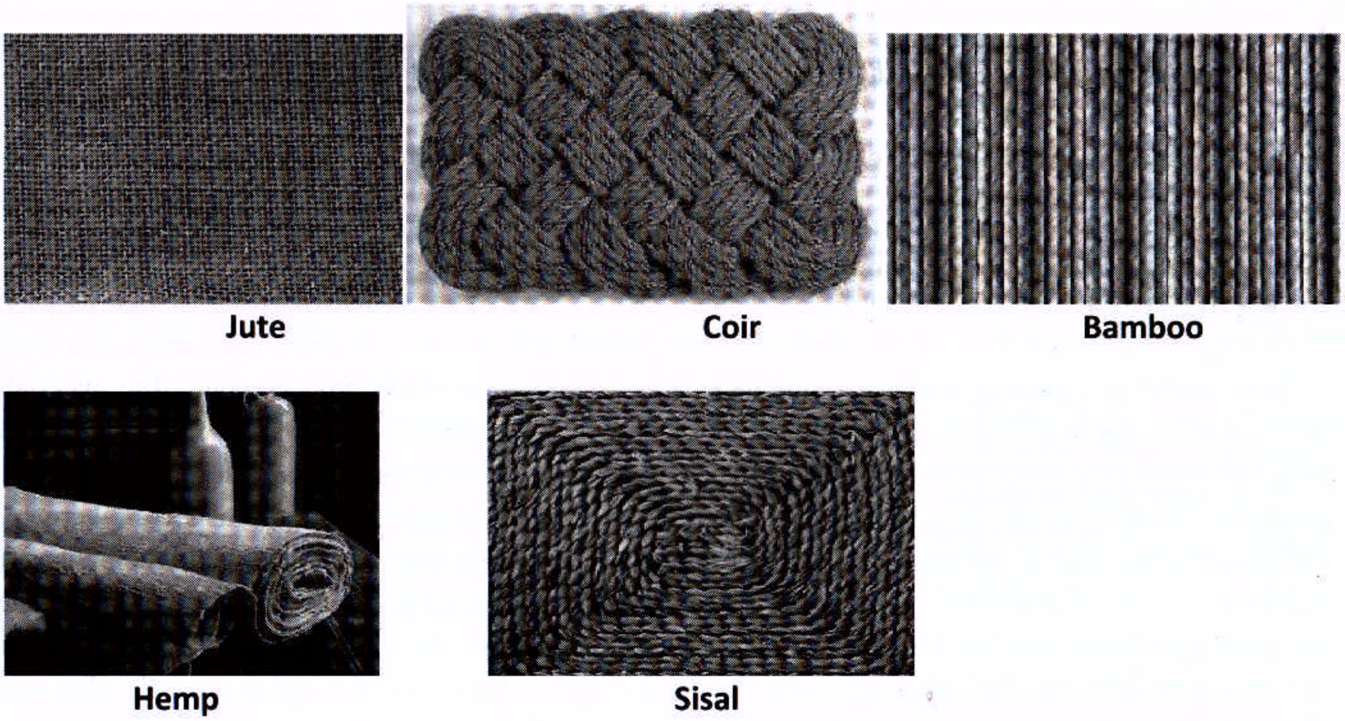

Fig. 1. Variety of natural fiber produced by plant

1.2 Natural fiber for betterment of product :

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 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/cm³ are significantly lighter than E-glass with 2.4 g/cm³.

1.3 Factors affecting the large scale production of natural fibers composites:

Composites are combination of two materials in which one of the materials is in the form of fibers, sheets or particles and are embedded in the other materials called matrix phase. The reinforcing and the matrix materials can be metal, ceramic or polymer. Typically, reinforcing materials are strong with low densities while the matrix is usually a ductile or tough material.

Two major factors are there which limit the large scale production of. First, the strength of natural fiber composites is very low compared to E-glass. This is often a result of the incompatibility between the fiber and the polymer matrix.

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% by weight, the light weight advantage is often nullified.

