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Research Article

Investigation on Tensile and Flexural Properties of Coir Fiber Reinforced Isophthalic Polyester Composites

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Abstract

The bio-degradability issue of polymer composites is studied to focus more on the use of the natural fibers such as bagasse, coir, sisal, jute etc. This has resulted in creation of more awareness about the use of natural fibers based materials mainly composites. In past decade there have been many efforts to develop composites to replace non decaying materials based products. The abundant availability of natural fiber in India gives attention on the development of natural fiber composites primarily to explore value-added application avenues. Reinforcement with natural fiber in composites has recently gained attention due to low cost, easy availability, low density, acceptable specific properties, ease of separation, enhanced energy recovery, CO_2 neutrality, bio-degradability and recyclable in nature. Isophthalic polyester resin are a broad class of resins specification is selected to impart desired properties and corrosion resistance. These resins can be used for moderate corrosion resistance applications to a temperature range around 180°F. Isophthalic resins exhibits good resistance to water, acid, weak bases and hydrocarbons such as gasoline and oil. Agricultural wastes can be used to prepare fiber reinforced polymer composites for commercial use. 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. In this connection, an investigation has been carried out to make use of coir; a natural fiber abundantly available in India. This investigation discusses the use of coir fiber and its current status of research. Many references to the latest work on properties, processing and application have cited in this paper.

Keywords: *Natural fiber, Coir, Isophthalic resin, Polymer Composites.*

1. Introduction

Unlike plastics, vegetable fibers are biodegradable, annually renewable, non-carcinogenic and therefore health-friendly. Traditionally, jute and jute-like mesta are being used for packaging as sacking, hessian, bags and soil savers besides being used as carpet backing, jute scrims, tarpaulins, canavas, tar felts, etc. There are other diversified uses too as technical textiles, geo-textiles, agro-textiles and handicrafts. Other allied vegetable fibers like ramie, sisal, flax, pineapple leaf fiber, coir, etc. are also used in single form or in union with jute. The agronomical factors that contribute to good quality jute fiber are close spacing of crops, reduced nitrogenous fertilizers, intercropping and multiple cropping, application of Azotobacter inoculants to soil, pre-flowering harvesting and canal retting. Post-producing retting and mechanical processing which are the two next most important factors specific to the crop are covered. Microbial activity in aqueous medium helps in eliminating pectinous gums and lignin that bind the fibers. The retting process varies from crop to crop and the same is covered in brief under each crop. All the plant fibers mentioned here are natural cellulosic and multicellular in nature except cotton which is unicellular. The major constituents of all cellulosic fibers are α-cellulose, pestosan and lignin. High α-cellulose and low lignin content of a fiber are necessary for its textile application. The chemical composition of the vegetable fibers is also reported.

1.1 Jute

(Chand, N *et al* 2006) The two cultivated varieties are Corchoruscapsularies&corchrousolitorius belonging to Tiliaceae; locally called pat, nalita, marapata, patua&jhot. Capsularies is usually called tita pat &olitorius called mitha pat, tossa&daisee. Jute has a mesh structure with reed length of about 1.5-4.5 m and each fiber element of a raw reed, available commercially and longitudinally by means of inter-cellular materials chiefly of non cellulosic composition and hence jute fiber is muticellular. The jute ultimates are 2.5 mm long on an average, approximately 18 microns wide at the middle and tapper towards each end. The average linear density of single jute filament usually lies between 1.3-4.0 tex for tossa jute.

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1.2 Cotton

(Anonymous *el al* 2003) Cotton is a natural fiber of vegetable origin like linen, jute or hemp. Mostly composed of cellulose (a carbohydrate plant substance) and formed by twisted, ribbon- like shaped fibers, cotton is the fruit of shrubby plant commonly referred to as the cotton plant. The cotton plant, Gossypiumsp (Malvacae) which comprises approximately 1500 species, also including the baobab tree, the boom box or the mallow. Either herbaceous or ligneous, it thrives in dry tropical and subtropical areas. Whereas by nature the plant is a perennial tree (lasting about 10 yrs), under extensive cultivation it is mostly grown as an annual shrub. The cotton fiber (Gossypiumhirsutum) (0.1-0.3 tex) is finer than jute fiber (1.3-4.0 tex). Cotton is a single fiber entity having an average length of 25-40 mm^2. The major end uses for cotton fiber including wearing apparel, home furnishings, and other industrial uses (such as medical supplies).

