Evaluation of Tensile and Interfacial Strength of Coconut Palm Leaf Midrib as a potential Reinforcement for Plastics

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Abstract- In the present scenario world is facing a serious problem of the polymer wastes due to its non-biodegradable nature. Production of the natural fiber composite is one of the noble approaches to minimize this problem and modify the polymer based materials as partially biodegradable. In last two decades many researchers have been investigating and exploring new natural fibers and their composites with polymers as matrix material. Due to various advantages and eco-friendly nature, natural fiber composites are replacing conventional materials and glass fibers in moderate strength applications. Strength of natural fiber/polymer composites highly depend upon interfacial strength between hydrophilic fiber and hydrophobic polymers. In this paper potential of a new natural fiber as midrib of coconut palm leaf is investigated for the purpose of synthesis of a new natural fiber composite. Tensile properties of midribs and interfacial strength between midrib and polyester resin and critical embedded length are determined by tensile test and fiber pull-out test. Results show that midrib of coconut palm leaves have potential for development of natural fiber composite.

Keywords – Polymer matrix composites, Natural fibers, midrib of coconut palm leaf, Interfacial strength, Pull-out test

I. INTRODUCTION

Plastics or polymers are replacing conventional materials like wood, metal, glass and ceramics and its application can be realized in many aspects of our lives. The advantages of plastics over conventional materials are ease of formability, Low processing temperature, very low density compared with metals, excellent surface finish and lack of corrosion. Due to advances in technology and growing global population production of plastics in the form of different products are also growing day by day. Worldwide production of plastic is approximately 140 million tons every year [1]. To increase the strength and performance of plastics, fibers are reinforced in it. Synthetic fibers like Carbon, Glass, Kevlar etc [2] are the most popular and commercial fibers used for reinforcement of plastics. Since most of the plastics (Polyethylene, polypropylene, polyvinyl chloride etc.) and synthetic fibers are non-biodegradable and build up in the surrounding at a rate of 25 tons per year which is proving to be a major ecological and environmental problem [1]. Also, Synthetic fibers require production of fiber itself and are dangerous to environment and health. With the increase of global crisis, ecological and environmental risk plant based natural fiber reinforced plastics have attracted much interest due to their potential of serving as alternative reinforcement to the synthetic fibers. Natural fibers like jute, flax, hemp, coir and sisal have gained a commercial value for the production of natural fiber reinforced plastics and also have proven as a greener substitute to glass fiber with excellent structural strength against moderate loading conditions [3].

Mechanical properties of a natural fiber composite mainly depend upon fiber matrix interface and efficiency of stress transfer from matrix to fibers as reported by many researchers [4-8]. Stress transfer ability from matrix to fiber depends upon interfacial adhesion between the fiber and the polymeric matrix [9, 10]. Experimental evaluation of interfacial strength between fiber and matrix material in a natural fiber reinforced composite, single fiber pull-out test is suggested by many researchers [11,12].

Midrib of coconut palm leaf (MCL) is the large, centre, main vein which helps to hold the leaf, facing the sun. It is commonly used for making brooms and also known as broom stick. Fig.1 shows picture of MCL and anatomical view of the cross section of midrib.

ISSN 2250-3153

(a) (b)

Figure1: (a) Midribs of coconut palm leaves (b) Anatomical view of cross section of midrib

Midrib of coconut palm leaf content 30% cellulose and 16% lignin and its properties is found appreciable for the purpose of reinforcement of plastics which can be used for different structural parts where moderate strength is required like door panels, roof sheets, packaging etc. [13,14]. This paper present a study on interfacial strength in a natural fiber composite and also investigate potential of MCL for the development of a new sustainable material as MCL reinforced polyester composite. Specimens are developed and tensile tests of MCL and polyester are conducted on an UTM also Single fiber pull out tests are conducted for determination of interfacial properties between MCL and polyester resin.

II. MATERIAL AND METHOD

A. Material

Midrib of coconut leaf (MCL) is supplied by Maharaja Broom Works, Bhopal, India. Polyester resin (Grade: VBR 4513) with Cobalt naphthanate as accelerator and methyl ethyle ketone peroxide (MEKP) as hardener is provided by Parmali Wallace Ltd. Bhopal, India. The resin has 500-600 cps viscosity, 15-25 min. gel time at 25°C and 38-40% volatile content. Healthy Midribs were selected from stock and cut uniformly. Selected part of midribs were finished with the help of a knife and then washed thoroughly in running water for clearing their surface from leaf residuals and other impurities. Midribs are allowed to dry first in sun light and than in hot air oven at 60° for 8 hrs.

