Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

# Overview of the Use of Natural Fibers to Reinforce Elastomeric Rubber

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**Abstract:**
Rubber goods are used extensively across a variety of sectors. Natural fibers are increasingly being used in place of synthetic reinforcements in rubber composites as a result of growing environmental concerns. With plant fibers serving as the primary focus of the survey, this review paper provides an overview of the components, processing techniques, characteristics, and performance of natural fiber reinforced rubber composites. The promise and difficulties of plant fibers make them an alternative to rubber for reinforcing.

**Keywords:** Natural fiber; Natural rubber; Reinforcement; Mechanical properties; Alkali; Silane.

## 1. Introduction

Due to their desirable qualities including elasticity, flexibility, shock absorption, and resistance to water and other chemicals, rubber compounds and rubber products are widely used in a variety of industrial settings. Tyres, Vee belts, conveyer belts, hoses, seals, antivibration pads, etc. are a few of the often utilised rubber items. Rubber is a viscoelastic polymer that is amorphous, soft, and elastic (thus the name elastomer). Rubber can be separated into two groups: synthetic rubber and natural rubber. Whereas synthetic rubber is made from petroleum chemicals, natural rubber is made from the sap of rubber trees. Rubber requires reinforcement to improve its strength, hardness, stiffness, and wear resistance, making it suitable for a variety of applications. The reinforcing materials for rubber are synthetic fibers like nylon, polyamide, polyester, rayon, polyaramide, glass fiber and steel wire or natural fibers derived from plants, animals and minerals[1-3]. These reinforcements are usually in powder, particulate, short fiber and long fiber (filament) forms. Owing to rising environmental concerns, modern day research in rubber technology is focused at replacing conventional synthetic reinforcements by natural ones[2-8]. Short palm fibers of 6 mm length treated with sodium hydroxide solution at 1, 3, 5, and 7% weight/volume concentration or benzoyl peroxide at 1, 3, and 5% fiber weight concentration were examined by Lopattananon et al. [9–10]. It was discovered that both surface treatments

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ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

enhanced the tensile and adhesive characteristics of the fiber matrix. In terms of mechanical qualities and compatibility between the fibers and the matrix, composites made with palm fibers treated with either 5% NaOH solution or 1% benzoyl peroxide were judged to be the best of the bunch. The thermal characteristics of the rubber matrix were improved by pristine palm fibers and were even better for treated fibers.

Jacob et al. [11-14] investigated rubber composites reinforced with a mix of sisal-oil palm fibers. Sisal fibers were 10 mm long whereas oil palm fibers 6 mm. The fibers were modified with varying concentration (0.5 – 10%) of sodium hydroxide solution at room temperature. Resorcinol-hexamethylene tetramine was the bonding agent used to promote fiber-matrix bonding. The processing and mechanical properties of sisal-oil palm rubber composites were monitored with fiber content, fiber ratio and treatment as the variables. The tensile strength and tear strength declined when the fiber content was increased beyond 30 phr, but hardness and tensile modulus increased. Ismail et al. [15] prepared rubber composites reinforced with bamboo fibers. Bamboo chips ground to particle size of 180-270 microns were oven dried at $80^0$C for 24 hours. Mixing of fiber and matrix was done on a two roll mill. Bonding agents used were phenolformaldehyde and hexamethylenetetramine. It was found that while scorch time and cure time decreased with increase in filler content aided by a coupling agent, tensile modulus and hardness increased.

Osabohien and Egboh [16-20] studied cure phenomena, physical and mechanical properties of natural rubber filled hemp vis-à-vis carbon black. The results indicated that scorch and cure times decreased with increase in filler content for both hemp filled and carbon black filled natural rubber composites. Optimum tensile strength was obtained at 40 phr loading for both the fillers. The tensile strength of carbon black filled composites was 1.5 times that of its hemp filled counterpart. Lower strength of hemp loaded rubber composites was because of higher moisture content and size of particle. Rahman et al. [21-22] treated jute-NR composites with varying dosages of gamma radiation in the range 50-1000 krad. It was found that there was a marked increase in tensile strength and tensile modulus of the composite up to radiation dose of 250krad. Thereafter at higher doses of 500krad and 1000krad, both the modulus values followed a declining trend. Smitthipong et al. [23] worked on replacing nylon in pure and impure rubber matrices with silk textile. Lamellar composites were prepared with silk layers alternating between two rubber layers. The authors observed that silk offered better tensile strength and elastic modulus as compared to nylon.

The objective of this review is to share an insight into types of natural fibers, fiber modifications, types of rubber matrices, fillers and additives used, processing and performance aspects involved in the development of natural fiber reinforced rubber composites and also figure out their application areas.

