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Development and Characterisation of Eco-Friendly 40% v/v Hybrid Banana/Sisal Fibers-Natural Rubber Latex Composite

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Abstract: The environmentally hazardous, non bio-degradable, toxic nature of synthetic materials and the depletion of their resources have necessitated engineers to look for eco-friendly, non-hazardous, bio-degradable, atoxic and obtained from renewable sources for a sustainable development. Hence, low cost vegetable fibers like banana fibers, sisal, flax, ramie, coir, pineapple, etc. are used as viable alternative to the synthetic fibers. This research aims to develop a hybrid composite with unidirectional, continuous and 40% v/v hybrid of banana fiber and sisal fibers (1:1) natural rubber latex and characterise its mechanical properties like tensile strength, tear strength and hardness for both longitudinal (0°) and transverse fiber orientations (90°). Tensile strength and Tear strength for 0° fibre orientations were found to increase by 42.5 and 282.72% over pure latex sample, respectively. Samples with 90° fiber loadings also showed improved strengths.

Key words: Hybrid composites, rubber latex, hybrid (B/S) fiber, sisal fiber, mechanical properties, elastomers, vegetable fibers, eco-friendly materials

INTRODUCTION

A lot of research is going on in the development of new composite materials with specific properties and applications. The expensive, hazardous and with depleting resources, synthetic fibers and materials need to be replaced with natural and renewable materials like natural fibers and composites. The natural fibers have the advantages like good specific strength, high toughness and good thermal insulation, low abrasion, bio-degradable and abundance in nature (Thiruchitrambalam *et al*., 2010). Works have been done on natural-natural fibers, natural-synthetic fibers and synthetic-synthetic fibes in different resin matrix composites (Mishra *et al*., 2003; Dam *et al*., 1994). Investigations are going on in natural fiber composites (Maleque *et al*., 2007). The present research aims to develop, fabricate and characterise a rubber composite using 40% volume fraction untreated banana and sisal fibers (1:1) as reinforcement in natural rubber latex (40% Dry rubber content). The specimen sheets are finally made by rolling in rubber rolling steel mills. Mechanical properties tested are tensile strength, tear strength and hardness.

Natural rubber: Latex is a white or yellowish opaque liquid having a specific gravity of 0.974-0.986 and is a weak colloidal system of spherical shaped rubber globules in an aqueous serum. Composition of latex is Rubber 30-40%, Resins 1-2.0%, Proteins 2-2.5%, Sugars 1-1.5%, Ash 0.7-0.9%, Water 55-65%.

Natural rubber latex is extracted from the barks of Para rubber tree (*Hevea brasiliensis*) and is indigenous to South America. Charles Marie de La Condamine introduces samples of rubber to the Académie Royale Des Sciences of France in 1736. In 1751, a paper presented by François Fresneau to the Academie that described rubber's properties, considered as the first scientific paper on rubber (Tully, 2011). India is a major cultivator of natural rubber is the world's 3rd largest producer and 4th largest consumer. Singapore, Malasia and Brazil are also major producers of natural rubber. Latex is used to make many products including mattresses, gloves, swim caps, condoms, car tyres, bushes, catheters and balloons, etc. (Fig. 1-4).

Banana and sisal fibers: Made up of thick-walled cell tissue and bonded by natural gums, banana fibre is similar to natural bamboo fibre but its fineness and spin ability are better than bamboo and ramie fibres. It is mainly composed of cellulose, hemicelluloses and lignin. Both banana and sisal fibres are good alternative to synthetic fibers. The fibers are also eco-friendly, chemical-free, non-toxic and odour-free. India is one of the leading producers of both banana and sisal palnts. Both fibers are

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Fig. 1: Banana cultivation

Fig. 2: Banana fiber

Fig. 3: Sisal cultivation

Fig. 4: Sisal fibers

Table 1: Banana and sisal fiber properties

Properties	Banana fiber	Sisal fiber
Tensile strength (MPa)	56	67
Youngs modulus (GPa)	3.5	3.7
Flexural modulus (GPa)	4	13.5
Elongation at break (%)	2.6	2.4
Cellulose (%)	62	66
Hemicelluloses (%)	18	13
Lignin content (%)	5	10
Moisture content (%)	11	10
Density (g/cm³)	1.35	1.45

used to make textile fibers, bags, carpets, etc. and paper from their pulps are used as a substitute for polythene bags. Eco-friendly bags are made from these fibers. Physical and chemical properties of banana and sisal fiber are shown in Table 1.

