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FAILURE MONITORING OF RUBBER PRODUCTS REINFORCED WITH WASTE FIBERS OF TIRE RECYCLING PROCESS

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Abstract

In this article, waste fibres from the recycling tire process with a different percentage of addition (0, 2.5, 5, 7.5, 10, 12.5) were mixed to increase their tensile strength, tear resistance, and bending resistance with natural rubber NR. The effect of short fiber on composite mechanical properties was investigated. Despite substantial research on the mechanical characteristics of rubber products reinforced with fiber waste, the experimental work focused on identifying precursory physical mechanisms that are responsible for fracture behavior during tests and structural monitoring. The findings reveal that milling and vulcanization conditions have a significant role in enhancing mechanical characteristics. The waste fibres and natural rubber provide strong interfacial adhesion during two rolls of milling and vulcanization at 140°C. Waste fiber may boost the tensile strength of a composite material by up to 7.5% of waste fiber, with a slight decrease at 10% and 12.5%. The flexing test findings showed that adding fiber to the recipe improved it by up to 7.5% before gradually degrading, and it is obvious that the recipes' tear resistance improves in comparison to the basic recipe. The discoveries have the potential to increase the tensile strength, tear resistance, and flexing resistance of industrially manufactured rubber conveyor belts, which are important physical properties in engineering applications.

Keywords: natural rubber, waste fiber, flexing resistance, failure monitoring, tear resistance

1. INTRODUCTION

Due to its exceptional physical qualities, which include high mechanical strength, low heat buildup, tremendous flexibility, resistance to impact and tear, and most importantly, its renewability, natural rubber (NR) is a unique material that has found commercial success [1, 2]. Raw dry rubber, on the other hand, is seldom utilized in its natural state for any household or engineering application. As a consequence, many auxiliary chemicals known as additives are added to rubber throughout the production process to aid in the processing and vulcanization of the rubber compounds and to improve their application qualities. Vulcanizing agents, accelerators, activators and/or retarders, fillers, and anti-degradants are a few of the additives used in the production of rubber [3]. Structural health monitoring (SHM) attempts to preserve the integrity of a whole structure by performing many activities such as detection of damage, localization, and measurement. The health monitoring techniques aim to identify failure by evaluating the structural response to certain natural or simulated stresses on the composite structure. Early detection of damage is preferable so that appropriate maintenance procedures may be implemented, ensuring structural reliability and strength. [4, 5].

One of the most crucial components in rubber compounding is fillers. In order to maximize the characteristics required for service applications, fillers are added to the formulation of rubber [6, 7]. Many researchers have developed an interest in the topic of particle filler reinforcement of rubber polymers [8–10]. Improved physical and mechanical characteristics, including tensile strength, hardness, and processing effectiveness, are present in filler-reinforced rubber vulcanizates [11–14]. These qualities include adaptability in design. Due to severe environmental regulations across the world, attempts have been made to create alternative reinforcements that are ecologically benign while delivering the same performance as their synthetic equivalents, thanks to a greater understanding of the appropriate use of renewable natural resources. [15, 16]. Because of their low cost and abundant availability, natural fibres provide an excellent, renewable, and biodegradable alternative to the most

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popular synthetic reinforcement due to their ease of chemical and mechanical modification and high specific mechanical properties [17, 18]. Waste disposal management is one of the issues that mankind confronts in the twenty-first century. Rubber is utilized in a wide range of applications, including tires, window seals, engine mountings, hoses, and isolation bearings. When these items reach the end of their useful service life, they must be disposed of or demolished. [19]. The reclamation and recycling of discarded rubber have significant consequences for environmental preservation, energy conservation, re-use with or in place of virgin rubber, cost savings, and a change in the processing behavior of rubber compounds. [20-22].

