Mechanical and Water Sorption Studies of Ecofriendly Banana Fiber-Reinforced Polyester Composites Fabricated by RTM

P. A Sreekumar,[1] Pradeesh Albert,[2] G. Unnikrishnan,[1] Kuruvilla Joseph,[3] Sabu Thomas[4]

[1]*National Institute of Technology Calicut, NIT Campus P.O., Calicut, Kerala 673601, India*
[2]*Naval Material Research Laboratory, Anand Nagar P.O., Ambernath, Maharashtra 421 506, India*
[3]*Department of Chemistry, St.Berchman's College, Changanacherry P.O., Kottayam, Kerala 686101, India*
[4]*School of Chemical Sciences, Mahatma Gandhi University, Priyadarshini Hills P.O., Kottayam, Kerala 686 560, India*

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ABSTRACT: Banana fiber, one of the world's most important natural fiber obtained from the bast of the plant *Musa Saptentum Linn,* is available in plenty in Kerala. Without reinforcement, polyester resins are hard and brittle and cannot be used for structural applications. In the present study, short banana fiber-reinforced polyester composite materials have been fabricated using resin transfer molding technique. Mechanical properties such as tensile, flexural, and impact strength were studied as a function of fiber length and fiber content. It is seen that the addition of fibers makes the composite more ductile. The composites having fiber length of 30 mm and a fiber content of 40 vol % showed the maximum tensile strength. Flexural strength and impact properties showed similar trend. Scanning electron microscopy was performed to get an insight into the morphology of the composites. Water absorption study proved that fiber content and temperature conditions influences the diffusion of water into the composite. The composite having a fiber content of 50 vol % showed maximum values for diffusion, sorption, and permeability coefficient. Finally, the mechanical properties and water absorption behavior of the composites fabricated by RTM were compared with theoretical predictions. © 2008 Wiley Periodicals, Inc. J Appl Polym Sci 109: 1547–1555, 2008

Key words: resin transfer molding; mechanical properties; scanning electron microscopy; water absorption

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INTRODUCTION

In recent years, there has been a tremendous growth in the study and development of natural fiber-reinforced composite materials. Natural fibers, which have good mechanical properties, are relatively inexpensive and are renewable resource of materials throughout the world, especially in tropical region. Because of low density, low cost, renewability, and biodegradability natural fibers can be used as a substitute for synthetic fibers in many respects. In recent years, researcher's interest has focused on the use of natural fibers as reinforcement in polymeric matrix. Considering the environmental aspect, it would be very healthy to use natural fibers instead of synthetic fibers. Several investigations were made on the potentiality of natural fibers like coir, hemp, sisal, pineapple leaf fibers, jute etc to produce thermoset composites.[1–9] Banana fiber is one of the world's most important natural fibers obtained from the bast of the plant *Musa Saptentum Linn* and is plenty in Kerala. The high cellulose content and low microfibrillar angle indicate that banana fiber could act as a successful reinforcement in thermoset matrix. Satyanarayan et al.[10] proved the potentiality of usage of banana/cotton hybrid in polyester matrix. In a recent study, Pothan et al.[11] proved the role of fiber/matrix interactions in chemically modified banana fiber composites using dynamic mechanical analysis and compared with those of untreated fiber composites.

Resin transfer molding (RTM) technique is a profitable process for producing high quality complex geometry products. The process makes use of a closed mold into which dry reinforcement is placed and resin is injected to the mold to impregnate the reinforcement. The resin is often injected at the lowest point and fills the mold upward to reduce the entrapping of air. When the resin starts to leak into the resin trap, the tube is clamped to minimize resin loss. Since the process takes place in a closed mold, the evolution of styrene will be less. RTM does not involve large injection pressure. Injection time ranges from few minutes for small and simple components to hours for large, complex components with high fiber content. One of the major advantages of RTM is the modest requirements on the mold since rela-

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Correspondence to: S. Thomas (sabut@sancharnet.in or sabut552001@yahoo.com).

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TABLE I
Properties of Banana Fibers

Diameter (μm)	80–250
Density (g cm^{-3})	1.350
Cellulose (%)	63–64
Hemicellulose (%)	19
Lignin (%)	5
Elongation at break (%)	3–4
Tensile strength (MPa)	550
Young's Modulus (MPa)	22,000

tively low pressures and temperatures are encountered.[12] A lot of studies were reported regarding the modeling of cure kinetics of resin, process optimization, flow visualization, permeability properties of fibrous reinforcements, etc in RTM process.[13–20] Lee and Wei[21] studied the curing kinetics and resulting viscosity changes of a two-part epoxy resin during mold filling in RTM. Rouison et al.[22] prepared hemp/kenaf fiber-reinforced unsaturated polyester composites of various fiber content up to 20.6 vol % using RTM method. A good wetting of the fibers was observed. As fiber content increased, the resin injection time increased dramatically due to the low permeability of mat. Comparatively, a few studies were reported on natural fiber-reinforced composites fabricated by RTM.[23,24]

In the present study, a thorough investigation has been carried on the variation of mechanical properties such as tensile and flexural strength and water absorption characteristics of banana fiber-reinforced composites prepared by RTM technique. The studies were done by varying fiber length and fiber loading. SEM studies have been carried out to get an insight into fiber/matrix interaction, fiber orientation and fiber breakage. Finally, the experimental mechanical and diffusion data have been modeled.