B. Preparation of specimens

Specimens for tensile testing of MCL were prepared by cutting selected (middle part) length of MCT from finished stock of MCL. Diameter of sticks was measured by a digital vernier scale. Gauge length of 150 mm was kept between griping ends, prepared by glass fiber reinforced sheets (Fig.2). Fig. 3 shows mould for casting of single fiber pull-out test specimens , which was developed on a surface plate by joining loose pieces of the tiles. A through hole is generated in the walls of the mould to support and facilitate extended length of the fiber embedded in the resin. Fig.4 shows specimens for single fiber pull-out test, five specimens for single fiber pull out test were prepared with cross-section 20x20 mm and gauge length can cut to a suitable length according to pull out strength.

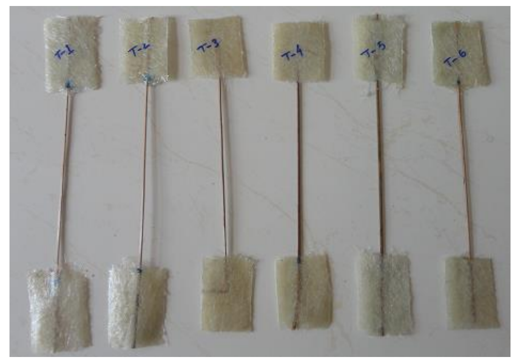

Figure 2: Specimens for tensile test of MCL fiber

Figure 3: Mould for single fiber pull-out test

Figure 4: Specimens for single fiber pull-out test

C. Density measurement

Ten samples of suitable size were chopped from midribs. Weight of each midrib measured with the help of Electronic Balance (Contech Instruments Ltd. Model No.ca 124). Volume of each sample was measured by liquid displacement method. Density of midrib was evaluated as average value of density calculated for each sample by weight upon volume.

D. Mechanical testing

To determine tensile strength of MCL fiber tensile test were conducted on at least five specimens of Midribs on Instron 3382 UTM at cross head speed of 5 mm/min. In order to identify interfacial shear strength and stress transfer capability of matrix to fiber single fiber pull out test were conducted at cross head speed of 2mm/min on the same UTM, on at least five specimens. Fig.5 and Fig.6 shows experimental set up for tensile test and single fiber pull out test respectively. All test were conducted at 23^0C room temperature and 55% Humidity.

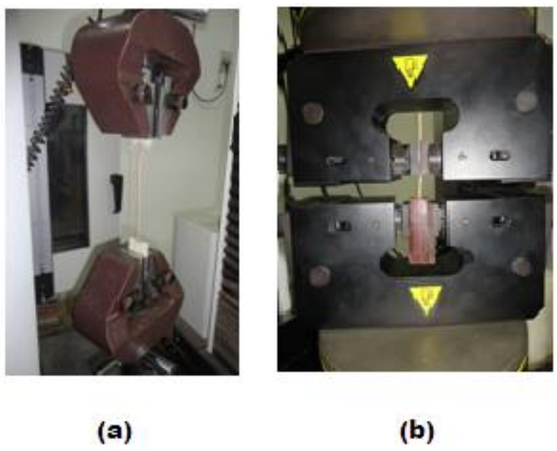

Figure 5: Experimental set up for (a) Tensile testing of MCL, (b) Single fiber pull-out test

III. RESULTS AND DISCUSSION

A. Density of MCL

Fig. 6 shows a comparison of density and therefore, lightness of MCL fiber with other synthetic and natural fibers from reported journal data. It can be observed that density of midrib is about 1.3 gm/cm^3, in comparison to density of other fibers it is lighter than synthetic fibers like glass fiber, carbon fiber, Aramide, and natural fibers like Cotton, Flax, Hemp, Ramie, Sisal its density is equal to density of Coir fiber and Jute fiber as compared with reported journal data [15].