Until now, textile fiber derived from tire disposal has been classified as trash. Rubber pollutants from tire shredding are often seen in textile fibers. Rubber content in fibric material varies by tire type and ranges from 5 to 20% by weight. In order to produce a "pure" material that may be used in another application, it is crucial to eliminate any leftover rubber component, according to the scientific theory behind the reuse of textile fibres [23]. Bignozzi and colleagues have published various studies on the use of end-of-life tire (ELT) fibers in modified mortars. [24]. Fibres, primarily a blend of nylon, rayon, and polyester fibres, increased the mechanical qualities of the mortar, but the process was not commercially viable due to financial restrictions [25]. Czvikovszky [26] studied the use of discarded textile fibres as reinforcing material for polypropylene (PP) used in vehicle bumper manufacturing. Finding information on the possible reuse of ELT textile fibres is challenging, even in scientific publications [27].

The current study focused on the use of damaged fibers from recycled tires in recipes for manufacturing basic conveyor belt layers or protection layers, which are placed under different loads according to the technological application, thus reducing costs and achieving economic and environmental goals.

2. EXPERIMENTAL PART

2.1. Materials

The general firm for the tire industry provided NR and other industrial-grade chemical ingredients. The waste fibres were obtained via the tyre recycling procedure. Fiber percentage ratio *wt*% is (0, 2.5, 5, 7.5, 10, 12.5). The following chemicals were used in the master batch: NR, carbon black (CB), oil, waste fibres, zinc oxide (ZnO), stearic acid, and sulfur. The precise equations for the composite are shown in Table 1.

2.2. Natural Rubber with Waste Fiber

Work is being done on the laboratory mill to produce a rubber formula in compliance with the standard specification. ASTM D3182 Rubber - Materials, Equipment, and Procedures for Preparing Standard Vulcanized Sheets and Mixing Standard Compounds. Specification necessitates the presence of a laboratory mill (two rolls) of sufficient capacity, as well as a scale sensitive to the weight of rubber and the materials used in the recipe table 1, in addition to the environmental conditions required for the work of rubber recipes such as heat and humidity, as well as other chemical agents.

Table 1. Combining NR/Waste fiber into recipes

Materials	Loading Ratio (pphr)
SMR 20	100
Zinc Oxide	5
Stearic Acid	2
Carbon Black 326	55
Process oil	10
6PPD	4
Sulphur	2.5
TBBS	0.8
Waste fiber	(0, 2.5, 5, 7.5, 10, 12.5)

2.3. Mechanical Characteristics

I. Tensile strength

One of the most important physical properties that are calculated for recipes is tensile strength, elongation when cutting (elongation at break), and elasticity or tensile strength at a certain elongation (modulus at a specified elongation). These properties are checked according to the International Standard ASTM 412, ASTM D3182, where a sheet of recipe is pressed (vulcanized) according to the appropriate times and left at room temperature for a period of 24 hours before the examination is performed on the tester (tensiometer). The sheet is cut to prepare the test specimen shown in figure 1, specimen after test figure 2, which are called dumb shapes, with a number of specimens per recipe and under the inspection conditions specified in the above-mentioned standard.

Fig. 1. Tensile specimen

Fig. 2. Tested Tensile specimen

II. Tear resistance

The tear resistance test is one of the physical tests that is undertaken in line with the standard specification ASTM D624-DieC, where the test forms illustrated in Figure 3 are made, and via a special machine, an incision of 1 mm is created in the center of the models for this examination. Via the tensile strength test equipment, the value of the force necessary to cut this model is measured in the presence of the beginning fracture, which is a standard for tear resistance. Figure 4 specimen after testing.

Fig. 3. Tear Specimen

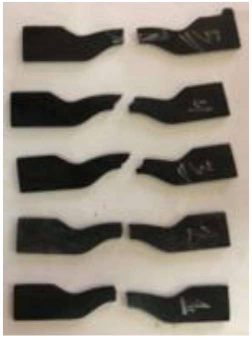

Fig. 4. Tested tear Specimen

III. Flexing resistance

The flexing test specimens shown in Figure 5 are produced in accordance with the international standards ASTM D430 and ASTM D813, and a first crack is created in the center of the specimen using a prissing tool, a machine designed specifically for this purpose in Figure 6.

