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Study on Mechanical Properties of Natural - Glass Fibre Reinforced Polymer Hybrid Composites: A Review

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Abstract

Natural fibres have attracting the interest to engineers, researchers, professionals and scientists all over the world as an alternative reinforcement for fibre reinforced polymer composites, because of its superior properties such as high specific strength, low weight, low cost, fairly good mechanical properties, non-abrasive, eco-friendly and bio-degradable characteristics. In this point of view, a brief review has been carried out to make use of natural fibres (such as abaca, banana, bamboo, cotton, coir, hemp, jute, pineapple, sisal etc) abundantly available in India. Glass Fibre Reinforced Polymers are mixing with natural fibres to increase Engineering and Technology applications. This paper presents a review on the mechanical properties of natural-glass fibre reinforced polymer composites.

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Keywords: Natural fibre; Natural fibre reinforced polymer composites (NFRPs); Glass fibre reinforced polymers (GFRPs); Mechanical properties.

1. Introduction

A composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the *reinforcing phase* and the one in which it is embedded is called the *matrix*. The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous [1]. The development of composite materials and their related design and manufacturing technologies is one of the most important advances in the history of materials. Research and engineering interest has been shifting from monolithic materials to Natural-glass fibre reinforced polymeric materials. In the recent decades, natural fibres as an alternative reinforcement in polymer composites have attracted the attention of many researchers and scientists due to their advantages over conventional glass and carbon fibres [2]. These natural fibers include flax, hemp, jute, sisal, kenaf, coir, kapok, banana and many others [3]. Natural fibers exhibit superior mechanical properties such as flexibility, stiffness and modulus compared to glass fibers [4].

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The various advantages of natural fibres over man-made glass and carbon fibres are low cost, low density, comparable specific tensile properties, nonabrasive to the equipments, non-irritation to the skin, reduced energy consumption, less health risk, renewability, recyclability and biodegradability [5]. Although glass and other synthetic fiber-reinforced plastics possess high specific strength, their fields of application are very limited because of their inherent higher cost of production. Natural fibers are not only strong and lightweight but also relatively very cheap [6].

Now a day's natural fibers such as sisal and jute fiber composite materials are replacing the glass and carbon fibers owing to their easy availability and cost [7]. Natural fibers may play an important role in developing biodegradable composites to resolve the current ecological and environmental problems. Natural fibers are lighter and cheaper, but they have low mechanical properties than glass fibers. The use of hybrid fibers may solve this issue. Most of the studies on natural fibers are concerned with single reinforcement. The addition of natural fiber to the glass fiber can make the composite hybrid which is comparatively cheaper and easy to use [8]. Natural fibers are chosen as reinforcement because they can reduce the tool wear when processing, respiratory irritation and serving as alternatives for artificial fiber composites in the increasing global energy crisis and ecological risks [9]. A fibre reinforced polymer (FRP) is a composite material consisting of a polymer matrix imbedded with high-strength fibres, such as glass, aramid and carbon [10].

Many authors have reported the mechanical properties of natural fibre reinforced composites. But less effort has been focused on Natural-glass fibre reinforced polymers. So this paper provides overview of Natural-glass fibre reinforced polymers.

2. Study on Natural fiber composites

Generally, polymer can be classified into two classes, thermoplastics and thermosettings. Thermoplastic materials currently dominate, as matrices for bio-fibres; the most commonly used thermoplastics for this purpose are polypropylene (PP), polyethylene, and poly vinyl chloride (PVC); while phenolic, epoxy and polyester resins are the most commonly used thermosetting matrices [11]. Plant fibres are classified into Bast, Leaf, Seed, Fruit, Wood and grasses. Figure.1.1 shows commonly used natural fibres and matrices for polymer composites [12].