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 article 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 [35]. Natural fibers produce composites that offer advantages like environmental friendliness, renewability of the fibers, good sound abatement capability and improved fuel efficiency.

2. Literature review:

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.

Table 2. Reported work on Natural fiber Fascility

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

The natural fibers have been used as reinforcement by different researchers include jute [59], banana [60], sisal [61] etc. A systematic classification of reinforced natural fibers is given in Fig. 2. The two main sources of natural fibers are plants (cellulose) 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, micro fibrils, hemicellulose, and lignin: examples include cotton, jute, flax, ramie, sisal, hemp, and so on. It has been observed that a lot of work is done on plant based natural fiber.

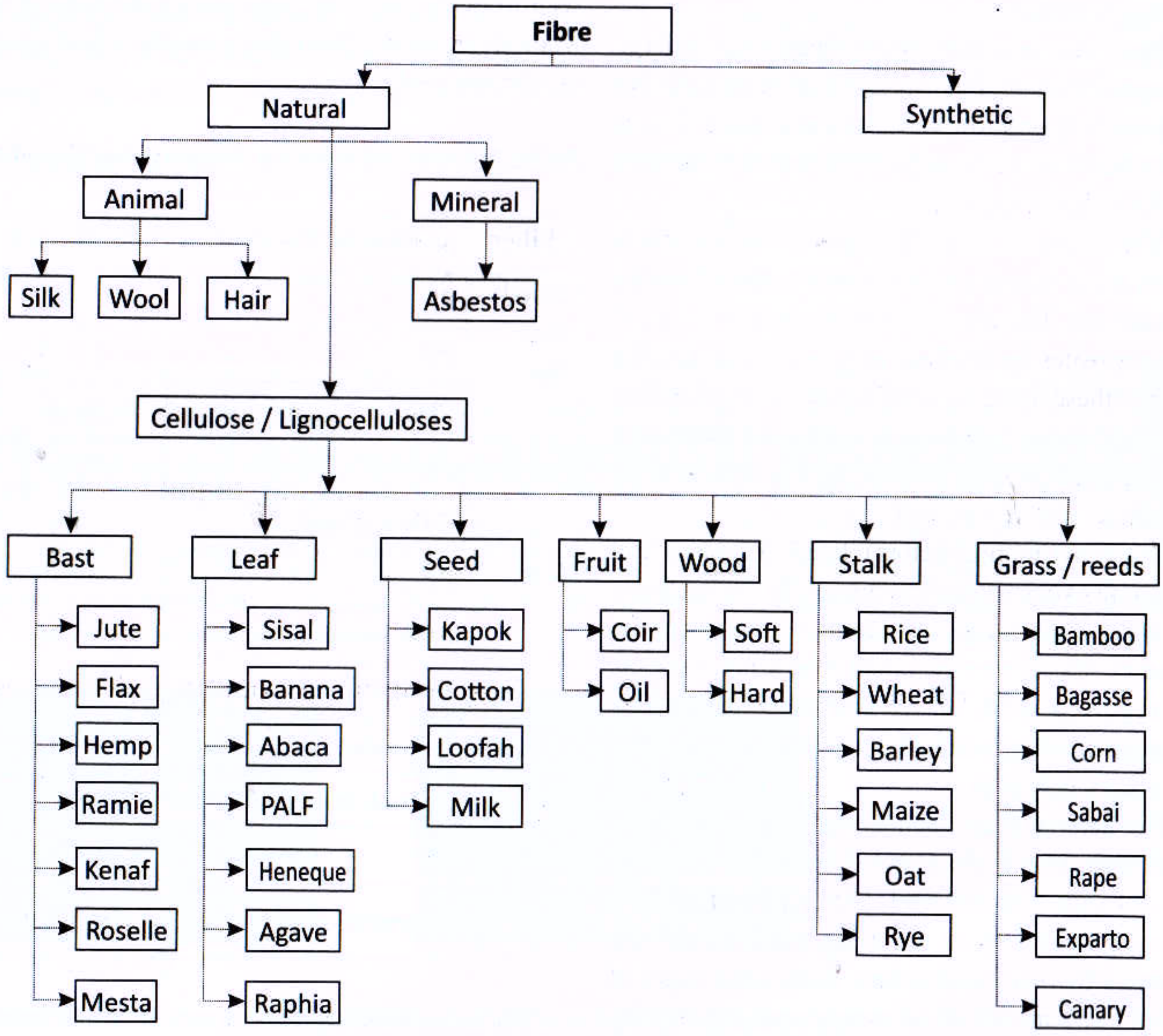

Figure 2. Classification of natural fiber

2.1 Effect of composite formation on physical properties :

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 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 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.

3. Methodology:

Polymer Composites are mainly fabricated by three different methods. They are extrusion, injection or by compression molding [62, 63] methods.

3.1 Composite preparation:

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). Many researchers fabricated polymer composites by the extrusion method. For example, Mora and his team developed flax/PP composite [64], Hassan team developed betel nut short fiber/PP composite [65], Oever team developed jute/PP [66] and Fu team developed glass fiber/PP and carbon fiber/PP [67] 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. This method is normally used for high-volume and low cost component manufacturing. Both thermoplastic and thermoset are subjected to injection molding. This 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 team using injection molding method [68].