Fig. 5. Flexing test specimen

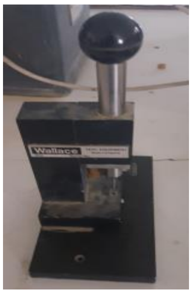

Fig. 6. Prissing tool

The specimen is then fitted in the examination equipment De -Mattia Flexing fatigue tester figure 7, which drives the model in an oscillatory motion for an undetermined number of cycles until the model fails, at which point the number of cycles necessary for the model to fail is recorded. The specimens shall be prepared in molds conforming to the shape and dimensions, also figure 8 shows the specimens after test process.

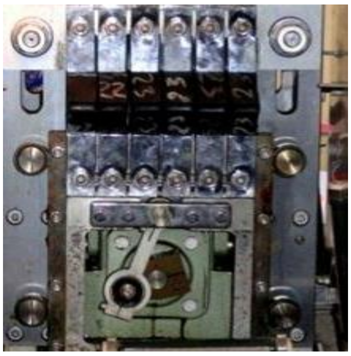

Fig. 7. DE-Mattia flexing machine

Fig. 8. Tested Flexing specimen

3. RESULTS AND DISCUSSION

I. Tensile strength: The results show that increasing the percentage of added fibres increases the tensile strength property of natural rubber recipes, followed by a slight decrease rate of 10%, or 12.5%. Also, the increase in the percentage of added fibres led to a decrease in the elongation of the recipes, in contrast to the tensile strength at 200% compared to the raw recipe, as shown in figures 9, 10. In earlier research [28], the mechanical properties and ability to cure of natural rubber, regular Nigerian rubber, SNR10 packed with cherry seed shell (CSS), and regular carbon black CB (N330) were compared**.** The vulcanizates with CSS and CB filler content exhibited the maximum tensile strength prior to lowering. The inclusion of filler increased both vulcanizates' moduli (M100 and M300), specific gravity (S.G.), hardness, and abrasion resistance while lowering their elongation at break and Dunlop resilience.

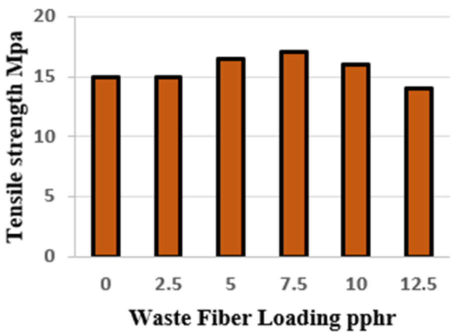

Fig. 9. Tensile strength result

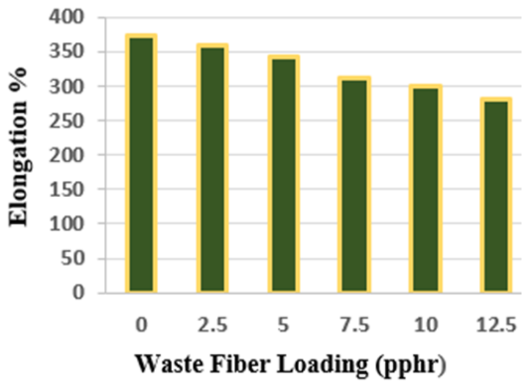

Fig. 10. Elongation at break result

II. Tear Resistance

The results of the tear test show that it is clear that the tear resistance of the recipes increases compared to the base recipe, as shown in figure 11. A previous study [29] increased the tear strength of natural rubber (NR) by employing short fibres constructed of ultra-high molecular weight polythene (UHMWPE) measuring 20 mm in diameter and 2 cm in length. The findings indicate that the chemical NR/resin powder combination's strength is somewhat greater than that of NR. Because the UHMWPE fibre has no sophisticated surface modification, discoveries have been made that improve the tearing resistance of rubber conveyor belts produced industrially.