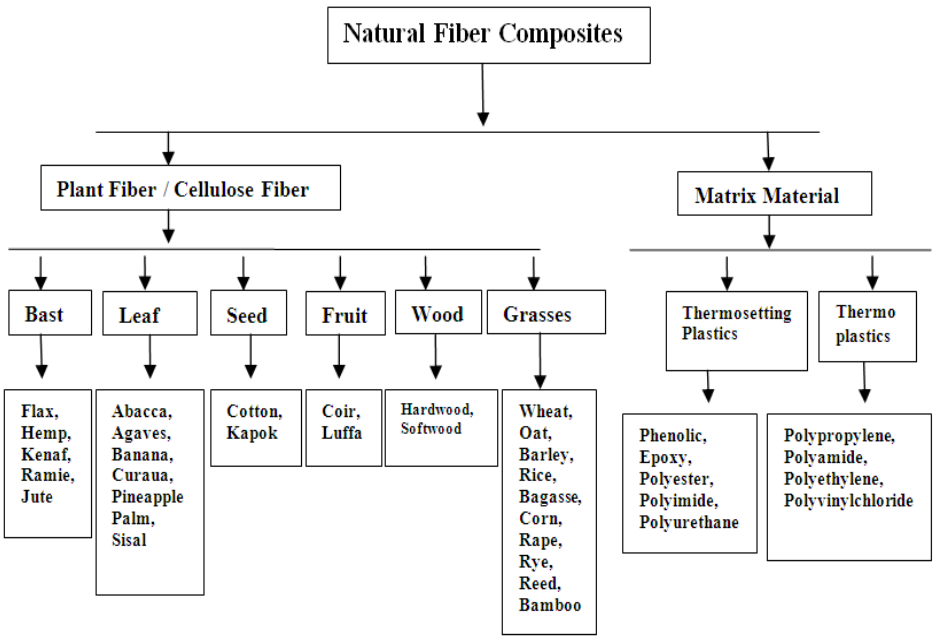

Fig.1. Commonly used natural fibers and matrices for polymer composites [12].

The Physical properties of some of natural fibres are presented in Table 1.1. These fibres are low-cost fibres with low density and high specific properties which are comparable to synthetic fibres.

Table.1.1. Physical Properties of Natural Fibres

Fibres	Tensile Strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Density (g/cm^3)	References
Abaca	400	12	3-10	1.5	[15]
Bagasse	350	22	5.8	0.89	[15]
Bamboo	290	17	-	1.25	[15]
Banana	529-914	27-32	5.9	1.35	[13]
Coir	220	6	15-25	1.25	[14]
Cotton	400	12	3-10	1.51	[14]
Curaua	500-1150	11.8	3.7-4.3	1.4	[15]
Flax	800-1500	60-80	1.2-1.6	1.4	[14]
Hemp	550-900	70	1.6	1.48	[14]
Jute	410-780	26.5	1.9	1.48	[8]
Kenaf	930	53	1.6	-	[14]
Pineapple	413-1627	60-82	14.5	1.44	[13]
Ramie	500	44	2	1.5	[14]
Sisal	610-720	9-24	2-3	1.34	[8]
E-glass	2400	73	3	2.55	[14]

Table.1.2. Presented the areas where the natural fibres have distinct advantages over the most commonly used synthetic fibre i.e. E-glass fibre [14].

Table.1.2. Comparison between natural and glass fibres [14]

	Natural fibres	Glass fibres
Density	Low	Twice that of natural fibres
Cost	Low	Low, but higher than NF
Renewability	Yes	No
Recyclability	Yes	No
Energy consumption	Low	High
Distribution	Wide	wide
CO_2 neutral	Yes	No
Abrasion to machines	No	Yes
Health risk when inhaled	No	Yes
Disposal	Biodegradable	Not biodegradable

3. Study on Natural-Glass Fibre Reinforced Polymers

GFRPs are a fiber reinforced polymer made of a plastic matrix reinforced by fine fibers of glass. Fiber glass is a lightweight, strong, and robust material used in different industries due to their excellent properties. GFRP composites are largely used mainly due to a combination of low cost and good mechanical properties. Although strength properties are somewhat lower than carbon fiber and it is less stiff, the material is typically far less brittle,

and the raw materials are much less expensive [4]. Its bulk strength and weight properties are very favourable when compared to metals, and it can be easily formed using moulding processes [16]. Glass fibres are most widely used to reinforce plastics due to their low cost (compared to aramid and carbon) and fairly good mechanical properties [14]. The incorporation of natural fibres such as sisal/jute with glass fiber composites has gained increasing applications both in many areas of engineering and technology [17]. Polymer-matrix composites, such as carbon or glass fiber reinforced plastics (CFRP/GFRP) have been widely used in industry since they have high strength and modulus [18]. Despite the attractiveness of natural fiber reinforced polymer composites, they suffer from lower modulus, lower strength, and relatively poor moisture resistance compared to synthetic fiber reinforced composites such as GFRP. Hybridization of natural fiber with stronger and more corrosion - resistant synthetic fiber, for example, glass fiber or carbon fiber, can also improve the stiffness, strength, as well as moisture resistant behaviour of the composite. Using a hybrid composite that contains two or more types of different fibers, the advantages of one type of fiber could complement what are lacking in the other. As a consequence, a balance in performance and cost could be achieved through proper material design. However, only a synthetic fiber reinforced polymer matrix hybrid composites are available today and in most cases durability issues are not addressed. The durability of bamboo-fiber reinforced polypropylene can be enhanced by hybridization with small amount of glass fibers [19]. Sisal–jute–GFRP hybrid composites are environment friendly and user friendly materials and have very good elastic properties. The method of disposal of GFRP and their recycling have been the serious issue and the natural fiber composites plays very important role in the environmental situation and variety of applications [8]. Despite the fact that glass fiber-reinforced plastics have excellent thermal and mechanical properties, it is difficult to devise suitable disposal methods for them. Due to many environmental problems, the disposal methods for GFRP and their recycling have been seriously acknowledged [20].