Literature review: Idicula *et al*. (2010) studied the mechanical properties of short sisal/banana hybrid composites. The results showed that better tensile strength is obtained when the banana:sisal ratio is 3:1. Hybridisation helped to improve the tensile and flexural properties while the impact performance lowered. Reddy *et al*. (2009) investigated properties of Kapok/Sisal polyester composites. The fibers are given 2% alkali treatment. By the addition of 25 and 75% wt. sisal fiber to to Kapok reinforced composites, its compression strengths increased by 14.8 and 72.5%, respectively. Also, a positive hybrid effect obtained for 1:1 (50:50) and 1:3 (25:75) volume ratios of Kapok and Sisal in the matrix. Jacob *et al*. (2004) evaluated the influence of fiber content, ratio and treatment in sisal/oil palm composites and found that the addition of fibes increased the tensile strength and modulus of the composites. Better mechanical strength exhibited by composites with longitudinal (0°) fiber orientations than with the transverse (90°) fiber orientations. Tensile test results shows that the shear of sisal fiber from the matrix is more compared to that of cotton fiber shear from the matrix. Wang *et al*. (2008) reported the impact property of 3D woven basalt/aramid hybrid composites. It is found that interplay hybrids showed better ductile, lower peak load and hih specific energy absorption than intraply hybrids. Venketswaran *et al*. (2011) evaluated the mechanical properties of banana/sisal-epoxy composites. Cartie and Irving (2002) observed that resin toughness is more important than the fiber strength and stiffness for the mechanical properties of the composites. Lobo Yan *et al* investigated the tensile strength of flax and linen fabric reinforced epoxy composites and found improvement of 64.5 and 644.1% in tensile strength over pure epoxy (73 MPa).

Researchers have been involved number of investigations on several types of natural fibers such as bamboo, kenaf, hemp, flax and jute to study the effect of these fibers on the mechanical properties of composite materials (Chandramohan and Marimuthu, 2011; Herrera-Franco and Valadez-Gonzalez, 2005). Reinforcing nature of natural fibers depends mainly on the nature and amount of cellulose and its crystalinity (Collier, 1994). The primary effect of fiber reinforcement on the mechanical properties of natural rubber composites include increased modulus. The hollow nature of natural fibers impart acoustic and damping properties to the matrices (Herrera-Franco and Valadez-Gonzalez, 2005). Rao *et al*. (2010) studied natural fiber composite properties with Vakka, sisal, bamboo and baanan fibers as reinforcement. Wambua *et al*. (2003) studied the viability of Natural fibers as a replacement to synthetic fibers.

MATERIALS AND METHODS

Natural Rubber Latex (40% DRC) collected from kerala, banana fiber and sisal fiber bundles obtained from Coimbatore, T.N. and Formic acid (for latex coagulation).

The 40 mm long continuous Banana and sisal fibers in 1:1 ratio (40% volume fraction w.r.t latex rubber) are attached stretched to aluminium frames fabricated of thesize of the latex molding tray (30×40 mm). Rubber latex (40% Dry rubber content w/w) is poured into the moulding trays and the aluminium frame with the fiber net is placed into it. The 1% formic acid mixed with the latex in the tray to accelerate the latex coagulation process and hardening. The latex is then allowed to dry in sunlight at 32°C for 2 h till the latex solidifies. The semi solid latex sheet is taken out and compressed into 3 mm sheets using a 3 roller rubber rolling mill. The sheets are then kept in dry sunlight for 72 h till it is completely dry. The specimens for tensile tests, tear tests and hardness tests for both longitudinal and transverse unidirectional fiber orientations are cut from this sheet as per ASTM standards. The tensile and tear tests are done in a UTM and the hardness found using a Shore A Durometer.

RESULTS AND DISCUSSION

Tensile strength: Figure 5 tensile strength of pure Natural Rubber (NR) latex sample is obtained as 0.386 N/mm^2. When this latex reinforced with continuous, unidirectional hybrid (B/S) fibers in the longitudinal direction (0°), the composite material exhibited an improved tensile strength of 0.55 N/mm^2 an improvement of 42.5% over pure rubber latex. The Sample Hyb(B/S)-NR 90° obtained a 41.9% improvement in tensile strength over pure latex.

