The Tribological and Compressive Behavior of Natural Rubber Composites Reinforced with Surface Modified Banana Fibers

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ABSTRATC---- ***Use of synthetic and non-biodegradable fibers and materials in engineering product development has led to a situation that their waste disposal has become a serious environmental problem. This led the researchers to look into natural materials which are ecofriendly, non-toxic, biodegradable and cheap, as a viable replacement of synthetic and toxic materials. The objective of the present work is to design and develop a new composite material using natural materials only- 40% v/v banana fiber as reinforcement in natural rubber. Banana fibers having four surface modifications are used for the composite making- raw fibers, alkalized fibers, rubber pre-impregnated raw fibers, and rubber impregnated alkalized fibers. In addition to the above four composites, two specimens added with 10% w/w coconut shell powder also made, to study their influence on the composites. A total of six specimens made and their wear resistance, hardness, and compressive strength are tested. All the composites developed exhibited an impressive increase in wear resistance, hardness, and compressive strengths. Best wear resistance exhibited by raw banana fiber-rubber followed by rubber pre-impregnated fiber with coconut shell powder- rubber composite. Maximum hardness is shown by raw fiber with coconut shell powder-rubber composite (192% more than pure rubber). The raw fiber impregnated with rubber- rubber composite with coconut shell powder exhibited the best compressive strength, followed by the raw fiber with coconut shell powder composite.***

Keywords--- Rubber Composites; Banana fiber; Tribology; Hardness; Compressive Strength, Ecofriendly; Natural fiber; Natural Rubber.

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1. INTRODUCTION

Objective of the present work is to design and develop an ecofrindly rubber composite using natural rubber and sisal fiber reinforcement. This finds lot applications in engineering industries. Composite materials using natural reinforcements are replacing synthetic materials due to their advantages of low density, low cost, bio-degradability and recyclability [1,2]. Natural fiber composites finds applications in the tribol components of automobiles like gears, wheels, bushes etc [3,4]. Most of the natural fibers like sisal, jute, coir, oil palm, flax etc. are discarded as wastage. Research is going on to use these fibers in making new composite materials with improved properties. In this context, a new composite material using 100% natural materials- Banana fibers and Natural Rubber is designed, fabricated and tested for its tribological properties, hardness, and compressive strength.

Few work has been done on the tribological behavior of natural fiber reinforced composite materials [5,6]. Natural rubber is obtained from Rubber tree ***Heavea brasiliensis*** cultivated in South East Asia. Basically, it is a polymer consisting carbon chains of Isoprene Monomers.

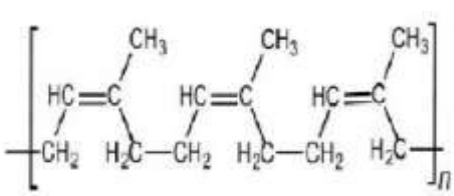


Fig.1. The structure of Natural Rubber.

Banana fiber is a waste product of plantain cultivation. 70% of these stems are discarded as waste. In some places banana, stem fibers are used to make carpets, bags, rugs etc. It is of low cost, abundantly available and completely biodegradable.

Table.1. Banana fiber properties.

Properties	Banana Fiber
Cellulose (%)	62-64
Hemicelluloses (%)	19
Lignin (%)	5
Moisture Content (%)	10-11.5
Density (g/cm^3)	1.35
Flexural Modulus (GPa)	2-5
Microfibrillar angle	11
Lumen Size (mm)	5
Tensile Strength (MPa)	54
Youngs Modulus (GPa)	3.48

Polyester is strengthened with oil palm fibers and the material exhibited better wear resistance. This may be due to better abrasion resistance or protection offered by oil palm fibers on the exposed rubbing layer of the composite along the sliding distance. Poor interfacial bonding leads to fiber pullouts from the matrix during high sliding velocities. [7]. Natural fibers like kenaf [8], Jute [9], Ramie, Oil palm [10], and hemp [11] found to be good reinforcement for polymer composites. Bagasse fibers are used to make bagasse-cement composites for building industries [12]. Attempts have been made to study the wear anisotropy of natural fibers like cotton, bamboo [13,14], sisal [15], jute [16] and kenaf. Filler materials are found to have reinforcing strength which can enhance the modulus and composite properties. The main problem faced in the inclusion of agricultural fillers into polymers is their incompatibility [17]. Natural fibers are hydrophilic while the resins are hydrophobic. To overcome this, surface treatment of coir using chemicals has been reported to have a long lasting effect on the mechanical behavior of the fiber and is used to optimize the fiber-matrix interfacial bonding [18,19]. In spite of the merits offered by natural fibers, they offer poor wettability and hydrophilic behavior [20]. A number of physical and chemical fiber surface treatments are suggested by many. Among them the most common and effective one is alkali treatment [21,22].