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ISSN: 0970-2555
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## 2 Methodology

*1.1 Natural fibers in rubber matrix*

Natural fibers are preferred reinforcements for rubber because of their light weight, renewability, ease of availability, processing, biodegradability and low cost. However, these fibers have certain inherent disadvantages such as affinity towards moisture (hydrophilicity) and poor interface bonding with rubber. In order to overcome these drawbacks natural fibers are subjected to physical and chemical treatments, discussed in the next section. In addition, coupling agents such as maleic anhydride polypropylene (MAPP) and silane agents are used to link the two constituent phases namely natural fiber reinforcement and rubber matrix.

*1.2 Types of natural fibers used to reinforce rubber are*

The types of natural fibers used to reinforce rubber are

1. Plant fibers - pineapple leaf, oil palm, bamboo, coir, hemp, bagasse, sisal, jute, cotton, wood pulp, rice husk etc.
2. Animal fibers - silk
3. Mineral fibers -asbestos

Plant fibers are sourced from cultivated crops or by utilizing agricultural waste like olive husk powder, peanut shell powder, coconut shell powder, rice husk etc. Cellulose, hemicellulose and lignin are important chemical constituents of plant fibers. Cellulose, the primary component of plant cell is a profusely available organic polymer on our planet. Cellulose content varies from 35-50 % of dry weight in most green plants and is above 90 % for cotton. Performance and properties of natural fiber-rubber composites depend on fiber variables namely fiber type, fiber content, fiber aspect ratio, fiber orientation, fiber dispersion, fiber-matrix adhesion, matrix properties and processing methods. Table 1 represents account of different types of natural fibers used with rubber matrix.

**Table 1:** Natural fibers reinforced rubber

| Natural Fiber Reinforcement | Rubber Matrix |
|---|---|
| Coconut shell powder | Natural Rubber |
| Peanut shell powder | Natural Rubber |
| Rattan powder | Natural Rubber |
| Pineapple leaf fiber | Natural Rubber/Acrylonitrile Butadiene Rubber |
| Sisal/Oil palm fiber | Natural Rubber |
| Oil palm fiber | Natural Rubber |
| Bamboo fiber | Natural Rubber |
| Sisal fiber | Natural Rubber |
| Coir fiber | Natural Rubber |
| Hemp fiber | Natural Rubber |
| Bagasse fiber | Natural Rubber |
| Jute fiber | Natural Rubber |
| Cotton fiber | Natural Rubber |
| Silk fiber | Natural Rubber |

*1.3 Fiber treatment*

Natural fibers are pretreated to undergo surface modifications and to promote their bonding with the rubber matrix. Treatment techniques can be broadly classified as physical and chemical. One of the effective physical methods adopted in treating natural fibers is radiation treatment. Corona treatment, UV radiation, gamma radiation and electron beam radiation lie in the above mentioned category. Alkali treatment (mercerization), acetylation, benzoylation, permanganate and peroxide treatments are commonly used chemical methods. Alkali treatment involves dipping natural fibers in sodium hydroxide (NaOH) solution in order to clean their surface by removing fats, waxes and other impurities, thereby exposing reactive hydroxyl groups(-OH). Sodium hydroxide solution is also used for extraction of certain elementary/technical bast fibers by retting. It is noteworthy that the properties like tensile strength, tensile modulus and elongation at break of alkali treated natural fiber rubber composites improve only when sodium hydroxide concentration is less than 10%. At higher concentrations of NaOH, the above properties follow a decreasing trend. Acetylation treatment of plant fibers replacement of hydroxyl groups in cellulose by acetyl groups, thereby decreasing their affinity towards moisture and ensuring better adhesion with rubber matrix.

*1.4 Rubber matrices*

Frequently studied rubber matrices are natural rubber (NR), Acrylonitrile Butadiene Rubber (NBR) and Styrene Butadiene Rubber (SBR). Rubber matrices are sometimes blended in order to improve the performance of the composite in general and better matrix to fiber stress transfer in particular.