EXPERIMENTAL

Materials

Banana fiber was obtained from Sheeba Fibers and Handicrafts, Poovancode, Tamilnadu. Isophthalic polyester resin used for the study was purchased from Makson enterprises, Kottayam, Kerala. Commercial grade cobaltnapthenate (accelerator), methyl ethyl ketone peroxide (curing agent) were used. The physical and mechanical characteristics of banana fiber and isophthalic polyester resin are given in Tables I and II respectively.

Preparation of composites

The well-separated, cleaned fibers were chopped to desired length. They were washed with water, dried in air and desired amount was weighed. Composites were prepared with fibers of varying length (10 mm, 20 mm, 30 mm, 40 mm) and of varying fiber content (20, 30, 40, and 50 vol %). RTM technique was used for the composite fabrication. The cleaned fibers were arranged in mold in the form of a mat and compressed. Isophthalic polyester resin was then mixed with 1 wt % cobaltnapthenate (accelerator) and 1 wt % methyl ethyl ketone peroxide (curing agent). The resin mixture was allowed to pass through the mold under optimum pressure. Vacuum was applied simultaneously. After 12 h curing, it was demoulded and samples were allowed to post cure at a temperature of 60°C for 24 h.

Mechanical testing of composites

Tensile test was carried out using FIE electronic tensile machine TNE-500 according to ASTM D638-76. Flexural tests were done using the same machine according to ASTM D790. The tests were done at a speed of 5 mm/min. Izod impact test was done on notched specimen with incident energy of 25 J according to ASTM D256. Five samples were tested in each experiment and the average value is reported. The surfaces of the tensile failure specimens were examined using the Jeol scanning electron microscope.

Water sorption experiments

For water sorption studies, rectangular samples of size 10 × 10 mm^2 were cut from the composite sheets. The edges of the samples are slightly curved to have uniform absorption. The thickness of each samples were measured. The samples were fully immersed in water and kept at 30, 60, and 90°C, respectively. At specific time intervals the specimens were removed from water one at a time, wiped with filter paper to remove surface water, and weighed with an analytical balance until the increase in weight of water reaches equilibrium.

The mole percent uptake Q_t for water by 100 g of the polymer was plotted against the square root of time in minutes. The Q_t value was calculated using the eq. (1).

TABLE II
Properties of Isophthalic Polyester Resin

Appearance	Pale yellow color
Viscosity (cPs)	650
Density (g cm^{-3})	1.15
Elongation at break (%)	4.7
Tensile strength (MPa)	34 ± 2.8
Young's Modulus (MPa)	958 ± 3.17
Flexural strength (MPa)	56 ± 2.16
Flexural modulus (MPa)	1961 ± 3.22

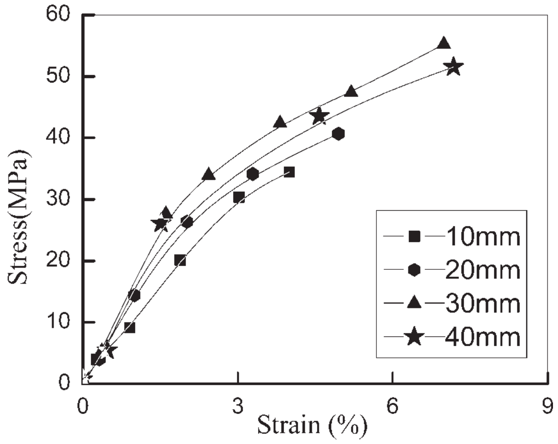

Figure 1 Stress–strain behavior of banana/polyester composites with varying fiber length prepared by resin transfer molding (Fiber content 30 vol %).

$$Q_t = \frac{M_e(\mathrm{W})/M_r(\mathrm{W})}{M_i(\mathrm{s})} \times 100 \qquad (1)$$

where M_e(W) is the mass of water at equilibrium, M_r(W) is the relative molecular mass of water, M_i(s) is the initial mass of the sample. At equilibrium Q_t, was taken as the mole percent uptake at infinite time.