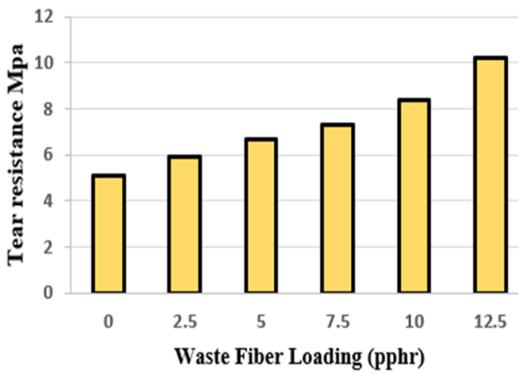

Fig. 11. The effect of fiber content on tear resistance

III. Flexing Test: The results were as shown in figure 12, which is an average of specimens for each rubber recipe, as it was found that adding fibre to the recipe led to an improvement in the recipe up to 7.5% and then a gradual decrease. The crystalline domains of NR give it its green strength as well as remarkable growth resistance under extreme deformation even without reinforcement. When BRcis is mixed with NR and SBR, it improves flex cracking and fatigue resistance, resulting in technical and economic benefits [30].

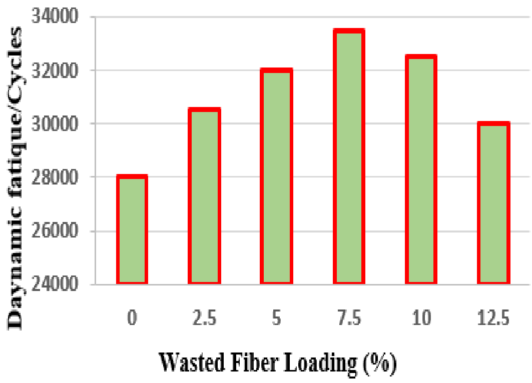

Fig. 12. Flexing fatigue result

Engineering structure must check under application loads, so previous study deals with dynamic initiation fracture at specific loading rate to investigate the mechanical behavior of these materials [31- 33].

4. NUMERICAL ANALYSIS

This paper, Finite Elements Analysis for Composite Materials using Abaqus, shows how useful finite element tools are for solving real problems in the structural analysis of composites. It was based on advanced mechanics of composite materials. The techniques for a basic finite element analysis (FEA) utilizing an Abaqus case study are thoroughly explained in this part, along with instructions for each stage. Geometry is the model's initial requirement. The components that combine to create a geometry are then given the material attributes. The geometry is then applied with element type having six degrees of freedom, as seen in figure 13.

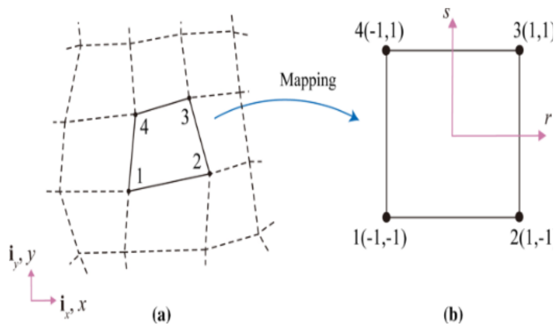

Fig. 13. Four nodes element type

A node is basically a point in geometry described by its coordinates, which define degrees of freedom. A degree of freedom within finite element analysis can take many different forms, depending on the type of analysis being carried out. Figures 14, 15, and 16 show how the geometry is meshed.