1.3 Sisal

(Alvarez el al 2003) Sisal (Agave Sisalaana) is a multicellular leaf fiber with very short ultimates (0.5-6 mm) but long as a bundle with tenacity of 40-45 g_f/tex, which is higher than jute (30-35 g_f/tex). The fiber foremost among the hard fibers is long, bold, creamy white and exceptionally strong. Sisal grows well on a dry permeable sandy loam and is exceedingly drought resistant. The leaves are cut for fiber between the third and fourth year. Each plant yields about 250-300 leaves suring its life time of 7-8 years. Sisal leaf is decorticated mechanically to extract fibers which washed in plain water and sun dried. It has no established spinning system; rather the fibers are twisted into rope. The fiber is eminently suited for cordage of all kinds. It has the ability to carry loads and can, therefore, be attractive as the reinforcement.

1.4 Banana

(Sudhakar R el al 2003)The stem of the banana plant is usually thrown away once the plantain is harvested. The stem forms a major waste material in large-scale banana plantations. And for the large scale farmers, the disposal of these stems is a real problem. Fiber can be extracted from banana stem both manually and by mechanical extractor. A wide range of products including bags, baskets, wall hangings, floor mats, home furnishings, etc. can be made with banana fiber. The fiber extracted by mechanical process is of superior quality and is extensively used for making high quality special paper and decorative papers. Banana fiber is used to manufacture handicrafts, home decorative, door mats, table mats, pooja and meditation mats. In some countries, banana fiber used for making of currency paper. Banana fiber is being used in making socks in European countries.

1.5 Coir

(Asasutjarit*et al* 2009) Ripe and dried coconut husk produce coir fibers which are short in length (ultimate cell length 0.5-4 mm) and coarse. Coconut husk is kept submerged in water up to 6 months and then bitten to loosen coir. It is very coarse with very low aspect ratio and is, therefore, not suitable for spinning. Coir fibers are twisted into rope. Spinning into yarn from coir is not possible; however the practice of alkali boil in soda makes the fibers somewhat soft to be blended with jute for manufacturing yarn of medium to higher poundage. As such, coir has, therefore, no spinning system for making single yarn of its own. Hence, rope is the only technically feasible product from the coir fibers. There are also possibilities of using waste fiber as fillers in cement, latex and other industrial adhesives.

1.6 Requirement of Composites

Over a past few decades composites, plastics, ceramics have been the dominant engineering materials. The areas of applications of composite materials have grown rapidly and have even found new markets. Modern day composite materials consist of many materials in day to day use and also being used in sophisticated applications while composites have already proven their worth as weight saving materials the current challenge is to make them durable in tough conditions to replace other materials and also to make them cost effective. This has resulted in development of many new techniques currently being used in the industry. The composite industry has begun to recognize the various applications in industry mainly in the transportation sector. New polymer resin matrix materials and high performance fibers of glass, carbon and aramid which have been introduced recently have resulted in steady expansion in uses and volume of composites. This increase has resulted in obvious reduction of cost. High performance FRP are also found in many diverse applications such as composite armoring design to resist the impact of explosions, wind mill blades, industrial shafts, and fuel cylinders for natural gas vehicles paper making rollers and even support beams of bridges. Existing structures that have to be retrofitted to make them seismic resistant or to repair damage caused by seismic activity are also done with help of composite materials.

While the use of composites is a clear choice in many applications but the selection of materials will depend on the factors such as working life, lifetime requirements complexity of product shape, no of items to be produced , savings in terms of cost and the experience and skill of designer to trap the optimum skill of the composites.