RESULTS AND DISCUSSION

Tensile properties

Effect of fiber length

Figure 1 shows the variation of uniaxial stress–strain behavior of banana fiber-reinforced polyester composites with respect to fiber length having a fiber content of 30 vol %. Here, at lower strains, the composite shows a linear behavior and when the strain % increased, a nonlinear behavior is observed. The nature of the fiber-reinforced composites depends on several factors such as fiber length, fiber content, void content, etc. Table III shows the dependence of the mechanical properties such as tensile strength and Young's modulus on fiber length. It is clear that as fiber length increases from 10 to 30 mm tensile strength and Young's modulus shows an increasing trend and is maximum at 30 mm. When the fiber length increased further both the properties decreased. If the fiber length is greater than critical fiber length the effective stress transfer is not possible due fiber curling and fiber bending. At higher fiber length, fiber curling and entanglement occur and cause a reduction in the effective length of fiber. Therefore stress transfer will not occur properly. Joseph et al.[8] reported a similar trend in the case of banana/phenol formaldehyde composites that the maximum mechanical properties were for the composite having critical fiber length. From these studies the fiber having length of 30 mm was found to be the optimum for effective reinforcement in isophthalic polyester resin.

Effect of fiber loading

Figure 2 represents the stress–strain behavior of the banana reinforced polyester composites with different fiber loading on application of tensile stress. Here also at lower strain values, the composite shows a linear behavior and when the strain % increased a nonlinear behavior is observed. From the figure it is clear that increase in fiber content increases the ductility, which is evident from the elongation at break values. Table IV shows the variation of tensile strength and Young's modulus with respect to fiber loading for composites prepared by RTM. As fiber content increases tensile strength and Young's modulus of the composite also increased up to a fiber loading of 40 vol % and further the mechanical properties decreased. The tensile strength and Young's modulus of the composites are 223 and 226% higher than that of the neat resin. At lower fiber loading, dispersion of fiber is very poor so that stress transfer will not occur properly. At higher fiber loading, there is a strong tendency for fiber–fiber interaction. This leads to poor wetting of fibers and fiber dispersion. In such systems, the crack initiation and its propagation will be easier.

Scanning electron micrograph of tensile surface of composites samples was taken to understand the fracture mechanism. Figure 3(a,b) are the tensile fractographs for the composites containing 40 and 50 vol % of fiber, respectively. On the fractured surface of the composite, fiber breakage, fiber pullout and fibrillation can be observed. At higher fiber loading void formation due to fiber pullout is also high which is clear from the SEM micrographs. This is

TABLE III
Mechanical Properties of Banana/Polyester Composites at Different Fiber Length (30 vol %)

Fibre length (mm)	Tensile strength (MPa)	Young's modulus (MPa)	Elongation (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Elongation (%)
10	36 ± 1.2	995 ± 5.4	3	57 ± 2.2	2329 ± 5.2	2
20	40 ± 2.4	1458 ± 4.5	4	66 ± 0.9	2601 ± 4.6	2
30	55 ± 1.8	1734 ± 6.3	6	78 ± 3.2	2997 ± 3.8	2
40	51 ± 1.9	1645 ± 3.3	7	69 ± 2.4	2684 ± 6.4	2

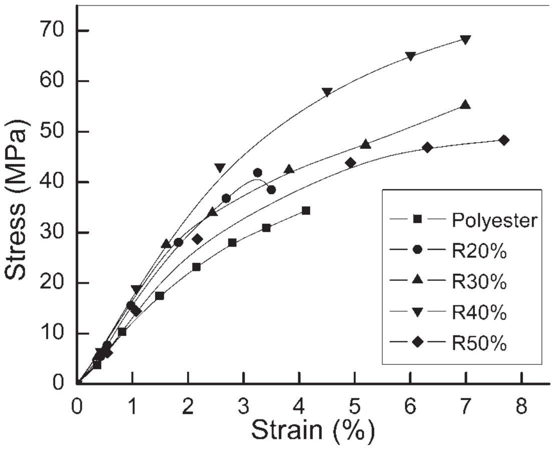

Figure 2 Stress–strain behavior of banana/polyester composites with varying fiber content prepared by resin transfer molding (Fiber length 30 mm).

one of the reasons for the decrease in mechanical properties at higher fiber loading.

Flexural properties

Flexural studies were done by three point bending. It is the ability of the material to withstand the bending forces applied to its longitudinal axis. The flexural strength of the composite is significantly higher than tensile values. The flexural modulus is also a measure of the stiffness of material. Figures 4 and 5 represent the flexural stress–strain behavior of the banana reinforced polyester composites of different fiber length and loading. Here also it is seen that flexural stress increases linearly with strain followed by nonlinear portion. It is due to the increase in ductile nature by the addition of fibers. Table III and IV represent the variation of flexural strength and modulus of the composites as a function of fiber content. From the table, we can see that as fiber length of composite increases the flexural properties also increases up to 30 mm and then decreases. This is because 30 mm is its optimum fiber length. As the fiber content increases the same trend is observed. Flexural properties are maximum for the composite having a fiber loading of 40 vol % which is its optimum fiber content and beyond that limit agglomeration of fiber occurs.