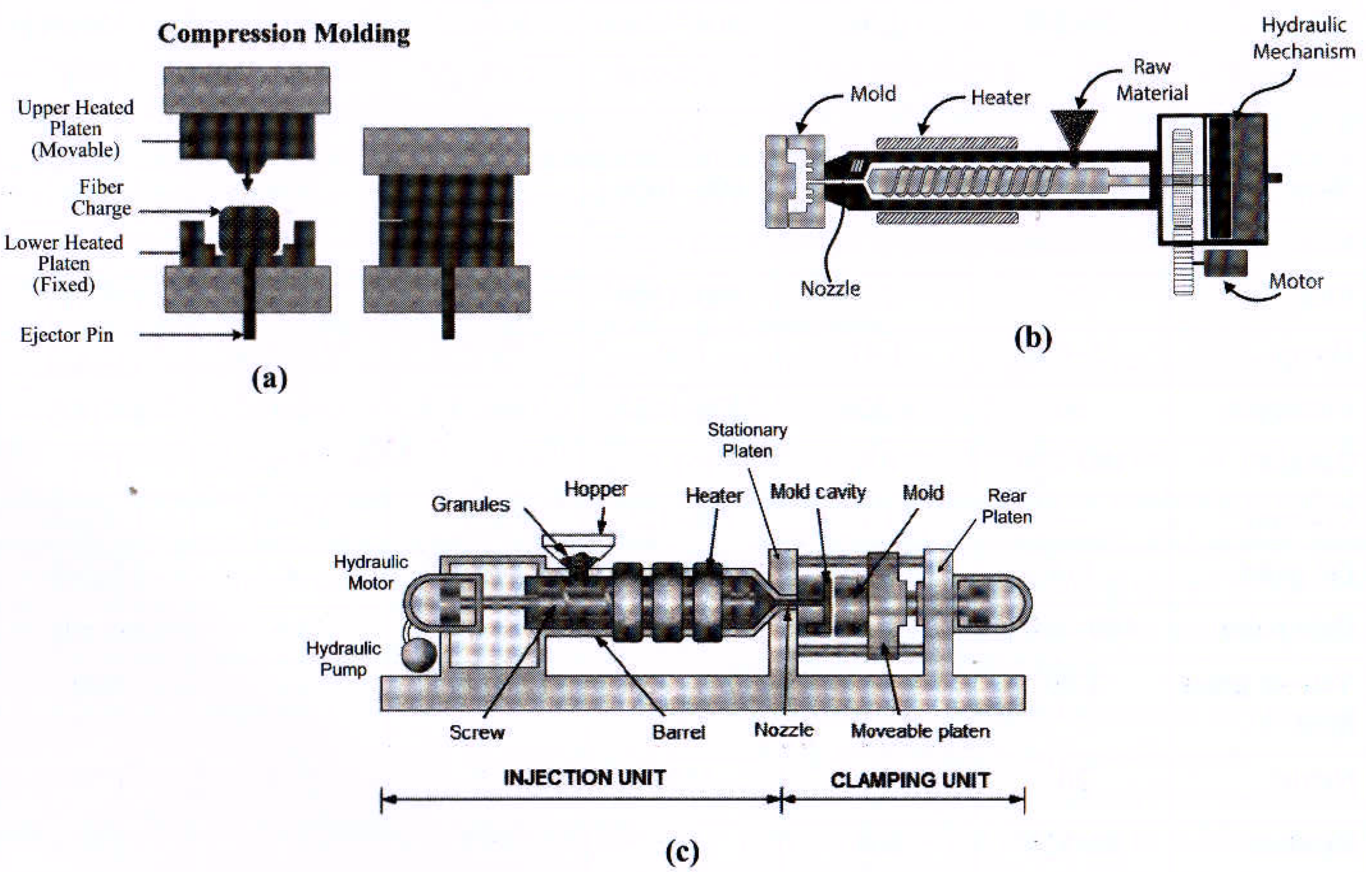

Figure 3. (a) Compression, (b) extrusion and (c) injection molding machines

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. In comparison with the injection molding process, it generally provides better physical and mechanical properties. Compression molding (Fig.3) basically involves the pressing of a deformable materials placed between the two heated mold and its transformation into a solid product under the effect of the elevated mold temperature. 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. Shubhra team developed unidirectional silk/PP composite using compression molding method [69]. Similarly, Avik team developed Ca-alginate fiber/PP composite [70].

3.2 Tensile properties of natural fiber composites:

Mechanical properties of natural fiber are an important parameter on which mechanical properties of composite depend. Table 4 shows the mechanical properties of few natural fibers along with references.

Table 4. Mechanical properties of natural fiber

Fibers	Diameter (μm)	Density (g/cm3)	TS (MPa)	TM (GPa)	Elongation (%)	Reference
Jute	25–250	1.3–1.49	393–800	13–26	1.16–1.5	[73]
Sisal	50–200	1.34	610–710	9.4–22	2–3	[74,75,84]
Cotton	-	1.5–1.6	287–597	5.5–12.6	7.0–8.	[75]
Kenaf	-	1.45	930	53	1.6	[75]
Wood (soft)	-	1.5	600–1020	18–40	4.4	[75,76]
Coir	150–250	1.2	175	4–6	30	[75,79]
Flex	25	1.5	500–1500	27.6	2.7–3.2	[75,71]
Hemp	25–600	1.47	690	70	2.0–4.0	[75,71]
Pineapple	50	1.526	170–1627	60–82	2.4	[75,72]
Banana	100–250	0.8	161.8	8.5	2.0	[77]
Coconut	—	1.1	140–225	3–5	25–40	[80,83]
Oil palm	174	0.7–1.55	206	3.567	4	[71,82]
Date palm	100–1000	—	135	4.6	3.6	[81,84]
Vetiver grass fiber	1.50	—	247–723	12.0–49.8	—	[83]
Nettle	20	—	1594	87	2.11	[85]
Bamboo	88–125	800	441	35.9	1.3	[78]
Betel nut husk	410	0.38	128.79	2.569	23.13	[86]

3.3 Discussions:

From the Table 3, it can be seen 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. 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 the 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. 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.

4. Recent developments :

A natural fiber composite with an outstanding combination of properties can be easily achieved today. Use of proper processing techniques, fiber treatments, and 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. 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% [83]. These composites provide wood like 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 °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 the 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.

5. Conclusion:

Following conclusions can be drawn from the above mentioned study:

1. Natural fibers 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.
2. Compression molding techniques are very popular among those manufacturing techniques.
3. 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.
4. 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.

5. 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.

Thus, further research and improvement work can be carried out so that fully degraded composites can easily be achieved and can give benefit to all mankind and environmental issues.

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