Scientific Journal Impact Factor (SJIF): 5.278
International Journal of Modern Trends in Engineering and Research
IJMTER
ISSN (ONLINE) : 2349 - 9745
ISSN (PRINT) : 2393 - 8161

Mechanical Properties and Processing Techniques of Natural Fibers Reinforced in a Polymer Matrix -A Review

Nikita Chavan[1], Jahnavi VVSS[2], Yash Pradeep Menon[3], Purushotham Shenoy K[4], Madhukumar K[5]

[1,2,3,4,5] *Department of IEM, Sir MVIT Bangalore*

Abstract – The usage of composite materials saw a sudden rise during the sixties, when glass fiber in combination with tough rigid resins were produced on large scale as it has many advantages over materials like synthetic and fiber glass as reinforcement. The present review paper emphasizes on natural fiber based polymer composites. It can be generally seen that the fibers possess high tensile strength and i t is confirmed from various studies that the tensile strength of the composite varies with the amount of fibers, thereby causing these fibers to be reinforced in a polymer matrix for manufacturing various kinds of products used in day to day life. In recent times, the car manufacturers are interested in incorporating natural fiber composite for the parts, some of which are already in use whic h serves to lower the overall weight of the vehicle which in turn increasesthe fuel efficiency, there by seving two major purposes. Hence, on account of the advantages of the natural polymer composites rendered to manufacturing industries, a brief overview on the general properties and various techniques adapted to manufacture these composites is highlighted in this paper. Certain tests on natural fibers like rice and coir hasalso been conducted to prove their mechanical properties.

Keywords – Natural fibers; Composites; processing techniques

I. INTRODUCTION

In recent years, there has been an increasing environmental consciousness and awareness of the need for sustainable development, which has raised interest in using natural fibers as reinforcements in polymer composites to replace synthetic fibers such as glass. Many natural fibers are used in various compositions as reinforcements in different categories of Polymer Matrix. Before getting to the classification of composites, a brief understanding of what composites and reinforcements are is looked upon to

The term composite can be defined as amixture oftwo more distinct phases. However, there are conditions which haveto be satisfied by the material before is said to be a composite. First, both constituents have to be present in reasonable proportions. Secondly, when the constituent phases have different properties, and hence the composite properties are noticeably different from the properties of the constituents, then we recognize these materials as composites.

A matrix is termed as the constituent that is continuous and is often present in greater quantity in the composite.

Reinforcement is the one that provides strength, stiffness, and the ability to carry a load to the composite. In most of the composites, the reinforcement is harder, stiffer and stronger than the matrix. In manufacturing, fibers are the most commonly used reinforcement. The reinforcement is embedded into the matrix[1].

II. CLASSIFICATION

There are two classification systems of composite materials. One of them is based on the matrix material (metal, ceramic, polymer) and the second is based on the material structure.

Therefore, based on the type of matrix and reinforcement materials, composites can be classified as follows:

a) Based on matrix material:

1.Metal Matrix Composites *(*MMC*)*

Matrix Composites are composed of a metallic matrix (aluminum, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase

2.Ceramic Matrix Composites *(*CMC*)*

Ceramic Matrix Composites are composed of a ceramic matrix and embedded fibers of other ceramic material (dispersed phase).

3. Polymer Matrix Composites *(*PMC*)*

Polymer Matrix Composites are composed of a matrix from thermoset (Unsaturated Polyester (UP), Epoxy (EP)) or thermoplastic (Polycarbonate (PC), Polyvinylchloride, Nylon, Polystyrene) and embedded glass, carbon, steel or Kevlar fibers (dispersed phase).

b) Based on reinforcing material structure:

1. Particulate Composites

Particulate Composites consist of a matrix reinforced by a dispersed phase in form of particles which are, Composites with random orientation of particles and Composites with preferred orientation of particles.

2. Fibrous Composites

They are of two types-

• Short-fiber reinforced composites. Short-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of discontinuous fibers (length < 100*diameter).