Impact properties

Impact strength of composites generally depends on nature of fiber, matrix, fiber/matrix interface, and the test conditions. Other factors such as micro scale morphological changes in composites also affect the impact property. A composite having good impact resistance should absorb most of the impact energy and propagate crack very slowly. Figure 6 shows the variations of impact strength for the banana fiber-reinforced polyester composites prepared by RTM as a function of fiber length. As the fiber length increases the impact strength also increases up to 30 mm and then decreases. This is because the composites having fiber length of 30 mm have the capacity to absorb large amount of energy and its distribution is very fast. Figure 7 shows the variation of impact strength for the banana fiber-reinforced polyester composites prepared by RTM as a function of fiber content. It is clear that impact strength for the composites increases with fiber content. In composite impact property is maximum for the composites having 40 vol % fiber content and decreases beyond that limit due to poor fiber dispersion. This is because at higher fiber loading there is a strong tendency for fiber–fiber interaction thereby reducing the wetting of fibers and fiber dispersion. The impact strength for the composites having fiber loading of 40 vol % is 497% higher than the neat polyester samples.

Water absorption

Water absorption behavior of a fiber-reinforced composite received considerable attention due to the increase in the usage of the composites for structural applications. The water absorption property of the composites depends on fiber content, temperature, fiber orientation, permeability of fibers, area of the exposed surfaces, void content, hydrophilicity of the individual components etc. The water absorption has greater influence on the physical and mechanical properties of natural fiber-reinforced composites. Figure 8(a–c) shows the variation of water uptake of composites having various fiber content at 30, 60, and 90°C prepared by RTM respectively. From the figure it is clear that as the fiber content increased

TABLE IV
Mechanical Properties of Banana/Polyester Composites at Different Fiber Loading Having Fiber Length of 30 mm

Fiber content (vol %)	Tensile strength (MPa)	Young's modulus (MPa)	Elongation (%)	Flexural strength (MPa)	Flexural modulus (MPa)	Elongation (%)
Polyester resin	34 ± 2.8	958 ± 3.17	4	56 ± 2.1	1961 ± 3.2	2
20	41 ± 3.2	1492 ± 3.6	3	61 ± 2.8	2100 ± 4.3	2
30	55 ± 1.8	1734 ± 6.3	6	78 ± 3.2	2997 ± 3.8	2
40	68 ± 1.6	1873 ±3.1	6	86 ± 3.0	3542 ± 5.8	3
50	48 ± 2.0	1526 ± 2.4	7	70 ± 1.7	2351 ± 4.1	2

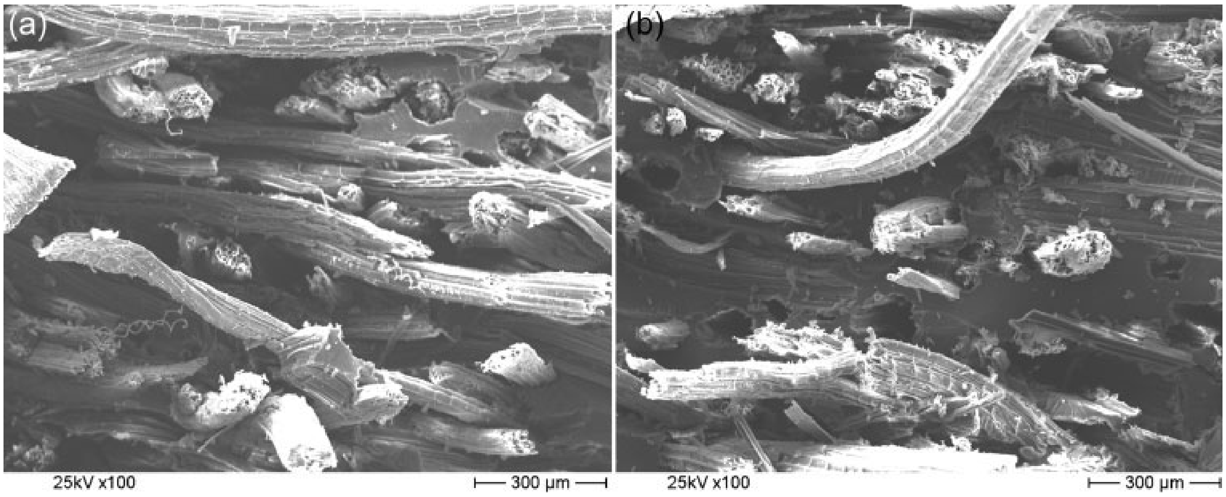

Figure 3 (a,b) Tensile fractographs for the composites containing 40 and 50 vol % of fiber.