NaOH treatment removes the dirt, wax and some lignin from the fiber surface making it more rough. It also exposes more hydroxyl groups. This rough surface helps in the making of better mechanical interlocking and bonding with the matrix [23].

2. MATERIALS AND METHODS

2.1. Materials.

Banana stem fibers, coconut shell powder are collected from Coimbatore, T.N., India. Natural rubber of grade ISNR20 purchased from crumb rubber factory, Trivandrum. Chemicals required (Sodium hydroxide, Toluene) for fiber surface processing, purchased from Nice Chemicals, Kochi.

2.2. Methods.

2.2.1. Fiber surface modifications.

A total of 4 different types of surface-modified banana fibers are used to make the rubber composites. They are raw banana fibers, Alkalized fibers, Rubber pre-impregnated raw fibers and rubber pre-impregnated alkalized fibers.

Alkalization.

It is done by keeping the chopped 10mm long fibers immersed in a 4% sodium hydroxide solution for 2 hrs. After that, the fibers are washed with fresh water to remove the alkalinity completely. They are then dried at 32°C for 48 hrs before blending with natural rubber.

Pre-impregnation of banana fibers with rubber.

Chopped 10mm long fibers are immersed in a 4%w/w natural rubber –toluene solution at 80°C for 1 hr. the solution is continuously stirred with fibers, to get a uniform impregnation of rubber on all the fiber surfaces. The fibers are then dispersed and dried at 32°C for 48 hrs till the solvent is completely evaporated. For making pre-impregnated raw fibers and pre-impregnated alkalized fibers, raw and alkalized banana fibers are used respectively.

2.2.2. Composite fabrication.

A total of six composites is made as follows.

(1) Raw banana fiber-natural rubber composite (BRaNR).
(2) Alkalized banana fiber-natural rubber composite (BNaNR)
(3) Rubber pre-impregnated Raw banana fiber-natural rubber composite (BRaINR).
(4) Rubber pre-impregnated Alkalized banana fiber-natural rubber composite (BNaINR)
(5) Raw banana fiber-coconut shell powder-natural rubber composite (BRaCsNR).
(6) Pre-impregnated Raw banana fiber-coconut shell powder-natural rubber composite (BRaICsNR)

The ingredients are first mixed in a two roll mill for 30 minutes. The chopped fibers are added during the mixing process. Mill rollers gap kept at 2mm. The resulting rubber compound kept for 16hrs and then Compression Molded into Cylindrical shapes as per ASTM standards- in a laboratory model compression molding machine at 150°C and for 15 minutes.

2.2.3. Testing Methods.

Hardness is tested using a Shore A Durometer as per **ASTM D2240.** Wear resistance found by a Rotating drum type Abrader as per **ASTM D5963** in terms of material removal rate. Compressive Strength measured in terms of compression set, the ability of rubber to recover after subjected to a compressive load as per **ASTM D395**.

Fig.2. Rotating drum Abrader.

3. RESULTS AND DISCUSSIONS

Table.2. Test Results.

Sl.No.	Specimen	Hardness (Shore A)	Wear Resistance (Material removal rate MM³)	Compression Set (%)
1	NR-Pure	25	-	9.43
2	BRaNR	66	225.07	5.54
3	BNaNR	60	320.83	4.56
4	BRaINR	64	307.82	4.87
5	BNaINR	70	267.76	4.77
6	BRaCsNR	73	249.36	3.42
7	BRaICsNR	69	230.64	2.67

3.1. Hardness (Fig.3)

The hardness of a material is its ability to resist plastic deformation, penetration, indentation, and scratching. Hardness is an important material property because the resistance to wear by friction or erosion and the compressive strength of the material generally increases with hardness. The wear resistance and compressive strength of a material are related to the hardness of the material.