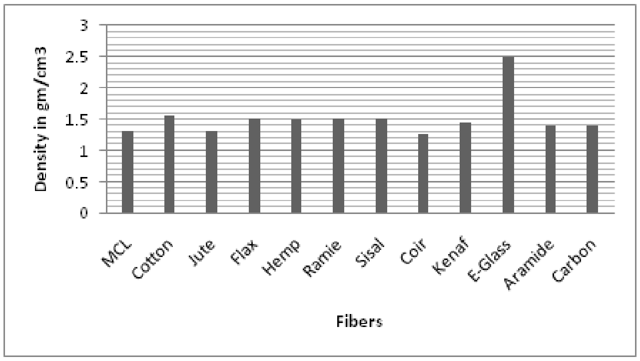

Figure 6: Comparison of density of MCL with other fibers

B. Tensile strength of MCL

Table I shows Mechanical properties of midrib as natural fiber. Higher strength of fiber than matrix material ensures the probability for improvement in the strength of plastic material.

Table I: Properties of MCL fiber

Density (in gm/cm^3)	Tensile strength (in MPa)	Tensile modulus (in GPa)	Specific Tensile strength	Specific Tensile modulus	Elongation at failure (in %)
1.3	177.5	14.85	132.5	11	2

Fig.7 shows machine generated load deflection curve for five samples of the *Cocos nucifera* leaf midrib. It can be observed that stress-strain behavior follow the same trend for all samples and maximum elongation at failure is found 2% which shows that the failure pertains to brittle in nature.

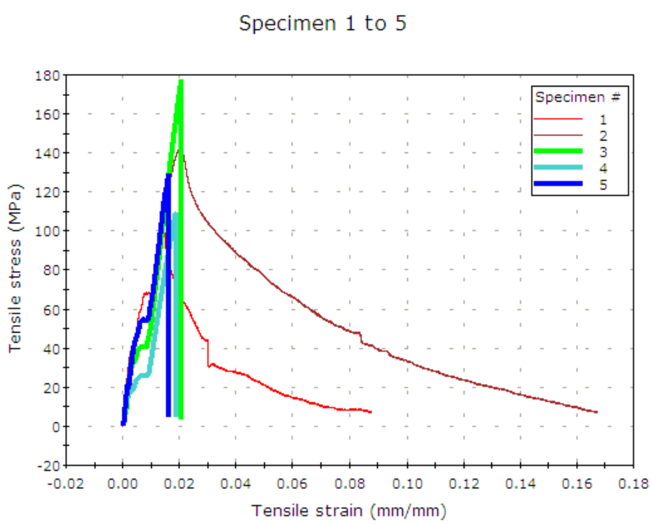

Figure 7: Stress-strain curves for MCL fiber

Specific properties calculated per unit density of fiber in which specific modulus of midrib is found more than coir and cotton fiber and in the range of jute fiber [3]. Mechanical properties of midrib highly depend upon nature. Even midribs of different leaves may have different properties [16]. Tensile test results shows maximum tensile strength of 177.5 MPa which is in the range of coir fiber strength, and tensile modulus of 14.85 GPa which is more than that for coir, cotton and sisal fibers but less than flax, hemp, ramie, jute and synthetic fibers as compared with reported journal data [3,17]. Midrib fiber can be considered as bundle of microfibrils having lesser binding strength between them and increases probability of inner cells failure [18] due to this reason, midrib fiber with larger diameter would expected to have lesser strength but midribs are found strong enough for the moderate strength purposes.

C. Single fiber pull-out strength

The ability to transfer stress from the matrix to fiber at the interface is the main factor on which efficiency of a natural fiber reinforced polymeric composite depend [19, 20]. Various models have been reported by researchers for investigation of interfacial adhesion between fiber and matrix, an analytical model developed by Kharrat et al [21] assumes an elastic load transfer between the fiber and matrix (shear-lag model) for the first phase of the pull-out test (before debonding). After debonding, the fiber is extracted from the matrix against friction. To analyze this phenomena an analytical model, which assumes Coulomb friction at the fiber-matrix interface and Poisson's effects on both fiber and matrix, was developed for the extraction process of fiber from matrix. This model was verified by the experiments for both stainless steel/polyester and stainless steel/epoxy composite systems. A fracture mechanics approach is proposed by Morrison et al [22] which can be applied to any fiber and matrix material to evaluate interfacial properties. Hutchinson and Jensen [23] proposed a pull-out model which was further developed by Marshel [24] in which unload- reload hysteresis is accounted for interfacial adhesion strength.