the water absorption also increased. Because of the three dimensionally crosslinked networks the cured polyester resin shows very low water absorption. The water absorption curves show a multistage mechanism. The initial portion of the moisture absorption curve is linear, after which the mechanism changes. The availability of free nanosized holes in the polymer and the polar sites present in the banana fiber also affect the water absorption nature of composites.[25] Further, the water in the nanopores may form hydrogen bonds with the polymer, blocking the nanopores and reducing water uptake. Besides affecting the diffusivity and equilibrium uptake, temperature also changes the fundamental diffusion mechanism in a material. Although the rates of diffusion and relaxation are both sensitive to temperature, their temperature dependencies may be different. According to Flory's two-stage theory, the swelled polymer chains induce increased elasticity of chain structure and thus increases chemical potential. The increased chemical potential inhibits further absorption of water, which may be observed as the first equilibrium of water uptake. However, the swelled polymer chains start relaxing with time and subsequently reduce chemical potential. Consequently, the second equilibrium is attained by the decreased elasticity. The effect of fiber loading on Q_∞ values for composites at different temperatures is given in Table V. From the Table it is clear that in the case of neat polyester resin and in fiber-reinforced composites, as the fiber content increases the water uptake also increases and is maximum for the composite having a fiber loading of 50 vol %. Also the rise in temperature leads to enhanced water uptake at equilibrium. At higher temperature there shows an irregularity since the activity of the water

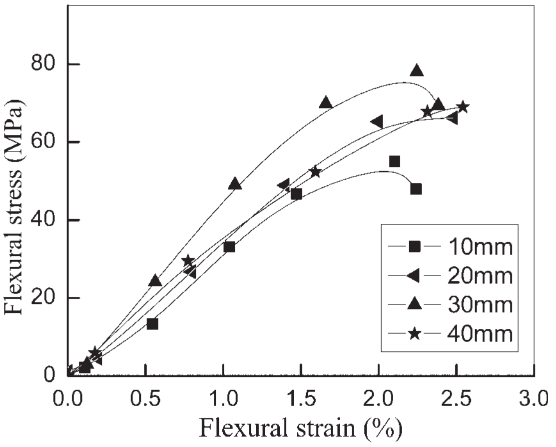

Figure 4 Flexural stress–strain behavior of banana/polyester composites on application of flexural stress having various fiber lengths prepared by resin transfer molding (Fiber loading 30 vol %).

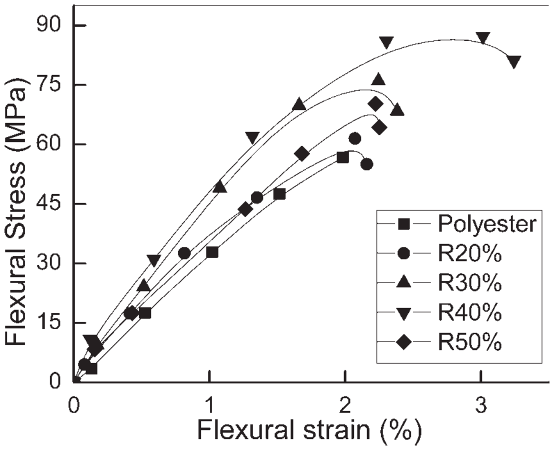

Figure 5 Flexural stress–strain behavior of banana/polyester composites on application of flexural stress having various fiber content prepared by resin transfer molding (Fiber length 30 mm).

molecule as well as variation at the interfaces of the fiber and matrix becomes predominant at that time. Moreover, there is a chance of desorption of water molecules as well as the value could be attributed to the dissolution of soluble materials at higher temperatures.

Kinetics of water sorption

To understand the mechanism of water absorption, kinetic parameters n and k, diffusion coefficient are essential factors. These parameters were analyzed from the following relationships.

$$\log\,(Q_t/Q_\alpha) = \log k + n \log t \tag{2}$$

where Q_t is the mole percentage of water uptake at time t, Q_α is the mole percentage of water uptake at equilibrium, k is a constant characteristic for the polymer. The values of n and k for water sorption for the banana fiber-reinforced polyester composites prepared by RTM are given in Table VI. When the value of $n = 0.5$, diffusion obeys Fick's law and is said to be Fickian. When $n > 1$ the diffusion is said to be anomalous. When the value of n is between 0.5 and 1 the diffusion is nonfickian. The constant k indicates the interaction between polymer and water and n indicates the mode of diffusion.