Pure rubber latex has weak and less polymer chains. Hence has a tensile strength of 0.386 N/mm^2. The latex sample Hyb(B/S) NR 0° has a 42.5% better tensile strength over pure rubber latex. This implies that the applied load has been transferred better to the fibres or in other words the interfacial bonding between the latex and fibres helped in it.

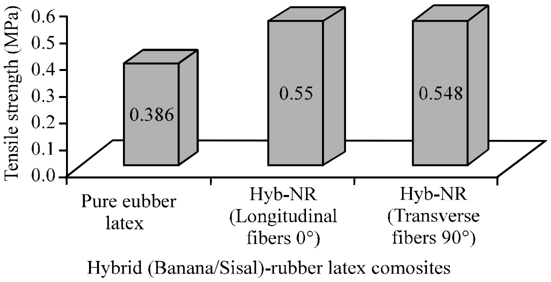

Fig. 5: Tensile strength

Fig. 6: Microscopic image-tensile failure edge (0° fibers)

Fig. 7: Microscopic image-tensile failure edge (90° fibers)

In the case of transversely loaded hybrid (B/S) fibers-latex material, the matrix-matrix bond carried the load. Hence, the sample has a better load bearing capability than pure latex material.

The microscopic images of the Tensile tested specimens failure edges for longitudinal (Fig. 6) and transverse (Fig. 7) fiber loadings shows the effective transfer of load from matrix to fibers. It can be seen from the images that fiber breakage happened before the matrix failure indicating a good matrix-fiber adhesion (Table 2).

Table 2: Results

Sample	Tensile strength max. (N/mm^2)	Tear strength max. (N/mm)	Strain max. (%)	E = σ/ε	Stress at 100% (N/mm^2)	Stress at 200% (N/mm^2)	Stress at 300% (N/mm^2)
Pure-Rubber latex	0.386	4.05	85.760	4.05×10^{-3}	0.3730	0.0648	0
Hyb(B/S)-NR (Longitudinal fibers 0°)	0.550	15.50	134.05	4.103×10^{3}	0.4390	0.0000	0
Hyb(B/S)-NR (Transverse fibers 90°)	0.548	9.70	177.88	3.08×10^{-3}	0.3698	0.3978	0

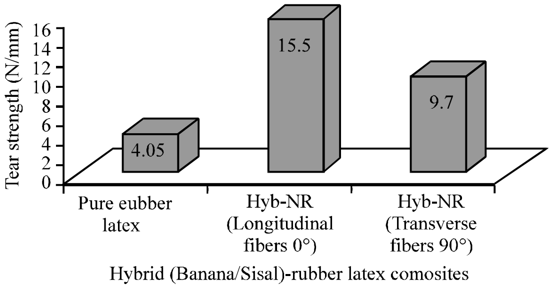

Fig. 8: Tear strength

Fig. 9: Microscopic image-tear failure edge (0° fibers)

Tear strength: Figure 8 for pure rolled natural rubber latex sheet obtained as 4.05 N/mm. For the same latex loaded with continuous, unidirectional, longitudinally loaded hybrid (B/S) fibers (0°) the sample material obtained an increased tear strength of 15.5 N/mm an improvement of 282.7% over pure latex material.

This improvement in Tear strength is due to the good fiber-latex matrix interfacial bonding obtained and thereby effective matrix-fiber load transfer. Here, the fiber breakage is observed before the matrix failure (Fig. 9) during the longitudinal loading. The latex composite sample with transversely loaded (0°) fibers showed reduced (9.7 N/mm) tear strength compared to longitudinally loaded hybrid (B/S) fibers-latex specimen. This is because the fibers are not subjected to axial or longitudinal loads as in the second case. In the 90° fiber oriented latex sample once the fiber-matrix adhesion fails the matrix failure occurs. But this sample has better tear strength than pure rubber latex material an increase of 139.5% over pure latex.

