



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 13, Issue 8, August 2024

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.524

9940 572 462

6381 907 438

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Review Paper on Mechanical Properties of Natural Fiber Reinforced Composites

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ABSTRACT: In the contemporary world, natural fibers reinforced polymer composite (NFRPC) materials are of great interest owing to their eco-friendly nature, lightweight, life-cycle superiority, biodegradability, low cost, noble mechanical properties. NFRPCs are widely applied in various engineering applications and this research field is continuously developing. However, the researchers are facing numerous challenges regarding the developments and applications of NFRPCs due to the inherent characteristics of natural fibers (NFs). These challenges include quality of the fiber, thermal stability, water absorption capacity, and incompatibility with the polymer matrices. Natural fiber reinforced composites have extensively used in non-structural components, mainly in the automotive industry. The use of short and random fibers in those composites leads to discontinuity. These create a non-uniform stress distribution in the matrix during loading. Due to this non-uniform stress distribution, the composite fails early with a lower strain rate. This limitation can be overcome by using fabric reinforced composites. However, most of the textile properties are influences the performance of the composites.

KEYWORDS: , Natural fiber, Natural Fibers Reinforced Polymer composite (NFRPC), textile properties, non-structural Components

I. INTRODUCTION

The consumption of polymers and polymer based materials is ever increasing with a growing range of applications in diverse fields. Fiber-reinforced composites are very attractive in polymer industries, and offer many advantages. The advantages include but not limited to high strength-to-weight ratio, good corrosion resistance as well as structural and manufacturing flexibilities compared to metals and their composites.

Composite materials are in use in a wide range of industrial applications for several decades. Air, land, and sea transportation areas cover large scale applications while sports equipment and biomedical devices cover small scale applications. About 35-40% of the annually produced fiber-reinforced polymeric composites are of thermoplastics (Marosi *et al.* 2016). Other composites are reinforced with glass, carbon, or natural fibers, while the rest is made of high-strength carbon or glass fiber reinforced thermosets. The number of fire risk scenarios are drastically increased with the expansion of plastic usage endangering our everyday life. Moreover, most commercial composites are fossil fuel-based synthetic materials that harm the environment during its disposal at the end of the product life cycle. Furthermore, with the growth in environmental awareness and a series of new regulations, the industries are being forced to search for eco-friendly materials to replace the existing fossil fuel based polymer materials (Shankar Adhikari *et al.* 2018). Therefore, the introduction of eco-friendly composites made of biodegradable or sustainable materials such as natural fibers or man-made cellulose fibers reinforced biodegradable polymer composites have attracted growing interest in recent years (Huda *et al.* 2008).

During the year 2018, As per the IHS (Information Handling Services), global level demand biodegradable class of polymers was 3,60,000 metric tons, but the overall consumption of biodegradable polymers may be expected to increase up to 5,50,000 metric tons by the end of 2023. This represents an average annual growth rate of up to 9% in

the duration of five years, almost equivalent to a volume increase of more than 50 percent from 2018 to 2023 reported by Bio-plastics market data 2018.

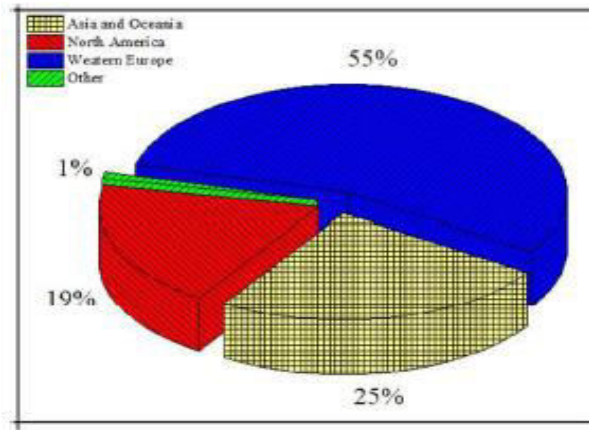


Figure 1.1: World consumption of biodegradable polymer by region – 2018

The demand for crude oil can be controlled by producing efficient vehicles, not only by placing efficient engines in vehicles but also by reducing the weight of the vehicles, which will result in less consumption of fuel. In order to decrease the weight of the vehicle, the strength and safety issues of the vehicle must not be compromised. However, in general, a high strength of material comes with a higher weight. Therefore, it seems very difficult to achieve good strength with use of materials having a low weight as compared to the conventional materials. The only feasible solution to this problem is using plant-based materials, which have good potential to replace the conventional synthetic materials such as steel. Therefore, the automotive industries are drifting towards use of plant-based materials for manufacturing the bodies of vehicles.