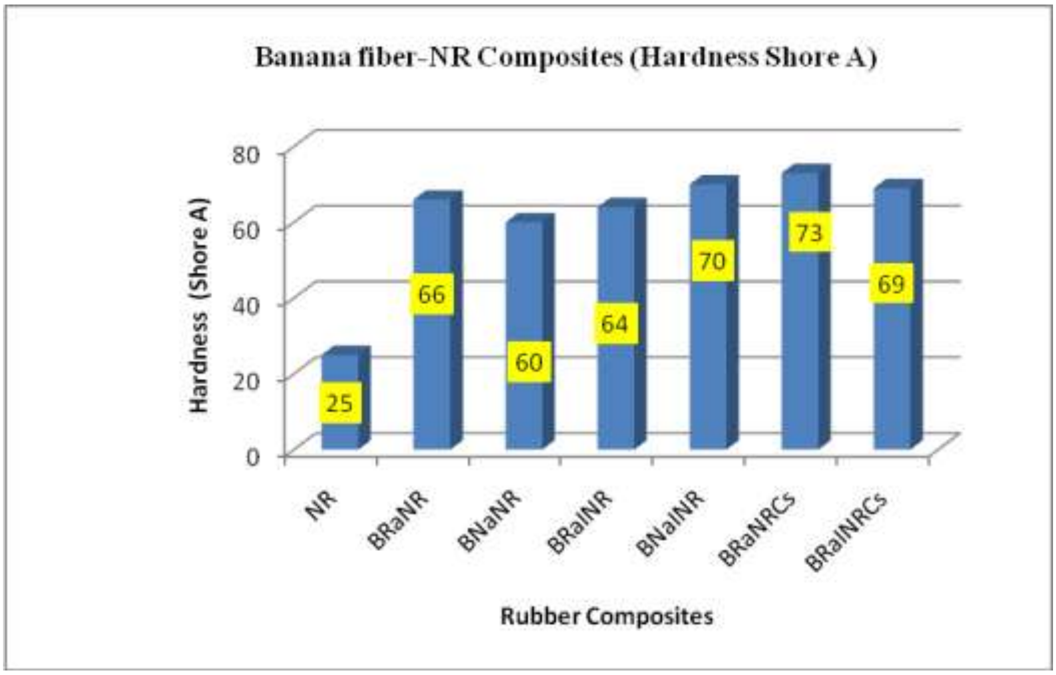


Fig.3. Hardness (Shore A).

The inclusion of banana fibers into natural rubber material is found to improve the hardness of the composite to an impressive and applicable level. The maximum hardness is shown by the composite BRaCsNR (73 Shore A).Raw banana fibers exhibit better modulus and rigidity compared to the treated fibers. This advantage in addition to the inclusion of 10% w/w coconut shell powder in the sample provided an increase of 192% in hardness over pure rubber (25 Shore A). The second best hardness exhibited by the sample BNaNR (70 Shore A) which is closely followed by BRaICsNR (69 Shore A). This shows that the pre-impregnation of the fibers with the matrix rubber improves the hardness of the resultant composites. Pre-impregnation after alkalization has yielded a slight edge over pre-impregnated raw fiber composites. The pre-impregnation process helped the rubber to penetrate deep into the fiber surface, thus making a deep bond with the fibers. These fibers, when compounded with rubber, gave a homogeneous interphase and a good interfacial fiber-matrix bonding. The other samples BRaNR, BRaINR, BNaNR- 66, 64, 60 Shore A respectively) also exhibited notable improvement in hardness over pure NR samples an average increase of 153% over pure rubber.

3.2. Compressive Strength (Fig.4)

The compressive strength of elastic materials is defined as the amount of stress required to distort the material by an arbitrary amount. A cylindrical button of (2cm diameter and 1cm thick) is compressed to a fixed height (75% of its original height) at atmospheric conditions and temperature (around 30°C) for 24hrs. The button is then released, allowed to recover for 30 minutes and the thickness is measured. Compression set is the height that is not recovered expressed as a percentage of the amount by which it was compressed (ASTM D395).