Composites with random orientation of fibers.

Composites with preferred orientation of fibers.

• Long-fiber reinforced composites. Long-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of continuous fibers.

Unidirectional orientation of fibers.

Bidirectional orientation of fibers (woven).

c) Laminate Composites

When a fiber reinforced composite consists of several layers with different fiber orientations, it is called multilayer (angle-ply) composite [2].

III. NATURAL FIBERS

Natural fibers consist of four major constituents: Cellulose, hemicellulose, lignin and pectin. Natural fibers, asreinforcement, have recently attracted the attention ofresearchers because of their advantages over other established materials. They are environmentally friendly, fully biodegradable, abundantly available, renewable, cheap and have low density. Plant fibers are light compared to glass, carbon and aramid fibers [3]. Thebiodegradability of plant fibers cancontribute to a healthy ecosystem while their low cost and high performance fulfills the economic interest of industry. The natural fibers reinforced polypropylene composites were processed by compression molding method. Although, there are some drawbacks of natural (plant) fibers compared to synthetic fibers, i.e their non uniformity, variety of dimensions and their mechanical properties, the high specific strength and modulus, fiber reinforce composites are receiving widespread attention [4]. Certain features of interest about the polypropylene is that it is robust, i.e the plolypropylene binder fibers can be customized as per our needs, The density of polypropylene is much lower than polyester, leading to production of lightweight composites [5]. The greater advantages of polypropylene is that it does not absorb moisture, it is inert to acids, alkalis and also to other chemicals. Rice panicle(Scientific name of the plant, *Oriza sativa)* is known for its high tensile strength, mechanically, the intact rice panicle has a complex structure with eight to ten branches, each bearing grains, are connected to the main axis. To study the mechanical properties the rachis, the structure was simpified by removing branches with scissors until the main axis remains [6]. Coconut fiber is obtained from the husk of the fruit of the coconut palm; The fruits have to be dehusked with on a spike and after retting , the fibers are subtracted from the husk with beating and washing. The fibers are strong, light and easily withstand heat and water. Coconut is very easily available in southern part of India nad can be put inti extensive usage rather than wastage of the fibers [7]. It has been observed that the coir has the following properties , density 1.2 g/cm^3, failure strain of around 15-30% and a tensile stength of 131-220 Mpa [8].

IV. PROCESSING TECHNIQUES

The basic steps for processing of polymer matrix composites include:

1) Impregnation of the fiber with the resin,

2) Forming of the structure,

3) Curing (thermoset matrices) or thermal processing (thermoplastic matrices), and

4) Finishing[9]**.**

4.1 Resin Transfer Molding

It is sometimes referred to as liquid molding. RTM is a fairly simple process. It begins with a two-part, matched, closed mold that is made of metal or composite material. Dry reinforcement (typically a preform) is placed into the mold and the mold is closed. Resin and catalyst are metered and mixed in dispensing equipment, then pumped into the mold under low to moderate pressure through injection ports, following predesigned paths through the preform. Extremely low-viscosity resin is used in RTM applications for thick parts to permeate preforms quickly and evenly before cure. Both mold and resin can be heated, as necessary, for particular applications. Sisal fiber reinforced polyester composites, carbon fiber reinforced composites and carbon fabric hybrid multiscale composites are some examples.

4.2 Injection Molding

Injection molding is a closed mould process, in which molten polymer (commonly thermoplastic) is mixed with very short reinforcement fibers and injected (forced) under high pressure into a mould cavity having the shape of the component to be produced.

The polymer-fiber mixture in form of pellets is fed into an injection moulding machine through a hopper. The material is then conveyed forward by a feeding screw, which can move forward and backward according to the steps of the moulding cycle. The pellets flow into the heated barrel, where it is melted by heating elements. The screw now acts as a ram in the filling step, wherein the molten polymer - fiber mixture is injected into the mould (under pressure) through the nozzle and sprue. When the material cools and solidifies, the part is ejected by means of ejector pins. The mold is equipped with a cooling system providing controlled cooling and solidification of the materials. Hybrid composites of jute and man-made cellulose fibers with polypropylene, cellulose fiber-reinforced polylactide (PLA) composites, polypropylene single-polymer composites with sandwiched woven fabric, polypropylene single-polymer composites, and polypropylene-based cork–polymer composites are few examples.