II. TEXTILE PROPERTIES

The above section clearly describes the need for woven fabric in composite applications. However, many of the physical properties of a fabric influence the mechanical properties of the fabric-reinforced composites significantly. So, it is necessary to understand the main textile physical properties such as gram per unit area (GSM), woven pattern of a woven fabric, yarn diameter, number of yarn, yarn linear density, crimp of yarn, thickness of fabrics, and cover factor both in warp and weft directions.

Influence of crimp-on fabric properties:

Warp and weft crimp percentage are two factors which have an influence on the following fabric properties:

Resistance to abrasion: The abrasion resistance of fabric will be more if the yarn crimp is more. The yarns with high crimp take the brunt of abrasion action. This is because of crowns that are formed as the yarn bends around a transverse thread. This will be produced from the surface of the fabric and meet the destructive abrasion agent first. The other set of yarns lying in the center of the fabric will only play their part in resisting abrasion when the high crimped threads are nearly worn through.

Shrinkage: When the yarns are wet, they swell and consequently the warp thread takes longer bending path to align with the swollen weft thread. The warp thread must be either longer in length or alternatively the weft threads must move closer together. An increase in length of warp requires the application of tension is absent, equilibrium conditions will be attained by the weft threads moving closer together.

Fabric behaviour during strength testing: When a strip of fabric is extended in one direction, the crimp is removed and the threads are straightened. This causes the threads at right angles to the loading direction to be crimped further. When the load is applied along the warp threads, the crimp in the warp is removed and that in the weft threads is

increased which is known as crimp interchange. The sample loses its original rectangular shape the middle position to the strip contracts which is known as wasting. Due to the removal of crimp, the load-elongation curve will show relatively high extension per unit increase in load in the early stages of strength testing of a strip of fabric.

Faults of fabric: Variation in crimp can give rise to faults in fabric such as a reduction in strength, bright picks, diamond bars in rayon, stripes in yarn-dyed cloth, etc. The crimp variation is mainly due to the improper tension on the yarn during the preparation of the fabric.

Fabric design: Control of crimp percentage is necessary when a fabric is designed to give a desired degree of extensibility. Some fabrics require control of crimp in the finishing process to give the correct crimp balance between warp and weft so that the finished appearance is satisfactory. Therefore, the tension applied must be carefully controlled.

Fabric costing: Since crimp is related to length, it follows that the quantity of yarn required to produce a given length of fabric is affected by the warp, weft and crimp percentage. Therefore, in calculating the cost and the yarn requirements, the value of crimp play an important role.

III. LITERATURE REVIEW

Biodegradable polymers are one group of polymeric materials. The molecular chains of these kinds of polymers can be broken down either through hydrolytic degradation or by enzymatic means. The usage of biodegradable polymers in biomedical applications has increased and current trends show that in the future the biodegradable polymers may replace the use of conventional non-biodegradable materials, gradually (Zheng *et al.* 2014).

Biodegradable polymers cover a vast area of high molecular weight compounds. Usually, it is valuable to distinguish between biodegradable polymers of native and of synthetic origin. Native biodegradable polymers are the result of a synthesis developed during millions of years of evolution, leading to tailor-made materials for different applications in nature. These biopolymers include proteins, polysaccharides, nucleic acids or lipids which show completely different characteristics depending on the situation in which they are used. On the other hand, synthetic polymers are the result of many centuries of research and development. Synthetic polymers susceptible to biodegradation can be of different types, *e.g.*, polymers containing hydrolysable backbone polyesters. Recent research activity on biodegradable synthetic polymers has often been focused on the simulation of different biopolymers or polymers with degradable backbones, *e.g.* polyanhydrides, polycarbonates, polylactones, etc (Karak *et al.* 2012). In addition to that growing ecological and environmental consciousness has driven efforts for development of new innovative materials for various end-use applications. Polymers synthesized from natural resources have gained considerable research interest in recent years. By considering above points the usage eco-friendly materials like soy oil-based resin, cellulose fiber, Polylactic Acid (PLA), Polyvinyl Alcohol (PVA) based fiber and their blended materials find applications in roof structure, automobile parts, civil and construction industries (Dweib *et al.* 2006, Koronis *et al.* 2013 and Gurunathan *et al.* 2015). In addition, the applications of PVA also having a prominent role in biomedical devices like interference screws, tacks for ligament attachment, meniscal repair, suture anchors, rods and pins (Middleton and Tipton 2000).