1.6.1 Composites

A composite material is made by combining two or more materials to give a unique combination of properties, one of which is made up of stiff, long fibers and the other, a binder or 'matrix' which holds the fibers in place. (Kelly*et al* 1967) very clearly stated that the composites should not be regarded simple as a combination of two materials. In the broader significance; the combination has its own distinctive properties. In terms of strength to resistance to heat or some other desirable quality, it is better than either of the components alone or radically different from either of them. (Beghezan*et al 1966*) defined as "The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their short comings", in order to obtain improved materials. (Van Suchetclan*et al* 1972) explained composite materials as heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They can be also considered as homogeneous materials on a microscopic scale in the sense that any portion of it will have the same physical property**.**

1.6.2 Composites Properties

Composites consist of one or more discrete phases embedded in a continuous phase to produce a multiphase material which possesses superior properties that are not obtainable with any of the constituent materials acting alone. These constituents remain bonded together but retain their identity and properties. The continuous phase which is present in greater amount in composites is termed as „matrix‟. The discrete phase is generally harder and stronger than the continuous phase and is called the „reinforcement‟ or „reinforcing material‟. The geometry of the reinforced phase is one of the major parameter in determining the effectiveness of the reinforcement. Properties of composites are strongly depend on the characteristics of their constituent materials, their distribution and the interaction among them Further, the need of composite for high strength to weight ratio, corrosion resistance, lighter construction materials and more seismic resistant structures has placed high emphasis on the use of new and advanced materials that not only decreases weight but also absorbs the shock & vibrations through tailored microstructures. Modern and ancient applications all make use of the fact that composites can possess enhanced strength, stiffness and fracture, toughness whilst not exhibiting an increase in weight. Composites are being used for prefabricated, portable and modular buildings as well as for exterior cladding panels. Table 1 shows the cellulose and lignin contents and some other properties of a few fibers available in India. So far, the utilization of sisal, jute, coir and bagasse fibers has found many successful applications.

1.6.3 Composites constituents

Most composites consist of a bulk material („matrix‟) and a reinforcement of some kind, added primarily to increase the strength and stiffness of the matrix. Matrices (Mathews F.L, Rawlings R.D *et al* 1994) materials in composites are required to fulfill the following functions:
a) To bind together the fires by virtue of its cohesive and adhesive characteristics
b) To protect them from environments and handling.
c) To disperse the fibers and maintain the desired fiber orientation and spacing.
d) To transfer stresses to the fibers by adhesion and/or friction across the fiber-matrix interface when the composite is under load, and thus to avoid any catastrophic propagation of cracks and subsequent failure of composites.
e) To be chemically and thermally compatible with the reinforcing fibers.
f) To be compatible with the manufacturing methods which are available to fabricate the desired composite components.

1.6.4 Epoxy resins

Epoxy resins are characterized by the presence of more than one 1, 2- epoxide groups per molecule. Cross-linking is achieved by introducing curatives that react with epoxy and hydroxyl groups situated on adjacent chains.

Advantages and Limitations of resin matrix

Advantages

1. Low Densities
2. Good Corrosion Resistance
3. Low Thermal Conductivities
4. Low Electrical Conductivities
5.Translucence
6.Aesthetic Color Effects

Limitations

1. Low Transverse Strength.
2. Low Operational Temperature Limits

1.6.6 Reinforcement

The objective of the reinforcement in a composite material is to enhance the mechanical properties of the resin system. All of the distinct fibers that are used in composites have distinct properties and so affect the properties of the composite in different ways. For most of the applications, the fibers need to be arranged into some form of sheet, known as a fabric, to make handling possible.

2. Experimental methodology

Basically three main tasks were carried out to achieve the objectives of study. The first task was the preparation of composite material by combining the polyester and coconut coir. Then it was continued by performing the tensile test and flexural test lastly the microstructure analysis was carried out for the composite.