Fig. 10: Microscopic image-tear failure edge (90° fibers)

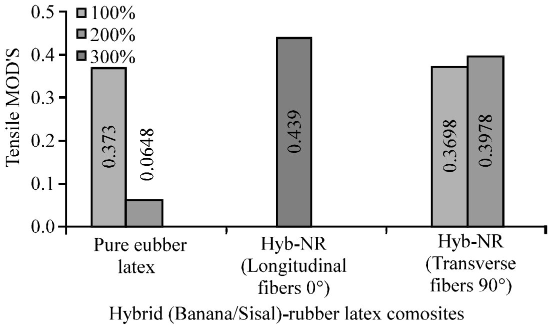

Fig. 11: Stresses at 100, 200 and 300%

Referring to the microscopic images of the torn edges of Tear tested specimens for longitudinal (Fig. 9) and transverse (Fig. 10), fiber orientations, a good matrix to fiber load transfer can be observed, indicated by the fiber breakages.

Stresses at 100, 20 and 300% elongations: Figure 11 at 100% elongation the maximum stress is for longitudinally loaded fiber-latex composite Hyb(B/S) NR 0°) a value of 0.439 N/mm^2. This is followed by pure latex (0.373 N/mm^2) and then by transversely loaded fibers-latex composite (0.3698 N/mm^2). For 200% material elongations maximum tensile modulus is for 90° fiber Hyb(B/S)-NR (0.3978 N/mm^2) followed by pure latex (0.0648 N/mm^2).

Comparison of modulus of Elasticity (E): Figure 12 shows the maximum values of Youngs modulus or Modulus of Elasticity (E) is obtained for pure latex-a value of 4.5×10^{-3}. This is followed by 0° fibers Hyb(B/S)-NR composite which has and E of 41×10^{-3} and lastly by 90° fibers Hyb(B/S)-NR which showed a value of 3.08×10^{-3}. The lower values for E mean higher elasticity and lower rigidity for the material.

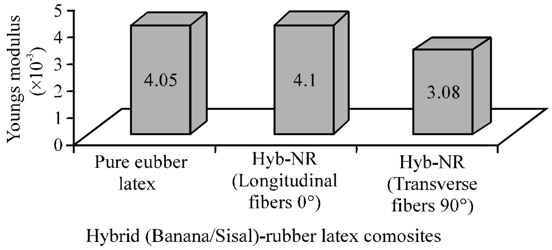

Fig. 12: Modulus of Elasticity (E)

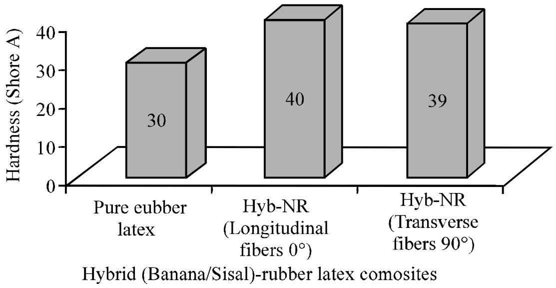

Fig. 13: Hardness

The transverse (90°) loaded fibers-latex composite shows a lower modulus than pure latex because in 90° fiber Hyb(B/S)-NR. once the fiber-latex matrix bonding becomes weak or fails, the material becomes heterogeneous and shows more plastic nature compared to pure latex which retains its carbon chains till its failure.

Hardness: Figure 13 shows hardness obtained for the developed materials did not show much variation. Pure latex gave a hardness of 30 shore A while the other two samples loaded with 40% raw hybrid(B/S) fibers loaded in the longitudinal (0°) and transverse (90°) fiber directions showed a hardness of 40 and 39 Shore A. This is due to the greater hardness of the filler material-the fibers in the latex composite.

The fiber orientations do not influence the hardness of the composite material. Only the fiber volume content and fiber hardness influences the composite hardness.

CONCLUSION

The elastomer material developed from rubber latex and hybrid (B/S) fibers as reinforcement exhibited improved mechanical properties like tensile strength, tear strength and hardness. The longitudinal (0°) loaded hybrid (B/S) fiber-latex specimen gave an increase of 42.4% in tensile strength over pure rubber latex and an increase of 282.7% in tear strength over pure latex for 40% v/v fiber loading. The hardness of the developed materials also improved compared to pure latex. This materials can find a lot engineering, industrial and commercial applications.

RECOMMENDATIONS

In this case 40% fiber volume is chosen as optimum value based on literature survey. Materials with different fiber combinations may be developed depending on the applications. This reduces the latex usage and utilisation of more vegetable fibers having unique applications.

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