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Natural fiber reinforced polymer composite and their tensile properties – a review

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ABSTRACT

There has been a growing interest to produce composite polymeric materialsusing natural fibers as reinforcement. Scientists prefer natural fiber as a reinforced material to make polymer composites due to their bio-degradability characteristics,strong mechanical properties, high specific strength, low cost, non-abrasiveand ecofriendly nature . This review presents the reported work on natural plant based fiber reinforced polymer composites with special reference to the type of natural fibers and host polymers. Various fiber treatments, which are carried out to improve the fiber– hostadhesion, improved mechanical properties that greatly increase the application of these polymer composites specially in automobile industries and bioapplications are highlighted.

Keywords: *Natural Fibers; Reinforcement; Polymer composites; Tensile Properties.*

1. INTRODUCTION

Nowadays, we find that polymers have replaced many of the conventional metals/materials in various applications. This has been 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 preparedby combining two or more materials to give a unique combination of improved properties. A composite material is generally composed of reinforcement (fibers, particles, etc.) embedded in a host(polymers, metals, ceramics, etc) material. The hostholds the reinforcement while the reinforced material improves the overall mechanical properties of the composite.

In fiber-reinforced polymer composite, reinforcement may either include synthetic fibers or natural fibers in polymer host. Natural fibers due to their advantages over synthetic fiber have become a better replacement tosynthetic fibers. Natural fibers such as kena,cotton, sisaletc. show advantages such aslow density, availability in abundance, low cost, environmental friendly, non-toxicity, high flexibility, bio- degradability, renewability, relative non abrasiveness, high specific strength and modulus, and ease of processing. However, these natural fibers used as a reinforcement material are all plant based and having one major drawback of water absorption. 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. Due to this the polymer fiber dimension is going to change and even a few physical properties may also get altered. Hence it is proposed with the help of this review article to use animal based natural fiber as a reinforcement material for improving the suitable physical properties of the polymer composite.

2. MATERIALS AND METHODS

2.1. Natural fiber.

The Natural fiber composites and their importance due to environmental friendlinesshas attracted the 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 non-renewable sources [1-3].Table 1 shows the tensile properties of Natural Fibers and glass fiber.

From table 1 it is observed that when E-glass is added as reinforcement material in host polymers, it gives enhancement intensile property (2000-3500Mpa) and provides good strength to the polymer, but as the density and cost of the glass arehigh, the fiber will become more bulky and relatively costly. Hence during subsequent years the plant based natural fibers like cotton, kena, sisal etc. have been used to overcome the bulkiness and cost effectiveness of the composite material. Natural fiber composites have already been incorporated by car manufacturers 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 2.5 g/cm³ as indicated in Table 1.

Table 1. Selected tensile properties of Natural and Synthetic Fibers.

Fiber	Density (g/cm^3)	Tensile strength (Mpa)	Elastic Modulus (GPa)
Cotton	1.5-1.6	400	5.5-12.6
Kena	1.45	930	53
Sisal	1.5	511-635	9.4-22
E-glass	2.5	2,000-3,500	70
Carbon	1.4	4,000	230-240

Two major factors are responsible to limit the large scale production of natural fibers composites. The strength of natural fiber and water absorbtion coefficient. The strength of natural fibers (Table 1) is very low compared to E- glass. This is often a result of the incompatibility between the fiber and the polymer host. Natural fibers absorb water from the air and by direct contact from the environment. The result of waterabsorption is deformedsurface of the composites. These deformations lowers the strength and increasesthe mass of polymer composite. Additionally, with water absorption rates as high as 20 wt% the light weight advantage is often nullified. To overcome these two limiting factors related tothe 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/E-glass fiber for environmental concern. The most used synthetic fibers in composites are glass [47–50], carbon[51,53] 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 physic-mechanical properties[56]. The natural fibers have been used as reinforcement by different researchers include jute [57,58] banana [58,59] sisal [59,60] etc.

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	43–47
	Phenol–formaldehyde	50
Sisal	PE	51–53
	Polyester epoxy	54, 55, 56
Abaca	Epoxy	70
Pineapple	PE, polyester	65–67
Sun hemp	Polyester, PP	74
Oil palm	Rubber	78
Kenaf	PE, PP	61–64
Coir	Natural rubber	73
Banana	Polyester	71–72
Flax	PP	68–69
Wheat straw	PP	68
Bamboo	Epoxy	76

2.2. Natural fiber and matrix polymer.

Numerous research papers 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 the 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.