2.1. Material

The studied composite material is made of polyester matrix reinforced with coconut fibres which were arranged in discontinuous randomly oriented configuration. Basically, the coir fibres obtained from the coconut husk which was abstracted from coconut fruit. After they had been abstracted, the coir fibres will be dried at 70°C to 80°C using drying oven. In order to avoid degradation factor, the coir fibres need to go through the treatment process. This process consists of immersing the coir fibres into 5% Natrium Hydroxide (NaOH) solution for 24 hours to remove the first layer of coconut coir fibres. After that, the obtained fibres were washed abundantly with water to remove the NaOH before they dried again in furnace at 70°C to 80°C for next 24 hours. The coir fibres were then soaked into 5% of silane and 95% of methanol solution for 4 hour and dried at 70°C for next 24 hours curing time. After the drying process finished, the coconut fibres was inserted into the cutting machine to cut into smaller pieces. This form is called whickers which its length is less than about 10 mm. The advantage of whickers is that they can easily pour into the mixture of coconut fibres and polyester in ASTM D638 Type 1 mould (Turtle 2004).

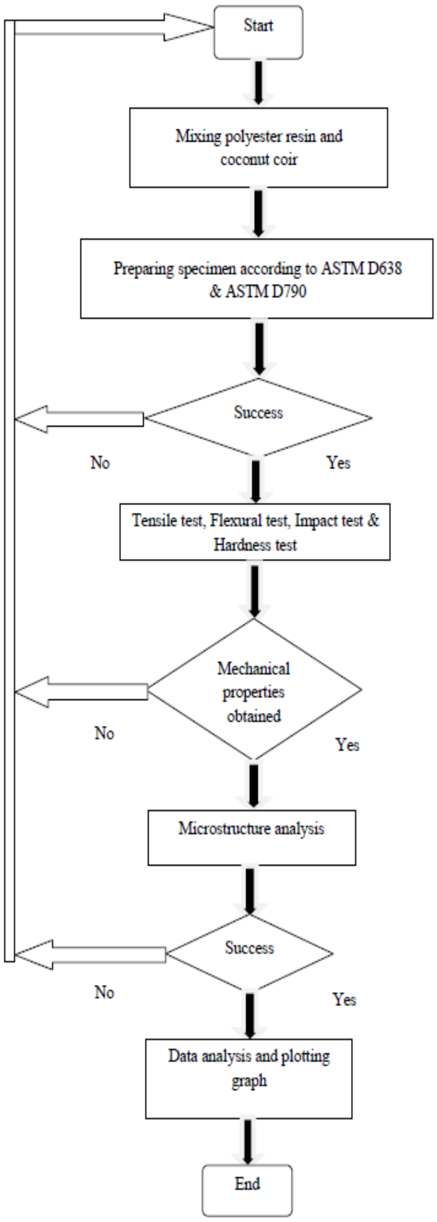

Fig.1: Flow chart of the process

The physical properties of coir fibres are as follows:

- Density (g/cm3) = 1.2
- Elongation at break (%) = 30
- Tensile strength (MPa) = 175
- Young modulus (GPa) = 4 - 6
- Water absorption (%) = 130-180

The mechanical properties of polyester resin are as follows:

- Density (g/cm3) = 1.2 - 1. 5
- Young modulus (GPa) = 2 - 4.5
- Tensile strength (MPa) = 40 - 9 0
- Compressive strength (MPa) = 90 -250
- Tensile elongation at break (%) = 2
- Water absorption 24h at 20 °C = 0.1 - 0 . 3

Fig.2: Coir

The usage of isophathalic polyester resin as a matrix was chosen because it is the standard economic resin commonly used, preferred material in industry and besides, it yields highly rigid products with a low heat resistance property. The polyester resin was prepared by mixing polyester of density 1.28 g/cm3 with hardener 3554B of density 1.05 g/cm3 at weight ratio 100: 1.