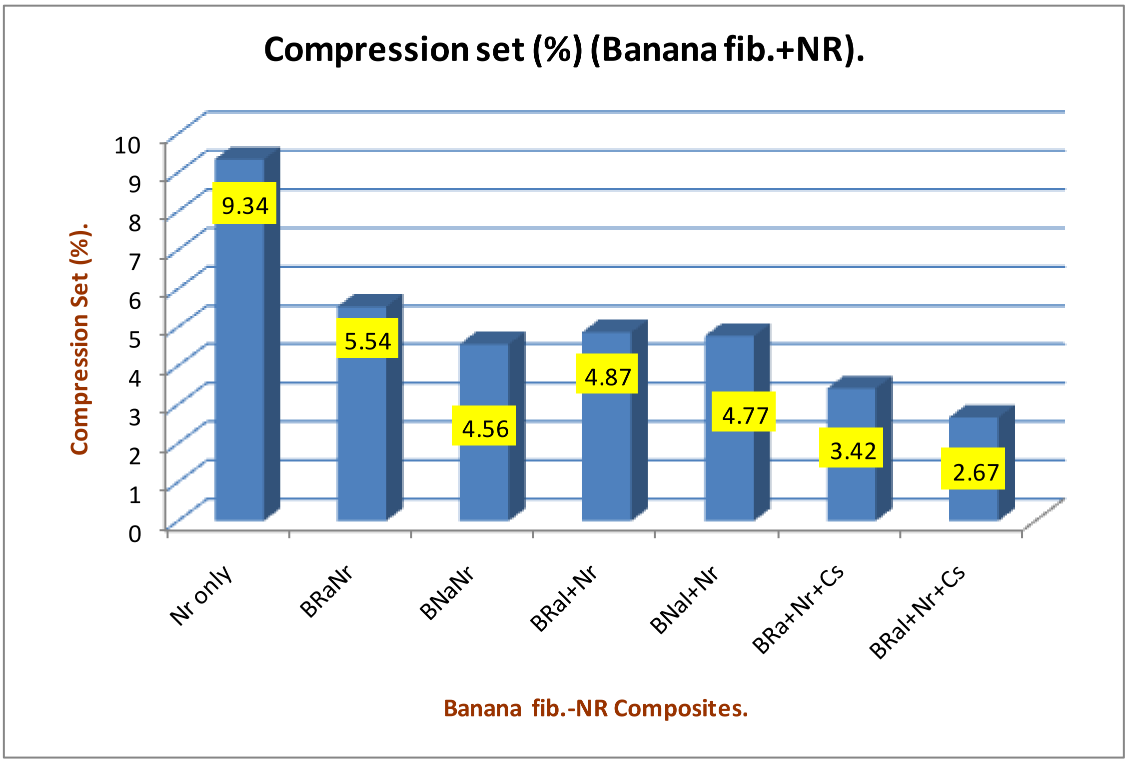


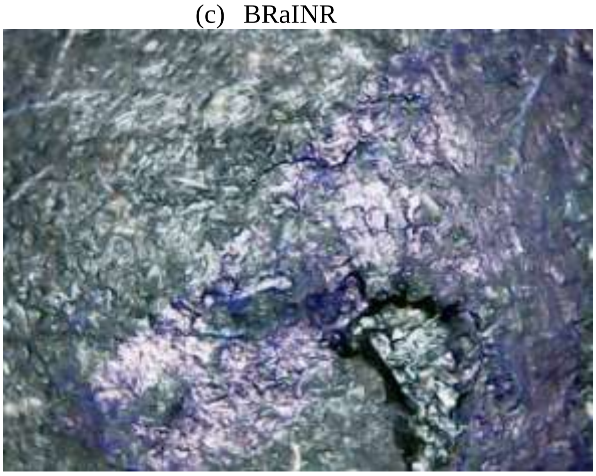
Fig.4. Compression Set (%).