In the banana fiber-reinforced composites, the n value is found to be much lower than 0.5. This may be due to the penetration of water molecules through the interfacial regions, and micro voids present in the composite, which are the other water absorption mechanisms in fiber-reinforced composites. In the case of fiber-reinforced composites also the value of n is lower than 0.5. Diffusion coefficient characterizes the ability of water molecule to diffuse through the polymer. The value of diffusion coefficient D was calculated from the relationship.

$$D = \pi(h\theta/4Q_\alpha)^2 \tag{3}$$

where θ is the slope of the linear portion of the sorption curves and h is the initial thickness of the samples. The sorption coefficient has been calculated using the equation

$$S = M_\alpha/M_p \tag{4}$$

where M_α is the mass of water taken up at equilibrium and M_p is the initial mass of the polymer. By using the above eqs. (3) and (4) the permeability coefficient can be calculated.

It can be expressed as

$$P = D \cdot S \tag{5}$$

The variation of diffusion coefficient, sorption coefficient, and permeability coefficient were given in Table VII. The diffusion coefficient was found to increase with increase in fiber content at all temperatures. The sorption coefficient is found to be higher at higher fiber loading. The permeability coefficient, a function of sorption and diffusion, showed maximum value at higher fiber loading. At lower fiber loading, the dispersion of fiber is less, hence the diffusion coefficient, sorption coefficient, and permeability coefficient values showed lower values. As the fiber content increases, due to the high void content and fiber/fiber interaction the fiber/matrix adhesion becomes less, which increases the diffusion coefficient, sorption coefficient and permeability coefficient.

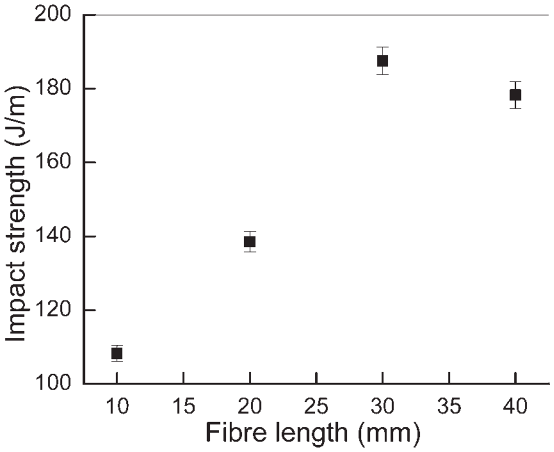

Figure 6 Variation of impact strength with fiber length for banana fiber reinforced polyester composites (Fiber content 30 vol%).

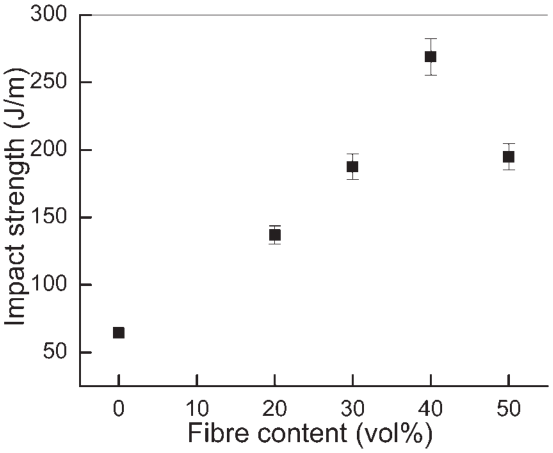

Figure 7 Variation of impact strength with fiber content for banana fiber reinforced polyester composites (Fiber length 30 mm).

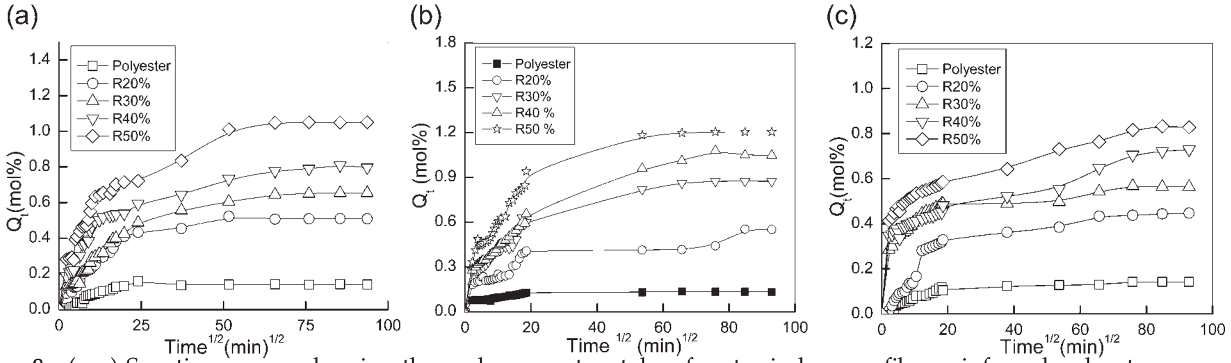

Figure 8 (a–c) Sorption curves showing the mole percent uptake of water in banana fiber reinforced polyester composites having different fiber loading at various temperatures.