Fig.3: Isophathalic polyester resin

2.3. Specimen preparation

(ASM International *et al* 1988) For tensile testing and flexural testing purpose the coconut fibers composite is made from hand layup process which is followed with ASTM D638 and ASTM D790. Hand lay-up is a simple method for composite production. A mold must be used for hand lay-up parts unless the composite is to be joined directly to another structure. The mold can be as simple as a flat sheet or have infinite curves and edges. For some shapes, molds must be joined in sections so they can be taken apart for part removal after curing. Before lay-up, the mold is prepared with a release agent to insure that the part will not adhere to the mold. Reinforcement fibers can be cut and laid in the mold. It is up to the designer to organize the type, amount and direction of the fibers being used. Resin must then be catalyzed and added to the fibers. A brush, roller or squeegee can be used to impregnate the fibers with the resin. The lay-up technician is responsible for controlling the amount of resin and the quality of saturation.

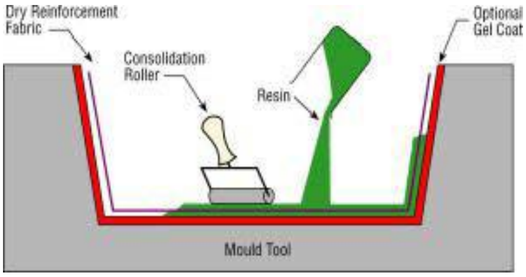

Fig.4: Hand lay-up process

2.4 Preparation of Composites

Composites having different fibers content were prepared by varying the fibers volume fraction from 10% to 40%. In the first process of preparing the composite, a release agent was used to clean and dry the mould before the polyester can be laid up on the mould. The polyester was then mixed uniformly with the coconut fibers by using a special brush in the mixed container. The mixture was poured carefully into the moulds and flattened appropriately by using the roller before being dried for 24 hours. After the composites were fully dried, they were separated off from the moulds.

2.4. Analysis

2.4.1. Tensile testing of a single fiber

The tensile properties of the long continuous snake grass fiberwere measured by a single fiber tensile testing method accordingto the ASTM D3379-75standards using the Instron UniversalTesting machine. The gauge length of each fiber was taken as100 mm and a 1000 g load cell was used for the testing. The crosshead speed of the grippers was 5 mm/min and the same speed was used throughout the testing. Twenty-five samples were tested in this work and the average value of the tensile strength; tensile modulus and elongation at the failure/break were obtained. The density of the fiber was evaluated using the meltbertoledoxsz05 balances method.

2.4.2. Tensile testing of the composite

Tensile tests were conducted for the composite specimen usingthe electronic tensometer setup to obtain the tensile properties.The dog-bone specimens of the composites were prepared accordingto the ASTM D 638standards. The specimens weremachined to a standard size of 165 mm × 13 mm × 4 mm for agauge length of 50 mm. For this testing, the load cell of 5 kN wasutilized in the tensometer with the same cross head speed of1 mm/min. Four identical test specimens were used for eachtesting and numbered in series as T1, T2, T3 and T4 .Propertiessuch as tensile strength, tensile (elastic) modulus, tensile load andelongation at break of the composites were measured from theexperimentation. During tensile testing, the specimens were brokenin between the gauge length of the specimen and the correspondingimage was shown in

Fig.5: Tensile test specimens of coir fiber in polyester composites.

2.4.3. Flexural testing of the composite

Three point flexural testing were conducted according to the ASTM D 790standards using the spring mass testing machine. The specimens were machined for the dimensions of 125 mm × 12 mm × 4 mm. The span to the depth ratio of the specimens was considered as 16:1. For this testing, the load cell of 6 kN was utilized with the cross head speed of 2.5 mm/min. Four identicaltest specimens were prepared and numbered as F1, F2, F3 and F4 for each flexural testing. Deflections of the specimen were measured using the digital dial gauge and the flexural properties like flexural strength, flexural modulus, flexural load and deflection at break of the composites were evaluated. As similar to the tensile testing, the five identical specimens were broken in between the gauge length and the corresponding image was shown in