4.3 Pultrusion

Pultrusion is a continuous fiber reinforcement plastic moulding process. It starts with raw fibers or fiber roving being pulled off the reels and guided through a resin bath or resin impregnation system. The fiber reinforcement becomes fully impregnated with the resin such that all the fiber filaments are thoroughly saturated with the resin mixture. The wet fibers exit the bath and enter the performer where the excessive resin is squeezed out from the fibers and pre-compacted to the approximate profile. The performed fiber passes through a heated steel or ceramic die, which has the shape similar to the party to be produced. The heat energy transferred inside the metal die activates the curing or polymerization of the thermoset resin changing it from liquid to solid state. The part that exits the die is now a cured pultruded fiber reinforced polymer (FRP) composite. The cured product is cut to the desired length by the cut-off saw.

Thermoplastic composites, natural fiber reinforced composites, carbon reinforced polypropylene (CF/PP) pre-impregnated materials, glass reinforced polypropylene (GF/PP) towpregs are some examples of the materials manufactured by this technique.

4.4 Compression Molding

Compression moulding is a closed mold process in which the charge is squeezed into a preheated mold taking the shape of the mould cavity and performing curing due to heat and pressure applied to the material. In this technique, a precise amount of molding compound, called the charge is loaded into the bottom half of a heated mold. Then, the mold halves are brought together to compress the charge, forcing it to flow and conform to the shape of the cavity. Next, the charge is heated by means of the hot mold to polymerize and cure the material into a solidified part; and lastly,the mold halves are opened and the part is removed from the cavity.

Sugarcane bagasse cellulose/HDPE composites, polypropylene-based cork–polymer composites, multiscale carbon fiber/epoxy composites are some examples of the materials manufactured by this technique.

4.5 Filament Winding

Filament winding is an automated process, primarily used for production of hollow, generally circular or oval sectioned components, such as pipes and tanks. The mandrel (made of sand with water- soluble polyvinyl alcohol as binder) rotates at a predetermined speed while the carriage carrying the resin bath moves horizontally. Consolidation pressure is achieved through tensioning the fibers as they are wound onto the mandrel. Once it is completely covered to the desired thickness, the mandrel is placed in an oven to solidify the resin. When the resin has cured, the mandrel is removed, leaving the hollow final product.

Glass fiber reinforced polymer and Carbon fiber reinforced polymer composite tubes, kevlar fiber monofilament/epoxy composite, epoxy matrix for T800 carbon fiber are some examples of the materials manufactured by this technique.

V. TESTING OF SPECIMEN

Composite testing plays a vital role across the composites supply chain and product life cycle. A range of challenges in regard to safety, quality, process control, regulatory compliance and performance are encountered. Some tests include mechanical, physical, electrical, optical, thermal, flammability, exposure, emissions, barrier, surface, and chemical which identify the characteristics of materials such as resins, films, adhesives, fillers, prepreg or laminates such as thermoset composites and thermoplastic composites. The tensile, flexural and impact testing of certain composites along with compression and shear test are discussed below.

Composite tests have been standardized by a number of organizations. The main international composite testing standards are those maintained by ASTM, ISO, CEN (European Committee for Standardization). In addition to the international standards, there are a number of manufacturer's proprietary standards in widespread use including the BSS series from Boeing and the AITM series from Airbus.

5.1 Tensile Testing

The natural fibers are usually known for its good tensile strength. In-plane tensile testing of plain composite laminates is the most common test. Tensile tests are also performed on resin impregnated bundles of fibers ("tows"), through thickness specimens (cut from thick sections of laminates), and sections of sandwich core materials.