Many researchers studied different biodegradable polymers like Agro polymers (Stephane *et al.* 2005), Polyhydroxy Alkanoates (PHA) (Zulfikar *et al.* 2018), Polylactides (PLA) (Hagen *et al.* 2016), Polycaprolactones (PCA) (Debasish *et al.* 2016), Polyesteramides (PEA) (Yujiang *et al.* 2016), Aliphatic Copolyesters (Bajaj *et al.* 1979), Aromatic Copolyesters (Witt *et al.* 2001), Polyvinyl Alcohol (PVA) (Xiaohong *et al.* 2019), etc. Many researchers studied the effect of fiber and filler reinforcement on mechanical behavior of PLA based bio-degradable composites. Maya and Thomas (2008) made a survey in 2008 and reported that the bio-materials play a vital role in reducing environmental hazards. They also reported that cellulosic fiber reinforced polymeric composites are finding applications in many fields ranging from construction industry to automotive industry. Among green composites, hybrid biocomposites and textile bio-composites are having better mechanical properties.

Imre *et al.* (2013) observed that use of blended biopolymers increased drastically in 2010 onwards, and they have better performance when compared to base materials.

The modification of polymer is an approach to get better properties and attain property combinations essential for specific applications. Blending allows significant enhancement in the impact resistance of brittle polymers. They also reported that biopolymers and blended materials attracting and replacing non-biopolymers in several areas such as agriculture, consumer goods, packaging and automotive. Shuai *et al.* (2014) fabricated the PVA/calcium silicate (CaSiO₃) composite using selective laser sintering method. They found that effect of CaSiO₃ reinforcement on compressive strength of PVA composite is better for 15 wt%.

Amir *et al.* (2015) examined influence of PVA content, screw speed, and clay content on the performance of starch/PVA clay nanocomposite films prepared by twin-screw extruder. In order to obtain better compatibility among starch and silicate layers, Montmorillonite (MMT) modification is accomplished using citric acid. Tensile strength of the composite is (17.7 MPa) found better at 3 wt% MMT, 5 wt% of PVA, 24 r/min screw speed, and 90–100–110–120°C of extruder four stage temperature profile.

IV. NATURAL FIBRE COMPOSITES

Natural fibres are hair-like or thread-like naturally existing substances with a high aspect ratio. On the basis of their source, natural fibres are classified into three categories: animal fibres (silk), vegetable fibres (abaca), and mineral fibres (asbestos). It is well known that natural fibres are now on the verge of replacing synthetic fibres (glass fibres, carbon fibre, etc.) in many areas of application due to their advantages like low cost, low weight, and biodegradability. One of the most important materials used in polymer-based composites are plant fibres. This is due to their biodegradability, low cost, and renewability.

Leaf and bast fibres are known to be high-performance fibres. Fibres that are extracted from the phloem or inner bark are known as bast fibres. Sometimes, these are also referred to as skin fibres. Leaf fibres are obtained from the leaves of plants, such as abaca fibre obtained from the leaves of a plant (*M. textilis*) from the banana family. Coconut fibres are fruit fibres. As these plants can be cultivated in abundance as per requirements, there is a surplus amount of fibres that could be utilised for the purpose of reinforcement of composites. Thus, the abundant source of natural fibre makes it the most suitable one to become an alternative for conventional structural materials.

Many researchers in the last few decades have endeavoured to bring natural fibre-reinforced composites into the limelight. In the year 2009, a study was conducted on the erosion behaviour of composites reinforced with scales of freshwater fish (*Labeo rohita*) with epoxy as matrix. It was an unusual attempt made to utilise the scales of freshwater fish, which are considered as waste. Again, in 2012, waste grass broom fibre was utilised to develop a green composite with polyester as matrix. Broom grass is also known as tiger grass, which is rather tall and grows along the bank of rivers.

There is a lot of research done on jute as reinforcement in composites. Moreover, a study showed that jute composites developed by using the spray-up technique demonstrate many superior mechanical properties. In 2013, the mechanical and physical properties of bidirectional jute fibre epoxy composites were investigated, which were developed using the hand lay-up technique. Recently in 2014, the compressive behaviour of NFC was studied in which four compressive collapse modes were observed, i.e. micro-buckling, diamond-shaped buckling, concertina-shaped buckling, and progressive crushing.

Recently, abaca fibre also caught the attention of researchers due to its very high impact and flexural strengths compared to other natural fibres. Abaca fibre with man-made cellulose was investigated in 2009, which was processed by the combined moulding technique. Hybrid composites reinforced with abaca, jute, and glass fibres with epoxy as matrix were investigated for mechanical properties. It was concluded that abaca composites show higher values for impact and flexural strengths than hybrid composites.

In 2005, coconut fibre-reinforced polyethylene composite was investigated for the effect of a natural waxy surface layer on interfacial bonding and strength of composite. Low-density polyethylene matrix was used as matrix. The study showed that the wavy layer results in an increase in tensile properties as well as the interfacial bonding between the fibre and the matrix of the composite.