4. Study on Mechanical Properties Of Natural-Glass Fibre Reinforced Polymers

Natural fiber reinforced polymer matrix composites are very sensitive to influences from matrix composites are very sensitive to influence from environment agents such as water. The tensile strength of the jute fiber is directly proportional to the cross sectional area of the fiber [21] and delamination of layer is possible [22]. The incorporation of natural fiber with GFRP improves the tensile, flexural and impact strength of the materials [23] and placing the GFRP layers at the ends possess good mechanical strength [24]. The tensile properties of jute oil palm fiber hybrid composites are increased substantially with increasing the content of jute fibres loading as compared to oil palm epoxy composites [25]. The strength properties of natural fiber composites are somewhat lower, because of less stiff and typically less brittle. Reinforcing glass fiber into the sisal polypropylene composites enhanced tensile and flexural properties without any effect on tensile and flexural module. In addition to this, adding sisal fiber with glass fiber improves thermal properties and water resistance of the hybrid composites [26]. The sisal/banana hybrid natural fiber composite specimens are prepared with different ratios by taking 0.4 volume fraction and tensile properties of these hybrid natural fiber composites are examined by using Rule of Hybrid Mixture (RoHM) [27]. It was predicted the RoHM equation gives the tensile properties of the hybrid composites slightly higher than the experimental values. The tensile properties of vakka fiber composites increase with volume fraction of fiber and more than the sisal/banana fiber composites. The flexural properties of vakka fiber composites are closer to the sisal fiber composites and more than that of the banana fiber composites [28]. The addition of sisal fiber in the composite increases the tensile strength, flexural strength and also impact strength [29]. The overall tensile and flexural properties of natural fiber reinforced polymer hybrid composites are highly dependent on the aspect ratio, moisture absorption tendency, morphology and dimensional stability of the fibers used. The tensile and flexural properties of chemically treated natural fiber composites are slightly improved than the non-treated composites [30]. The reinforcement of hemp fiber with glass fiber hybrid composite material improves the flexural, impact properties and water resistance [31]. The tensile strength and elastic modulus increased upon glass fiber incorporation and for higher % volume fraction (V_f). This behaviour is mainly due to the higher strength and stiffness of the glass fiber in relation to curaua and the better adhesion of the former with the polyester resin [32]. Use of eco friendly composites gains attraction due to its lightweight and moderate strength in the recent years. The mechanical properties increased due to hybridization. The properties are increasing continuously due to the addition of glass fiber [33]. The mechanical behaviours of unidirectional flax and glass fiber reinforced hybrid composites with the aim of investigation on the hybrid effects of the composites made

by natural and synthetic fibers. The tensile properties of the flax/glass fiber reinforced hybrid Composites were improved with the increasing of glass fiber content [34]. The incorporation of sisal–jute fiber with GFRP can improve the properties and used as an alternate material for glass fiber reinforced polymer composites [8]. The mechanical properties of the jute fiber reinforced composites are higher than the sisal fiber reinforced Composites [35]. The jute and glass fiber hybrid composite leads to the successful fabrication of Glass, Jute fiber and chopped fiber reinforced polyester composites with different fiber lengths is possible by simple hand lay-up technique. The mechanical properties of the composites like tensile, flexural and impact strength of the composites are also greatly influenced by the fiber lengths [36]. The mechanical properties of jute/polyester composites do not possess strengths and module as high as those of other conventional composites; they can possess better strengths than wood composites and some plastics [37]. The increase of fibre loading the values of flexural strength and charpy impact strength of composite material has been decreased. But the values of other mechanical properties remain almost the same [38]. The hybridization of the reinforcement in the composite shows greater tensile strength when compared to individual type of natural fibers reinforced. Due to the low density of the natural fibers used compared to the synthetic fibers (Glass fibers, carbon fibers, etc...), the composites can be regarded as a useful light weight engineering material [39]. Mechanical properties of polymer composites increase with the incorporation of fibre into the polymer matrix due to the transfer of stress from the matrix to the fibre [40]. The tensile properties seem to be influenced by the fibre volume fraction, matrix properties and the fibre/matrix bond strength [41]. For compressive test jute composite shows higher strength as compared to bamboo composite but it is not at par with glass composites [42]. By incorporation of natural and synthetic fibres into the polymer, the mechanical properties almost enhanced to greater extent [43]. The tensile strength and elastic modulus increased upon glass fiber incorporation and for higher $\%V_f$ [44]. Scanning electron micrographs obtained from fracture surfaces were used for a qualitative evaluation of the interfacial properties of coir /epoxy and compared with glass fibers [6]. The fracture behaviour investigated by Scanning Electron Microscopy showed that extensive fiber pull-out mechanism was revealed at the tension side of jute mat composites under the bending load and by adding the jute cloth, the failure mode of jute mat was changed to fiber bridge mechanism [45]. The tensile, flexural and impact strength is observed to be maximum at 90^0 orientations in both epoxy and polyester based composites [46].