Mechanical properties of natural fiber reinforced polymeric composite strongly depend upon interfacial bonding because natural fibers are rich in hydroxyl groups like celluloses, hemicelluloses, pectin and lignin which causes strong polar and hydrophilic nature whereas polymers are significant hydrophobic in nature. Many researchers have studied interfacial characteristics of natural fiber composite by single fiber pull-out test [11,12,25]. In the present study single fiber pull- test is carried out for determination of interfacial bonding strength between MCL fiber and polyester resin as matrix material. Fig. 8 shows machine generated load- deflection curve for different specimens under single fiber pull-out test, maximum load ($F_{max.}$) at which fiber debonding starts is observed as 210 N. Interfacial shear strength (τ_c) between matrix and fiber is calculated from equation (1) [25].

$$\tau c = \frac{Fmax.}{\pi dl} \qquad (1)$$

Where *d* and *l* are the diameter and embedded length of the MCL. Results for fiber pull out test are shown in Table 2. Critical length (*Lc*) can be calculated by Equation (2) [26].

$$Lc = \frac{\sigma d}{2\boldsymbol{\tau}\mathbf{c}} \qquad (2)$$

Where, σ is the tensile strength of the fiber, d is the diameter of fiber; $\boldsymbol{\tau}_{\mathbf{c}}$ is the interfacial shear strength. Single fiber pullout strength in terms of interfacial shear strength $\boldsymbol{\tau}_{\mathbf{c}}$ and critical embedded length *Lc* is determined as 2.23MPa and 5.9 cm respectively with polyester resin as matrix material. Table II shows result of single fiber pull-out test.

The critical length, *Lc*, is the minimum length that the fibers must have to strengthen a material to their maximum load [27]. In single-fiber pullout test, the pullout stress increases linearly with the fiber length embedded in the matrix. The fiber fails when the pullout stress reaches the fiber failure stress and the minimum embedded length at which the fiber fails is termed as the critical fiber length. Higher the fiber–matrix adhesion, lower the value of *Lc*.

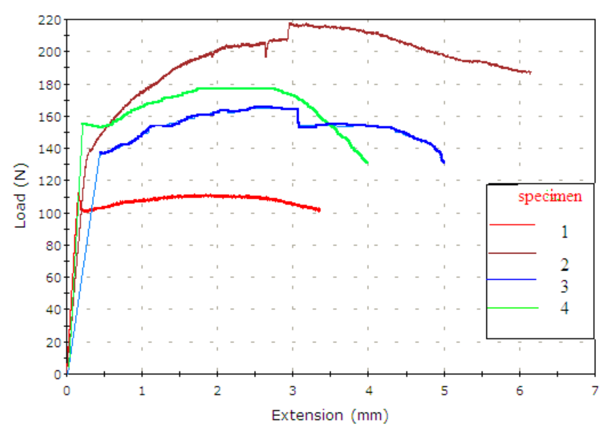

Figure 8: Machine generated Load-deflection curve for single fiber pull-out test

Table II: Single fiber pull-out test result

Diameter of MCL fiber	Embedded length of MCL	Maximum pull-out load	Interfacial shear strength (τ_c)	Critical length (Lc)
1.5 mm	20 mm	210 N	2.23 MPa	5.9 cm

Result shows higher value of *Lc* *hence* poor bonding between fiber and matrix material which can be improved by suitable fiber surface topography alteration. Weak adhesion may also be due to presence of waxy layer on the surface of midrib of coconut leaf [11].

IV CONCLUSION

Present study shows potential of the midribs of coconut palm leaves as an alternate fiber for reinforcement of plastics and proposes development of a new natural fiber composite. MCL fiber is found lighter than the many commercial fibers and have potential to develop a lighter composite for moderate strength purposes such as furniture, packaging, boards, sheets etc. Tensile strength of the MCL is found competitive with the other natural fibers. Single fiber pull out strength and the critical length strongly recommend for suitable surface treatment of the fiber to enhance the interfacial bonding with hydrophobic polymers. Development of the MCL /plastic composite can also provide a source of employment in the rural areas of tropical countries like India, Shri lanka, Indonesia etc.

ACKNOWLEDGMENT

The authors are indebted to the Parmali Wallace Ltd., Bhopal. MP, India for providing assistance for developing material and test facilities during the course of the investigation. Sincere thanks are due to Mr. Bhujang Seth, Mr. Balraj Singh Negi and Mr. Motilal Sharma of R&D Dept., Parmali Wallace Ltd.

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