Apart from these advantages, natural fibre also comes with drawbacks, i.e. its hydrophilic nature. Due to the presence of hydroxyl groups, fibres absorb moisture and become prone to damage or degradation. Generally, natural fibre contains cellulose, hemicelluloses, lignin, pectin, wax, ash, and moisture. It is necessary to know the composition because the mechanical properties of natural fibres depend on its composition. Table 1 presents the average chemical composition of popular natural fibres.

Table 1: Average chemical composition of natural fibres

Type of fibre	Cellulose	Hemicelluloses	Lignin	Pectin	Wax	Ash	Moisture
Abaca	56–64	25–29	11–14	–	–	–	–
Jute	64.4	12	0.2	11.8	0.5	0.5–2.1	10
Sisal	65.8	12	0.8	9.9	1.2	0.3	10
Kenaf	44.4	–	20.1	–	–	4.6	–
Coconut	37–43	24–28	26–28	–	–	–	–
Bamboo	78.83	–	10.15	–	–	–	–

The mechanical properties of composites depend on the fibre, matrix, interfacial strength, fibre dispersion, and fibre orientation. Table 2 shows the mechanical and physical properties of natural fibres. Precisely, the cellulose content in any natural fibre governs the mechanical properties of the fibre, as it controls the cell geometry condition, whereas the lignin content in natural fibres is responsible for water uptake into the core. However, addition of nanoclay and nanosilica carbide in natural fibre-reinforced polymer composites reduces the hydrophilicity, thus resulting in better mechanical properties, whereas in the present work the mechanical properties of various NFCs are discussed, which will hopefully help researchers working in pertinent domains.

Table 2: Mechanical and physical properties of natural fibres

Type of fibre	Diameter (µm)	Density (g/cm ³)	Tensile strength (MPa)	Young's modulus (GPa)
Abaca	250–300	1.5	717	18.6
Jute	250–2500	1.3–1.49	393–800	13–26.5
Sisal	205–230	1.41	350–370	12.8
Kenaf	83.5	1.2	282.60	7.13
Coconut	396.98	1.2	140–225	3–5
Bamboo	–	1.2–1.5	500–575	27–40

V. MATERIALS AND METHODS

Natural fibers such as jute, sisal, silk, and coir are inexpensive, abundantly available, lightweight with low density, high toughness, and are biodegradable. Some natural fibers have the potential to be used as a replacement for traditional reinforcement materials in composites for applications which require a high strength-to-weight ratio and further weight reduction. Among other natural fibers, the sisal fiber is abundantly available in south India. Literature survey revealed that limited work as been carried out on woven sisal fabric reinforced with a biodegradable matrix material. Polyvinyl Alcohol (PVA) is a hydrophilic synthetic polymer generated by the hydrolysis of poly(vinyl acetate), which is formed by the polymerization of vinyl acetate is selected as the matrix and it is biodegradable. This chapter focuses on materials selection and its processing, experimentation and different testing-standards. Initially, the matrix material is prepared by mixing Polyvinyl Alcohol (PVA) with Glutaraldehyde (GA) for various volume fractions (Ravindra *et al.* 2019).

Followed by this, the processed polymers are immersed in 2 mole of Sulphuric acid (H₂SO₄) for 24 hours for complete cross-linking (Kumbar *et al.* 2019). The chemical structural characterization of PVA and GA is analyzed using Fourier Transform Infrared spectroscopy (FTIR). Sisal fiber extracted from leaves of sisal plant and processed into yarn, then into three types of fabrics such as Plain 1 (P1), Plain 2 (P2) and Weft Rib (WR) fabrics. The two plain fabrics are prepared to analyse the effect of gram per unit area (GSM): plain 1 and plain 2 have GSM of 161.02±0.17 and 296.60±1.75 respectively.

The one weft rib fabric with GSM 300.45 ± 1.67 is prepared to analyse the effect of woven pattern by comparing with plain 2. The basic physical and mechanical properties of these fabrics are analysed using various textile testing standards. These fabrics are further used to prepare the biodegradable composites with different weight fractions using conventional compression moulding technique.

VI. CONCLUSION

The usage of natural fiber as reinforcement in polymer composites was inspected from the outlook of position and expectations of natural fibers, fabrication and characterization of natural fiber, fiber surface refitting using different fillers and properties change in the natural fiber based polymer composite. Comparing natural fiber and glass fiber reinforced composites found that natural fibers were superior in industrial application. Moreover, due to the usage of natural fibers in different engineering application and construction industries, it provides way for economic development in rural areas.

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