Fig .6: Flexural testing of coir fiber in polyester composites

3. Results and discussion

3.1. Effect of tensile properties of the coir fiber reinforced composites

The tensile properties of the coir fiber reinforcedcomposites are compared with the various fiber volumefractions for various fiber lengths. Fig 3.1 shows the variation of tensilestrength over the percentage increase in fiber volume fractions for the various fiber lengths. The tensile strength decreases from200.15 MPa to 170.25 MPa when the fiber length is increased from10 mm to 150 mm for 10% V_f. For 10% V_f, the fiber accumulationis very less in the composite, so the percentage increase betweenthe maximum and minimum tensile strength for the present caseis almost 16.8%. Similar decreasing trend in the tensile strengthis visible for other cases up to 25% V_f. The percentage increasebetween the maximum and minimum tensile strength for 15% $V_f$is 11.85%. This percentage was reduced when compare to 10%V_f is due to the more accumulation of fiber in the composite. Similarlythe improvement percentage between the maximum andminimum tensile strength was further reduced to 10.37% for 20%V_f. Maximum tensile strength of 252MPa is obtained for40 mm fiber length in the present work when the percentage volumefraction is 25.

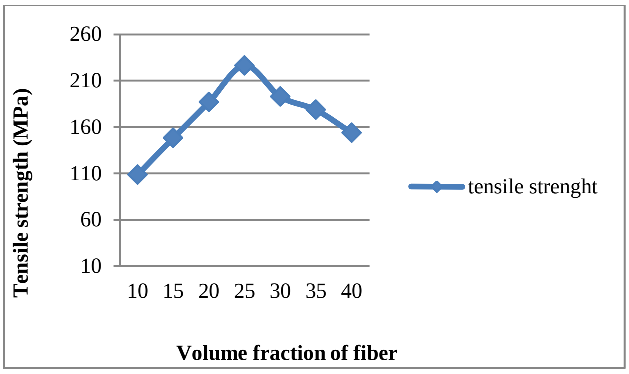

Fig .7 Effect of tensile properties of coir fiber reinforced composites

3.3. Effect of flexural properties of coir fiber reinforcedcomposites

The flexural property is one of the important parameter in composites mainly useful to quantify in structural applications.Fig 3.2shows the variations in the flexural strength values over% increase in volume fractions. It is observed that the flexural strength values are gradually increased up to 20% V_f. Beyond 20% $V_f$of fiber in composite, the flexural strength is suddenly increased. Then theincreasing trend suddenly changes and the flexural strength gets drastically reduced when V_f of fiber in composite is 30%. During the composite preparation, if the fiber content is more than 30% V_f, it leads to insufficient filling of matrix into the surrounding fibers and it is one of the main reason for the incomplete composite.

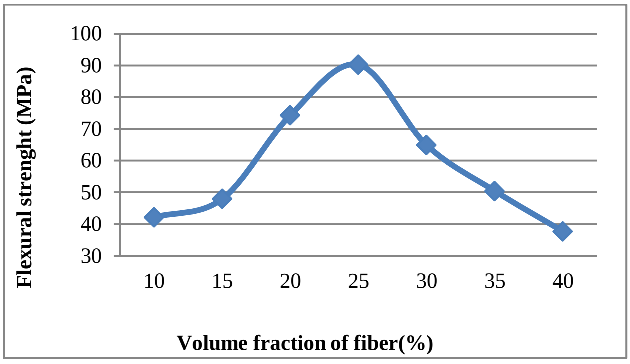

Fig .8 Effect of flexural strength of coir fiber reinforced composites

4. Conclusions

The work has been carried out, with an objective to explore the potential of the coir fiber polymer composites and to study the mechanical properties of composites.

1) This work focused at providing knowledge to enhance further research in this area.
2) The possibility of surface chemical modification of coir fibers have been extensively used in wide variety of application, e.g., packaging, furniture's etc.
3) A relative lower strength of coir composites does not have to be a negative aspect because there may be several non-structural applications where the strength properties of coir composites could meet the technical and product requirements, particulraly when the competitive price level of coir is taken into consideration.
4) The relative position of coir in relation to other natural fibers is still to be investigated in more detail.
5) It can be concluded that the 25% volume fraction (V_f) of the coir fibers composite have the maximum mechanical properties. While manufacturing the composite specimens, the fiber length plays an important role.

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