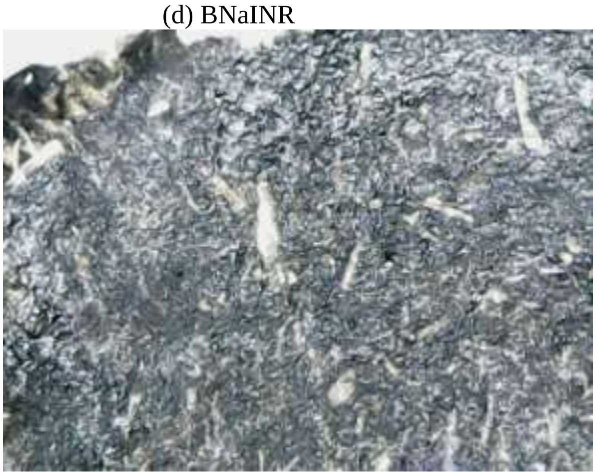
From the definition of compression set as above it can seen that the rubber composite sample with the least compression set has the best compressive strength. From the graph, it can be seen that the sample BRaICsNR has the least compression set or the best compressive strength. (Least compression set of 2.67%). The reinforcement of natural rubber with pre-impregnated banana fibers resulted in the formation of a homogeneous material. Also, the higher modulus fibers and the coconut shell powders improved the compressive strength of the composite, an improvement of 299.2% in compressive strength compared to pure natural rubber. This is followed by the composite sample BRaCsNR. This indicates that the coconut shell powder inclusion has a positive influence on the compressive strength of the rubber composites. The remaining composites (BNaNR, BRaINR and BRaNR) also exhibited a much better compressive strength than pure rubber.

Figure 5 (a-e) shows the microscopic images of the compressed composite specimens. The best compressive strength shown by the specimens with rubber –pre-impregnated-Coconut shell powder-rubber composite BRaCsNR [Fig.5(f)]. It can be seen from the image that the coconut shell powder and the fibers are closely compressed and packed on the surface, thus offering the maximum compressive strength. This is due to the high modulus and better fiber-matrix bonding. For the sample BRaCsNR {Fig.5(e)], the compressive strength is slightly less, because of lower raw fiber-rubber adhesion compared to the rubber-preimpregnated fiber-rubber bonding. From the results it can be concluded that the inclusion of coconut shell powder increases the compressive strength of rubber. The samples using alkalized fibers BNaNR and BNaINR [Fig.5 (b), (d)] showed good compressive strengths, indicating that alkalization helped to improve the fiber-matrix adhesion, thus preventing fiber slip during compression.

(a) BRaNR (b) BNaNR

(c) BRaINR (d) BNaINR





(e) BRaCsNR (f) BRaICsNR.

Fig.5. Specimen Surfaces after Compression Test (a) BRaNR, (b) BNaNR, (c) BRaINR, (d) BNaINR, (e) BRaCsNR, (f) BRaICsNR.

3.3. Wear Resistance (Fig.6).

Mechanical wear may be explained as the removal of material due to mechanical process under conditions of sliding, rolling or repeated impact. These include abrasive wear, fatigue wear, and adhesive wear. The wear resistance of the material is determined in terms of the material removal rate under standard conditions of abrasion process. The material having the least material removal rate has the best wear resistance. From the graph, it can be seen that the rubber composite with raw banana fiber reinforcement has the least material removal rate (225.07 mm^3) or the best wear resistance. This is due to the higher modulus of raw fibers compared to the treated fibers in rubber composites. This is followed by BRaCsNR and BRaICsNR composites with coconut shell powder included. The fibers together with the high modulus and dispersed coconut shell powder gave the composites better abrasion resistance. The remaining samples also exhibited good wear resistance compared to pure rubber.