3. TENSILE PROPERTIES

3.1.Factorsaffecting tensile properties of composites.

The aspect ratio of the fibers, properties of the fibers and the fiber–matrix interface governs 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 the 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.

3.2. Tensile properties of Natural Fiber Composites.

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

It can be seen from Table 3 that date palm having maximum diameter and vetiver grass having the lowest diameter. Fiber diameter is one of the important parameters 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 the 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 the choice of natural fiber for reinforcement in polymer depends on mechanical properties of natural fibers which are acceptable compared to synthetic fibers.

Thetensile properties of natural fiber reinforced composites depend on a number of other parameters also. These parameters are fiber– hostadhesion ,volume fraction of the fibers, fiber aspect ratio, stress transfer at the interface, and orientation. Most of the studies on natural fiber composites involve the study of mechanical properties as a function of fiber content, the effect of various treatments of fibers, and the use of external coupling agents [93-97].

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, [98-99] TS of Fiber reinforce polymer composites is determined by the following equation:

$$\mathbf{TS = F/A_f,}$$

where, F is the force at failure, A_f is the average cross-sectional area of filament.

Bending strength (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 polymer composite under load in a three-point bending setup, the BS is calculated by the following formula:

$$\mathbf{BS= 3FL/2bd^2},$$

where F is the load (force), L is the length of the support span, b is width and d is thickness.

Impact strength (IS) of fiber reinforced polymer composites 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.

The host and fiber properties, both are important in improving the 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, fiber orientation, a strong interface and low stress concentration 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 a 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.

An optimum bonding level is necessary for, good impact strength. 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 the percentage of fiber content does not hold at a high percentage (80%) of the fiber, probably due to lack of wetting of the fiber surface by the polymer.

3.3. Recent Development.

A natural fiber composite with an outstanding combination of properties can be easily achieved today. The use of proper fiber treatments, processing techniques, and coupling agents can lead to composites with optimum tensile 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, packaging applications,bio-medical and bio-technologicalfieldsand [100-102]. These composites with density around 0.9 g/cm^3, stiffness around 3000 MPa, the impact strength of 25 kJ/m^2, and good sound absorption characteristics are being used by a number of leading companies [89].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% [89].The 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^{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. Nano particles filler have tremendous potential to be used as filler material which can improve theoverall thermal properties of polymer composites[103].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.

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	[79]
Sisal	50–200	1.34	610–710	9.4–22	2–3	[80,81,90]
Cotton	-	1.5–1.6	287–597	5.5–12.6	7.0–8.	[81]
kenaf	-	1.45	930	53	1.6	[81]
Wood (soft)	-	1.5	600–1020	18–40	4.4	[81,82]
Coir	150–250	1.2	175	4–6	30	[81,85]
Flex	25	1.5	500–1500	27.6	2.7–3.2	[81]
hemp	25–600	1.47	690	70	2.0–4.0	[81]
Pineapple	50	1.526	170–1627	60–82	2.4	[81]
Banana	100–250	0.8	161.8	8.5	2.0	[83]
coconut	—	1.1	140–225	3–5	25–40	[86,89]
Oil palm	174	0.7–1.55	206	3.567	4	[88]
Date palm	100–1000	—	135	4.6	3.6	[87,90]
Vetiver grassfiber	1.50	—	247–723	12.0–49.8	—	[89]
Nettle	20	—	1594	87	2.11	[91]
Bamboo	88–125	800	441	35.9	1.3	[84]
betel nut husk	410	0.38	128-179	2.569	23.13	[92]

4. CONCLUSIONS

Following conclusions can be drawn from aforementioned study. Natural fibers have many advantages such as low cost, low density, eco-friendly, recyclable, and availability in abundance. Thus natural fibers can be used for making polymer composite in place of synthetic fiber.

Mechanical properties of natural Fiber Reinforced Polymer composite are found to increase as compared to other synthetic fiber having high elongation.

There are very fewerresearch 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. Animal based natural fiber isused for making polymer composite can overcome the drawback (poor resistance to moisture) faced by plant based natural fiber composite. This can also be thought of thrust area for researcher, as animal based fiber iseasily available, reproducible and give employment to the region where the animal belongs.

Thus, further research and improvement should be conducted on polymer composites so that these fully degraded composites can easily be manipulated and can give benefit to all mankind and environmental issues.

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