Theoretical modeling

Mechanical properties

The efficiency of the composite mainly depends upon its mechanical properties. Several theories have been proposed to model the mechanical properties of composites materials in terms of different parameters. Here the Young's modulus of randomly oriented banana fiber-reinforced polyester composites fabricated by RTM were compared to parallel, series, and Hirsch model. The Young's modulus was calculated using the following equations

$$X_c = X_m \cdot V_m + X_f \cdot V_f \qquad \text{Parallel model} \qquad (6)$$

$$X_c = \frac{X_m \cdot X_f}{X_m \cdot V_f + X_f \cdot V_m} \qquad \text{Series model} \qquad (7)$$

$$X_c = x\left(X_m \cdot V_m + X_f \cdot V_f\right) + (1 - x) \cdot \frac{X_f \cdot X_m}{X_m \cdot V_f + X_f \cdot V_m} \qquad \text{Hirsch model} \qquad (8)$$

where X_m is the Young's modulus of matrix; X_f is the Young's modulus of fiber; V_m is the volume fraction of the matrix, V_f is the volume fraction of fiber. The value of x lies between 0 and 1, which is a good indication of effective stress transfer in the composites.

Figure 9 represents a comparison of the experimental and theoretical Young's modulus values obtained by using parallel, series, and Hirsch modeling. Here the Young's modulus value for composite having low fiber content is very much closer to the Hirsch model. After the optimum fiber content the experimental value shows greater deviation from Hirsch's model. No correlation is obtained with the series and parallel modeling. The agreement between theoretical and experimental values with Hirsch model has been found only when the value of x in eq. (11) is 0.2. It is seen that the value of x is a determining factor in describing the real behavior of short-fiber composites. In the RTM fabricated composites at lower fiber volume fraction the agreement between the experimental and theoretical modeling value is due to the uniform stress or strain distribution in the composite through the well-dispersed matrix. But at higher fiber loading,

TABLE V
Values of Q_α for Banana Fiber-Reinforced Polyester Composites Having Different Fiber Loading at Different Temperatures (Fiber Length of 30 mm)

Fibre content (vol %)	Temperature (°C)	Q_∞ (mol %)
Polyester resin	30	0.1405
	60	0.1318
	90	0.1417
20	30	0.5093
	60	0.5519
	90	0.4835
30	30	0.6814
	60	0.8733
	90	0.5888
40	30	1.0505
	60	1.2042
	90	0.8617
50	30	1.3506
	60	1.0477
	90	0.7543

TABLE VI
Values of n and k for Banana Fiber-Reinforced Polyester Composites Having a Fiber Length of 30 mm for Different Fiber Loading at Different Temperatures

Fibre loading (vol %)	Temperature (°C)	n	k (g/g/min^2)
Polyester resin	30	0.1098	0.0421
	60	0.1120	0.0842
	90	0.1242	0.0983
20	30	0.1536	0.1275
	60	0.1628	0.1295
	90	0.1725	0.1397
30	30	0.1623	0.1113
	60	0.1970	0.1330
	90	0.2120	0.1437
40	30	0.1927	0.1322
	60	0.1998	0.1577
	90	0.2529	0.1671
50	30	0.2059	0.1682
	60	0.2286	0.1750
	90	0.2672	0.2116

TABLE VII
Values of Diffusion, Sorption, Permeability Coefficient for Banana Fiber-Reinforced Polyester Composites Having Different Fiber Loading at Different Temperatures

Fibre loading (vol %)	Temperature (°C)	Diffusion coefficient × 10^5 (cm^2/min)	Sorption coefficient (g/g)	Permeability coefficient × 10^5 (cm^2/min)
Polyester resin	30	1.14	0.025	0.028
	60	2.70	0.023	0.062
	90	5.05	0.025	0.126
20	30	7.68	0.091	0.698
	60	11.80	0.102	1.210
	90	18.96	0.125	2.370
30	30	10.25	0.122	1.250
	60	16.40	0.157	2.580
	90	34.62	0.106	3.670
40	30	14.33	0.189	2.710
	60	16.12	0.216	3.480
	90	30.20	0.155	4.680
50	30	27.10	0.129	3.510
	60	20.46	0.188	3.840
	90	56.90	0.135	7.680

fiber agglomeration takes place and the applied load will be distributed unevenly between nonagglomerated and agglomerated fibers. As a result at higher fiber loading, the experimental values deviate from the modified rule of mixture and Hirsch's model. In parallel and series modeling interaction of fiber and matrix is not considered. In fiber-reinforced composites there is interaction between fiber and matrix, which determines the mechanical properties. It is clear from the modeling that as fiber content increases the fiber-matrix interaction increases and is maximum for the composite having fiber loading of 40 vol %, which shows superior mechanical properties.