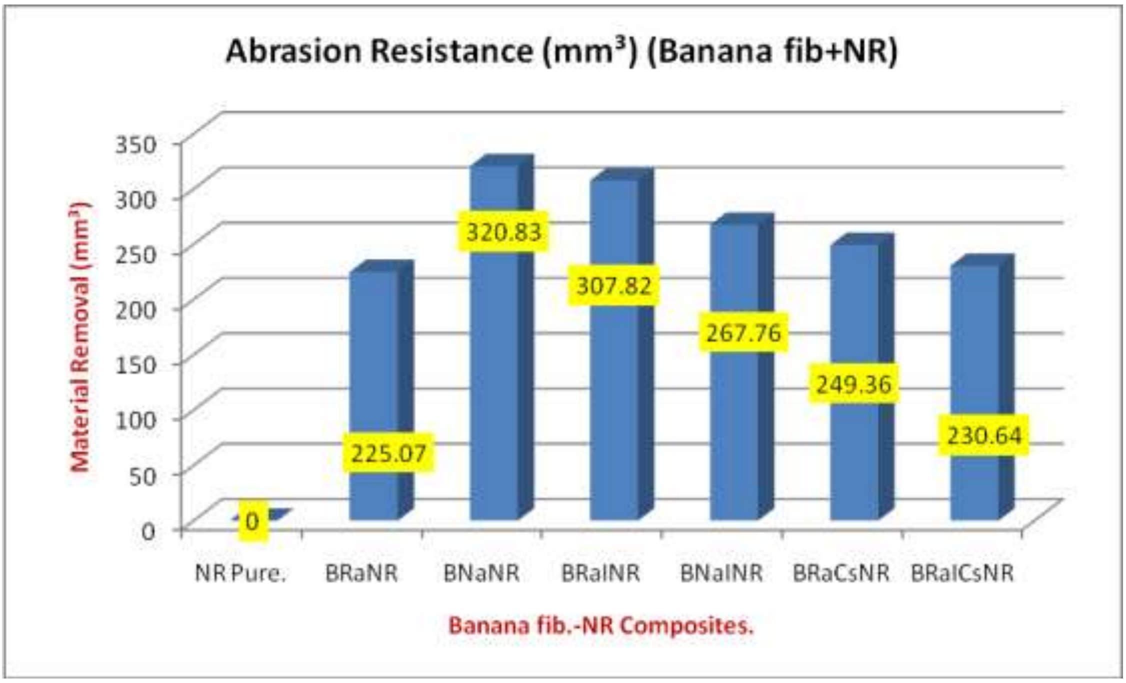


Fig.6. Wear Resistance/ Material Removal rate mm³/mm.

Figure 7 (a-e) shows the microscopic images of the worn out surfaces of the banana fiber-rubber composites. In the samples images for BRaNR, BRaICsNR, BRaCsNR [Fig.7-(a),(f),(e)], the fibers can be seen protruding abundantly on the worn out composite surface. These protruding fibers indicate that they offer better wear resistance than the matrix rubber protecting the rubber from abrasion. The specimen BRaNR (Fig.7-a) offered the best wear resistance, owing to the high rigidity and roughness of raw fibers embedded in the rubber compared to the alkalized banana fibers in other samples. Alkalisation removes the lignin- the cementing material for the cellulose in fibers, from fiber surface, thus reducing the effective diameter, rigidity and strength of fibers.