Examples of common standards for the tensile testing of laminates are ASTM D 3039, EN 2561, EN 2597, ISO 527-4, and ISO 527-5.

A natural fiber based polymer matrix composite was prepared by using natural fibers- Coir, Saw Dust, Rice husk and Unsaturated Polyester resin and their tensile properties are studied. The hand lay-up method was adoptedfor manufacturingthe composite[10]. Table 1 gives the data related to the composition of the materials used for testing and the resulting tensile strength is tabulated in table 2.

Table 1.Details of Composites Prepared.

SL. NO.	Specimen designation	%Coir (C)	% Rice husk (H)	% Saw dust (S)	% of USP

1	C5	5			95
2	C10	10			90
3	C15	15			85
4	C20	20			80
5	H5		5		95
6	H10		10		90
7	H15		15		85
8	H20		20		80
9	S5			5	95
10	S10			10	90
11	S15			15	85
12	S20			20	80
13	C10H10	10	10		80
14	C10S10	10		10	80
15	C10S10H10	10	10	10	70

Table2. Tensile strength of various specimens

Specimen	Tensile strength (MPa)
C5	10.3
C10	14.5
C15	21.79
C20	17.02
H5	9.2
H10	11.8
H15	14.96
H20	16.98
S5	12.6

S10	16.16
S15	18.06
S20	19.06
C10H10	29.09
C10S10	31.17
C10S10H10	34.53

5.2 Flexural Testing

Flexure tests are generally used to determine the flexure modulus / flexure strength i.e the load at which the specimen fractures. A flexure test is more affordable than a tensile test and test results are slightly different. The material is laid horizontally and force is applied over a specific no. of contact points until the specimen fails.

To measure the flexural properties of rice straw with polypropylene, three-point bend tests is performed in accordance with ASTM D790Mtest method 1, Procedure A. The ASTM D790 is one of the most commonly used specifications in plastic industry, used for the measure of flexure strength, this test uses a universal testing machine and a three point bend fixture to bend the test specimen and to acquire the data required for calcculations.

The samples are 98 mm long, 10 mm wide, 4mm thick and five identical specimens are tested for each composition. The samples are tested at a strain rate of 0.2mm/min and the outer rollers are 64mm apart.

The flexural modulus, E= Lm/4bt3

The maximum fiber stress S = 3PL/2bt2

Where L is the support span (64mm), b is the width and t is the thickness, P is the maximum load and m is the slope of the initial straight line portion of the load deflection curve. [8]

Table 3. Flexural strength Vs Percentage Weight of Rice Straw.

% Wt. of Rice straw	0%	5%	10%	15%	20%	25%
Flexural strength	45.53	40.04	28.65	34.92	40.7	38.3

5.3 Impact Testing

To test the impact properties of fiber reinforced composite specimens, an analog Izod/Charpy impact tester is used. The Impact strength is given by,

Impact Strength = [EI/T] Joules/m

Where,

EI = Impact Energy in joules recorded on the scale

T = Thickness of the sample used[2].

Table 4. Impact Strength for mixture of Rice Straw /PP composites.

Specimen	**Impact Strength (J/m) of composite at different weight fractions of rice straw fiber**				
	5%	**10%**	**15%**	**20%**	**25%**
1	44.1	22.2	16.7	44.4	33.3
2	33.3	16.7	11.1	27.8	38.9
3	38.9	27.8	22.2	38.9	38.9
4	44.4	50	27.8	27.8	44.4

5.4Compression Testing

Composite compression test methods need to provide a means of introducing a compressive load into the material while preventing it from buckling. Most composite materials are produced in the form of laminate panels, and hence, the material being tested will be in the form of a relatively thin and flat rectangular test specimen.

There are three methods of introducing a compressive load into a test specimen:

1) End loading: all of the load is introduced into the flat end of the test specimen.
2) Shear loading: the load is introduced into the wide faces of the test specimen.
3) Combined loading: A combination of shear and end loading is used.