Water sorption

The kinetics of water absorption of the dense polymeric materials are often fitted according to the following equations

$$Q_t/Q_\alpha = 4(\tau/\pi)^{1/2} \quad \text{for } \tau \le 0.049 \tag{9}$$

$$w/w(\text{eq}) = \left(1 - \frac{8}{\pi^2}\right)\sum_0^\infty \frac{1}{(2n+1)^2}\exp[-(2n+1)^2\pi^2\tau] \quad \text{for } \tau > 0.049 \tag{10}$$

where τ is a dimensionless parameter ($\tau = Dt/h^2$).

For this, the value of diffusion coefficient was calculated and Figure 10 represents the theoretical and experimental absorption curves for the composites fabricated by RTM having a fiber content of 30 vol % at 30°C. In this figure, sorption data have been plotted as Q_t/Q_α against the square root of τ. It can be seen that experimental data do not fit with the theoretical curve. From this, we can conclude that water sorption does not follow Fickian behavior due to the heterogenic nature of composites. This was

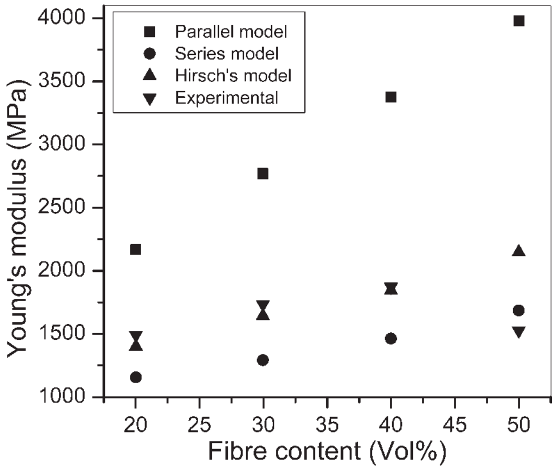

Figure 9 Comparison of experimental and theoretical Young's modulus value of banana fiber reinforced polyester composites.

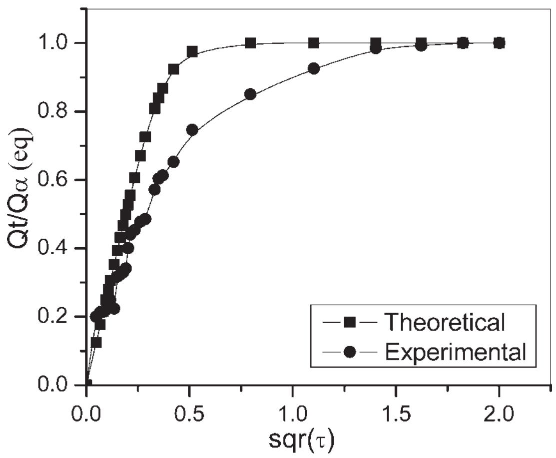

Figure 10 Comparison of experimental and theoretical water absorption value of banana fiber reinforced polyester composites.

clear from the *n* value in Table VI. Moreover long time is needed for the composites to reach the equilibrium.

CONCLUSIONS

In this article, a scenario of successful usage of banana fiber as a good reinforcement in the polyester resin was revealed. Mechanical properties such as tensile, flexural, and impact strength of banana fiber-reinforced polyester composite fabricated by a novel technology RTM as a function of fiber length and fiber loading were analyzed. The investigation proved that composite having 30 mm fiber length and 40 vol % fiber content showed maximum mechanical properties and decreased beyond this limit. Flexural strength and flexural modulus showed similar trend. The impact strength was maximum for composite having fiber length of 30 mm and fiber loading of 40 vol %. A good correlation was obtained for the mechanical properties with the morphology of the composites by using scanning electron micrograph. Water absorption behavior was greater for the composites having fiber loading of 50 vol % and it follows two-step process. The diffusion coefficient, sorption coefficient and permeability coefficient were found to increase with increase in fiber content at all temperature range. A comparison between the theoretical and experimental tensile strength value showed that at lower fiber loading it shows more resemblances to Hirsch model, which reveals that there is a fiber-matrix interaction in composite having fiber content of 40 vol %, which shows superior mechanical properties. In short, the present study came to a conclusion that banana fiber can be used as a potential reinforcement in the polyester matrix. Also RTM is a good processing technique to fabricate banana fiber reinforced composites having superior properties.

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