BRaNR


BNaNR

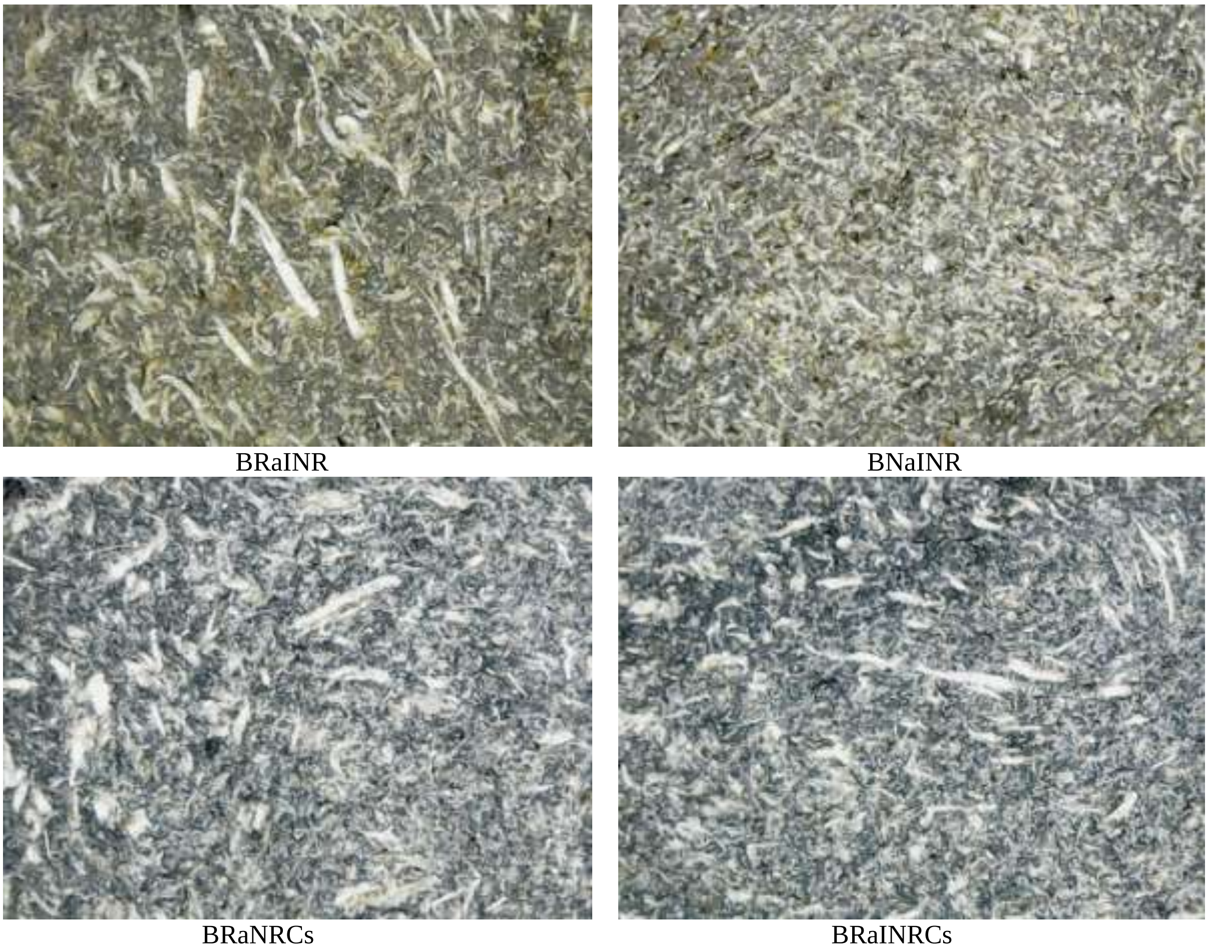


Fig.7. Abraded Surfaces of Specimens. (a) BRaNR, (b) BNaNR, (c) BRaINR, (d) BNaINR, (e) BRaCsNR, (f) BRaICsNR.

4. SOCIAL IMPLICATIONS

The developed rubber composite with 100% natural materials only like banana fibers, coconut shell powder, and natural rubber exhibited an impressive and useful improvement in hardness, wear resistance and compressive strength. These are essential requirements for engineering and industrial components like load bearing bushes, automotive parts, antivibration pads for both mechanical and civil engineering applications etc. the material used in the making of the composites are 100% natural, non-toxic, biodegradable, environment-friendly and recyclable.

5. CONCLUSIONS

The development and characterization of raw and treated banana fiber- natural rubber composites is done. The properties hardness, wear resistance and compressive strength of the composites were tested. The influence of inclusion of coconut shell powder in rubber also studied. The results show that banana fiber is a good reinforcement for natural rubber for improved hardness, wear resistance and compressive strength. Hardness value showed improvement up to 192% compared to pure rubber. Compressive strength increase to a value of 299.2% compared to pure rubber. Wear resistance also improved to an applicable level with the inclusions of fibers and coconut shell powder.