*1.5 Fillers and additives*

Role of filler in rubber matrix is to fill in the voids in the matrix and at the same time increase the stiffness and wear resistance of the matrix. Carbon black and silica have been extensively used as fillers in rubber matrices, both being non degradable and energy consuming. Powdered coconut shell, peanut shell, rattan and bagasse fiber ash have been tried as full or part replacement of conventional fillers. Additives include bonding (coupling) agents such as silane agents and MAPP and curing agents like accelerators (sulfonamides/ thiazoles) and activators (zinc oxide/stearic acid)

*1.6 Processing of natural fiber-rubber composites*

The processing of natural fiber-rubber composite involves two steps. At first fiber, additives and rubber matrix are mixed homogeneously in a conventional mixer. Fiber should be treated suitably beforehand for necessary surface modifications of the same. Thereafter, homogeneous rubber compound from the mixer is compression molded at suitable temperature and pressure to ensure proper curing of the material. Natural fiber-rubber composites are frequently prepared by milling/calendaring in which fibers orient longitudinally in the mill direction with nip gap, roll speed and number of passes as the process variables.

## 2. Results and discussion

### *2.1 Performance of natural fiber-rubber composites*

Properties and performance of natural fiber-rubber composites can be analyzed under the following heads:

#### *2.1.1 Cure characteristics*

NR in its pristine form cannot be readily used as it is sticky, elastic and brittle at low temperatures. Vulcanization is a chemical process wherein NR is heated with sulphur and other curatives to enhance its elasticity and resilience through formation of cross links between individual polymer chains. The maximum and minimum torques during viscosity measurement of the rubber composite increased with increase in fiber content thereby making it harder and stiffer. Further silane or alkali treated fibers in the rubber composite gave high torque readings at a particular fiber loading. Cure time and scorch time of the rubber composite diminished steadily with increment in fiber loading. It was also observed that small sized chemically treated fibers lowered the composite cure time as compared to both virgin (untreated) and larger sized fibers.

#### *2.1.2 Mechanical properties*

The mechanical properties of rubber composite depend on the efficiency of load transfer from matrix to the fibers which in turn is governed by the length of fiber, fiber content, fiber orientation and fiber matrix bonding. It was also revealed that for maximizing dynamic modulus and tensile properties optimum fiber length was 10 mm for sisal fiber and 6 mm for oil palm fiber which reaffirms that short fibers are better suited to the rubber matrix. Further silane and alkali treatments enhance the mechanical and dielectric properties of natural fiber-rubber composites due to more cross linking between the two constituent phases and stronger fiber-matrix bonding.

#### *2.1.3 Thermal properties*

The thermal behavior of different natural fibers especially plant fibers are more or less similar to that of natural rubber (NR). Thermogravimetric analysis of NR composites reinforced with coconut shell powder indicates that thermal stability of NR does not show any significant change with fiber inclusion.

#### *2.1.4 Interface Morphology*

Interface morphology of natural fiber-rubber composites can be studied in detail using Scanning electron microscope (SEM) to figure out fractured surfaces of the rubber composites, fiber-matrix bonding and fiber distribution in the rubber matrix. Sareena et al. reported that larger particles of peanut shell powder led to particle accumulation resulting in poor distribution of fibers. Fractured surfaces of rubber composites with alkaline/silane treated fibers had lesser holes, broken fibers and more rubber particles coated on the fiber surface as compared to rubber composite with virgin (untreated) fibers.

#### *2.1.5 Swelling measurement*

Interface morphology of natural fiber-rubber composites can be studied in detail using Scanning electron microscope (SEM) to figure out fractured surfaces of the rubber composites, fiber-matrix bonding and fiber distribution in the rubber matrix. Sareena et al. reported that larger particles of peanut shell powder led to particle accumulation resulting in poor distribution of fibers. Fractured surfaces of rubber composites with alkaline/silane treated fibers had lesser holes, broken fibers and more rubber particles coated on the fiber surface as compared to rubber composite with virgin (untreated) fibers.

#### *2.1.6 Biodegradation*

Biodegradation of natural fiber-rubber composites is observed by placing a composite sample in soil or compost with microbes for a period of 3 months. Sample usually degenerates into carbon dioxide and water. Natural fiber-rubber composites can be used effectively in biomedical, packaging, construction and agricultural sectors as they have high stiffness and hardness, light weight but are inexpensive, environment friendly and biodegradable.

## 3. Conclusion

This review focuses on plant fiber reinforced rubber composites and discusses the components, production techniques, characteristics, and performance of natural fiber-rubber composites. According to research on natural fiber reinforced rubber, short plant fibers with a length of 6 to 10 mm that have been alkali and silane treated have a strong bond with natural rubber and produce composites with exceptional qualities. While compression moulding and extrusion (milling) are the two most often used techniques for producing natural fiber-rubber composites, alternative techniques including resin transfer moulding and injection moulding can also be investigated. It is possible to experiment with blending short fibers from various plants, various fiber sizes (specifically, short fibers and fiber powder), and various rubber grades to create economical, environmentally friendly rubber composites with exceptional properties.

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