5. Applications

Environmental awareness among all over the world focused the attention towards the use of natural fiber as reinforcement in polymer matrix. Composites made of the same reinforcing material system may not give better results as it undergoes different loading conditions during the service life. In order to solve this problem, hybrid composites are the best solution for such applications. A hybrid composite is a combination of two or more different types of fibre in which one type of fibre balance the deficiency of another fibre. Among various natural plant fibers, sisal fiber has a great potential to be used as reinforcement in polymer composites. Over hundreds of years sisal has been used in the applications of ropes, beds, bags etc. Composites made of natural fibers offer the opportunity for extensive applications in fields such as consumer goods, low cost housing and civil structures, and for many other common applications where the prohibitive cost of reinforcements at present restricts the use of conventional lightweight reinforced plastics. In the past decade, natural fiber composites have been developed, in which several natural fibers such as ramie, hemp, jute, sisal, bamboo; banana, oil palm fibers, etc. are used as reinforcements in place of glass fibers and coir can be used as a potential reinforcing material for making low load bearing thermoplastic composites. Hybrid fiber composites with coir and other fibers rather than glass may open up new applications [6]. The use of natural fibers is improved remarkably due to the fact that the field of application is improved day by day especially in automotive industries [8]. Hybridization of natural fiber composite by another natural fiber does not yield superior mechanical properties as hybridization by glass fiber [50, 51] and hence this kind of hybrid composite are suitable for low cost applications and this kind of materials very popular in engineering market such as automotive and construction industries [35]. The natural fiber reinforced composite have low maintenance requirements, high stress to weight ratio, high corrosion, impact resistance, non-conductive, avoid electrical hazards, reduced cost, easy installation due to light weight and fire retardant. These composites are used in

aerospace industry (tails, wings, propellers), bicycle frames, boat hulls, fishing rods, storage tanks, baseball bats, ice skating boards, door panels, automobile industry, construction material for buildings, marine application and sporting goods industry [52]. The hybrid natural fibre composite materials are used in a number of consumable goods [53]. The natural fibres are of interest for low-cost engineering applications and can compete with artificial glass fibres and these composites were used as a source of energy to make shelters, clothes, construction of weapons [54]. The light-weight natural fiber composites improve fuel efficiency and reduce emissions in the use phase of the component, especially in auto applications [55]. Due to recent trend and increasing awareness towards sustainable product design, natural based fiber materials are gaining a revival popularity to replace synthetic based fiber in the formulation of composites especially for automotive structural and semi structural applications [56]. New applications should be found for sisal-fibre- based composites. Hybrid fibre composites with sisal and other fibres rather than glass may open up new applications. For example, from the economics point of view, sisal fibres may be hybridised with carbon or aramid fibres to reduce the costs of these expensive fibres reinforced composites whilst maintaining their good mechanical performance [57]. Fibre reinforced polymer composites have many applications as a class of structural materials because of their ease of fabrication, relatively low prize and higher mechanical properties compared to polymer resins. These composites are considered as replacements for metal materials where the association of metallic fibre with polymeric matrix is attractive material for electronic packaging applications [58]. Possible use of the composites in components such as pipes carrying coal dust, helicopter fan blades, desert roof structures and industrial fans [59]. Economic and other related factors in many developing countries where natural fibres are abundant demand that scientists and engineers apply appropriate technology to utilize the natural fibres as effectively and economically as possible for structural upgradation and also other purposes for housing and other needs and also for various other applications etc [60].

Conclusion

The mechanical and physical properties of natural fibers have varies from fiber to fiber. Natural fiber reinforced composites are used in many engineering applications, because of its superior properties such as specific strength, low weight, low cost, fairly good mechanical properties, non-abrasive, eco-friendly and bio-degradable characteristics. Incorporation of natural fibers with GFRP can improve the properties and used as an alternate material for glass fiber reinforced polymer composites.

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