6. ACKNOWLEDGMENT

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7. REFERENCES

[1] Mohanty AK, Wibodo A, Misra M, Dizal LT, (2003), Effect of process engineering on the performance of natural fiber-reinforced cellulose acetate biocomposites. Composites Part A; Applied Science and Manufacturing. Vol.35, No.3, pp.363-370.
[2] Baley C, (2002), Analysis of then flax fibers tensile behavior and analysis of the tensile stiffness increase. Composites Part A; Applied Science and Manufacturing, Vol.33, No.7, pp.939-348.
[3] Chand N, Naik A, Neogi S, (2000), Three Body Abrasive wear of Short glass fiber polyester Composite, Wear, Vol.242, pp.38-46.
[4] Hutton TJ, Johnson D, Mcenaney B, 2001. Effects of fiber orientation on the tribology of a model carbon-carbon composite, Wear, Vol., pp.647-655.
[5] Yousuf B F, El-Tayeb NSM (2006), Mechanical and Tribological Characteristics of OPRP and CGRP composites in The proceedings ICOMAST, GKH Press, Melaka, Malaysia, pp.384-387, ISBN 983-42051-1-2.
[6] Tong J, Ma Y, Chen D, Sun J, Ren I, (2005). Effect of vascular fiber content on the abrasive wear of bamboo, Wear, Vol.259, pp.78-83.
[7] El-Sayed AA, El-Sherbiny MG, Abo-EI-Ezz AS, Agga GA, (1995). Friction and wear properties of polymeric composite materials for bearing applications, Wear, Vol.184, pp.45-53.
[8] Nishano T, Hirao K, Katara M, Nakama K, Inagaki H, (2003), Kenaf reinforced Biodegradable Composite, Composites Science, and Technology, Vol.63, pp.1281-1286.
[9] Gowda T M, Naibu ACB, Chayya R, (1999), "Mechanical Properties of Untreated jute fabric Reinforced Polyester Composite", Composites Part A; Applied Science and Manufacturing, Vol.30, pp.277-284.
[10] Wollerdorfer M, Bader H, (1998), "Influence of Natural Fibers on the Mechanical Properties of bio-degradable polymers", Industrial Crops and Products, Vol.8, pp.105-112.
[11] Keller A, (2003), Compounding and Mechanical Properties of bio-degradable hemp fiber composites. Composite Science and Technology, Vol.63, pp.1307-1316.
[12] Bilba K, Arsene M A, Quensanga A, (2003), Sugarcane Bagasse fiber Reinforced cement Composites, part I, Influence of the Botanical Components of Bagasse on the setting of bagasse/cement composite. Cement Concrete Composite, Vol.25, pp.91-96.
[13] Chand N, Dwivedi U K, Acharya S K, (2007), Anisotropic Abrasive Wear behavior of bamboo. Wear, Vol.262, pp.1031-1037.
[14] Chand N, Dwivedi U K, (2007), High-Stress Abrasive Wear Study on Bamboo, Journal of Material Processing Technology, Vol.183, pp.155-159.
[15] Chand N, Dwivedi U K, (2007), Influence of fiber orientation on the high-stress behavior of Sisal fiber-reinforced epoxy composites. Polymer Composites, Vol.28, pp.437-441.
[16] Dwivedi U K, Chand N, (2009), Influence of fiber Orientation on friction and Sliding Wear behavior of Jute fiber reinforced Polyester Composite. Applied Composite Material, Vol.16, pp.93-100.
[17] Lei Y, Wu Q, Yao F, and Xu Y (2007). Preparation and Properties of Recycled HDPE/ Natural Fiber Composites, Composites Part A: Applied Science and Manufacturing, Vol.38, No.7, pp.1664-1674.
[18] Xue Li, Lope G T, Satyanarayan P, (2007), "ChemicalTreatments of Natural Fibers formUse in Natural Fiber-reinforced Composites", A Review, Journal of Polymer Environment, Vol.15(1), pp.25-33.
[19] Rout J, Mishra M, Tripathi S S, Nayak S K, Mohanty A K, (2001), "The Influence of Fiber Treatment on the Performance of Coir Polyester Composites". Compos. Sci. Tech, Vol.,61(9), pp.1303-1310.
[20] Bachtiar D., Sapuan S.M., Hamdan M.M., (2008), The Effect of alkali treatment on tensile properties of sugar palm reinforced epoxy composites, Materials & Design, 29, 1285-1290.
[21] Rokbi M., Osmani., Imad A., Benseddiq N., (2011), Effect of Chemical treatment on flexural properties of natural fiber reinforced Polyester Composite, Proceedia Engineering, 10, 2092-2097.
[22] Cao Y., Shibitha S., Fukumoto I., (2006), Mechanical Properties of bio-degradable composites reinforced with bagasse fiber before and after alkali treatments, Composites Part A, 37, 423-429.
[23] Yan L., Chouw N., Yuan X., (2012), Improving the mechanical properties of natural fiber fabric reinforced epoxy composites by7 alkali treatment, Journal of Reinforced Plastics and Composites, 31, 425-437.