There are two methods for preventing buckling of a test specimen:

1) Use of a test specimen with a short, unsupported gage length.
2) The use of lateral support along the length of the specimen.

In practice, there are several different compression test methods that utilize all possible combinations of the above methods of load introduction and buckling prevention.

All compression fixtures are required to have good axial alignment and a high lateral stiffness in order to provide and maintain accurate alignment under the lateral loads that can be generated by a compression test. Bending will have a significant effect on test results and most of the compression test methods include a value for the maximum allowed specimen bending. Common composites compression test standards include: ASTM D695, ASTM D3410, ASTM D6641, ISO 14126, and prEN 2850[11].

5.5 ShearTesting

In-plane shear properties can be measured on a tensile test specimen with a ±45 degree fiber orientation. The specimen's axial and transverse strain is measured using either strain gages or a biaxial extensometer. Standards for this test include ASTM D3518 and ISO 14129.

The inter-laminar shear strength test (ILSS), sometimes referred to as short beam shear, is a simple test performed using a small specimen loaded in a three-point bend configuration. The ratio of the specimen thickness to the support span is high; this helps generate large shear loads along the center line of the specimen. ILSS standards in common use include: ASTM D2344, EN2563 and ISO 14130.

Other laminate shear test methods include the rail shear (ASTM D4255 and ASTM D7078) and V-notched beam (ASTM D5379). Shear tests for sandwich core materials include: loading parallel to the plane of the facings (ASTM C273) and short beam shear (ASTM C393).

REFERENCE

[1]. Pardeep Ranga, Dr.Sandeep Singhal, Dr.Inderdeep Singh, A Review Paper on Natural Fiber Reinforced Composite,International Journal of Engineering Research & Technology (IJERT) ISSN:2278-0181 Vol. 3 Issue 2, February – 2014.

[2]. K Sudhakar, Ch Srinivas, Investigation of Mechanical Properties of Rice Straw Fiber Polypropylene Composites, K Sudhakar et al Int. Journal of Engineering Research and Applications, ISSN:2248-9622, Vol. 4, Issue 1(Version 2), January 2014.

[3]. Tong Yuanjian, D.H. Isaac, Impact and fatigue behaviour of hemp fibre composites, Composites Science and Technology 67 (2007) 3300–3307.

[4]. Pardeep Ranga, Dr. Sandeep Singhal, Dr. Inderdeep Singh, A Review Paper On Natural Fiber Reinforced Composite, IJERT, Vol. 3 Issue 2 , February 2014.

[5]. K. Sudhakar, C.H. Srinivas, Investigation of mechanical properties of Rice Straw fiber polypropylene composites, IJERA , vol. 4 , issue 1, Jan 2014, pp 182-187.

[6]. Wendy Kuhn Silk, Lily L. Wang and Robert E. Cleland , Mechanical Properties of the Rice Panicle , Plant physiol. (1982) 70, 460-464

[7]. Tara Sen, H.N. Jagannatha Reddy, Application of Sisal, Bamboo, Coir and Jute Natural Composites in Structural Upgradation, International Journal of Innovation, Management and technology, Vol 2, No.3 , June 2011.

[8]. K.I. Pickering , M.G. Aruan Efendy, T.M. Le, A Review of Recent developments in the natural fiber composites and their mechanical performance .

[9]. H.V.Divya, L.Laxmana Naik, B.Yogesha, Processing Techniques of Polymer Matrix Composites – A Review, International Journal of Engineering Research and General Science ISSN 2091-2730,Volume 4, Issue 3, May-June, 2016.

[10]. V.Mastan, Prof.N.Jeevan Kumar, A.Harish Kumar, A Review Paper on Tensile Properties of Natural Fiber Polymer Matrix Composites, International Journal Of Engineering And Science Vol.04, Issue 12 (December 2014).

[11]. Dr. Dan Adams, Director, Composite Mechanics Laboratory, University of Utah, Composite Structure Engineering, September 14-16, 2010.