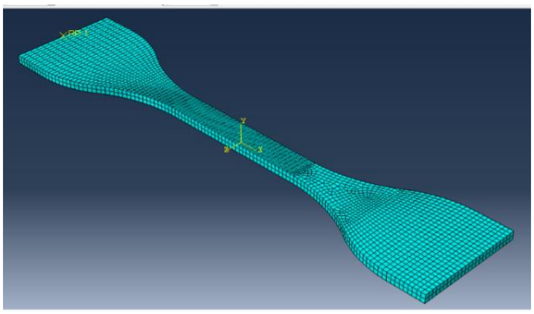

Fig. 14. Tensile specimen mesh

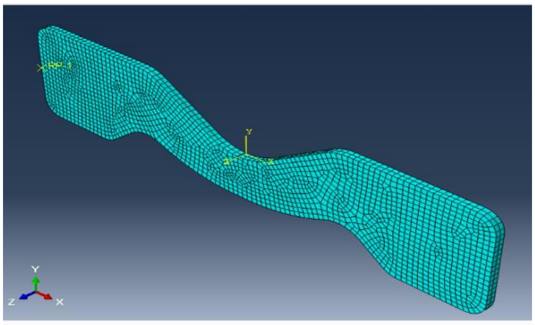

Fig. 15. Mesh of tear specimens

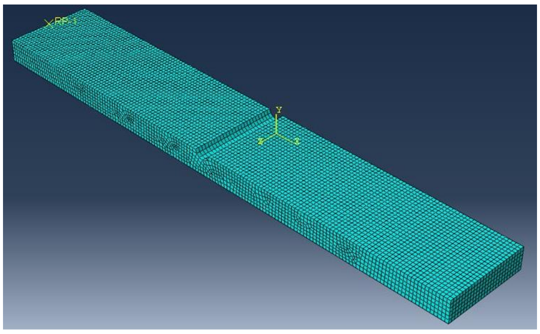

Fig. 16. Mesh of Flexing specimens

In general, the results improve as the number of elements increases, yet there is an optimum wherein the results are close to the real result. It implies getting close to the exact result with the lowest element number, as shown in figure 17.

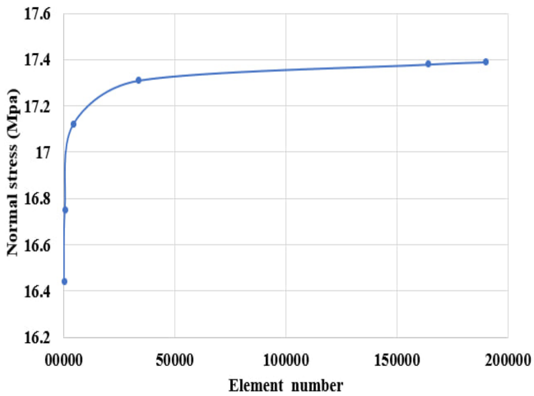

Fig. 17. Normal stress vs. element numbers

The type of element was chosen to represent the characteristics of the issue that has to be addressed. The model is then resolved. In the last stage, the results are computed and displayed. Figures 18 and 19 depict the contour of the stress distribution and stress-strain curve of the specimen during a tensile test. The analysis shows the greatest stress intensity at the effective length of the specimen because of the elevated stress concentration throughout the specimen's pull as well as the influence of necking in this region. The higher tensile strength at beginning load ratios may be attributed to the mix's superior homogeneity with more fibres, which results in improved tensile strength.

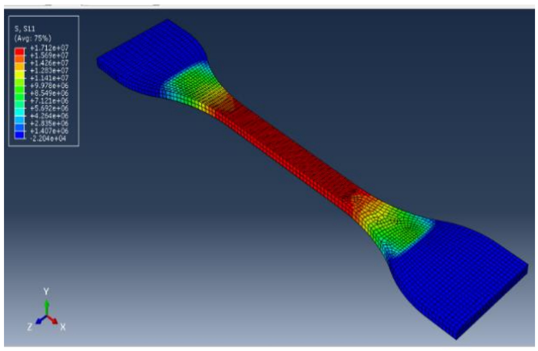

Fig. 18. Stress distribution of tensile specimen

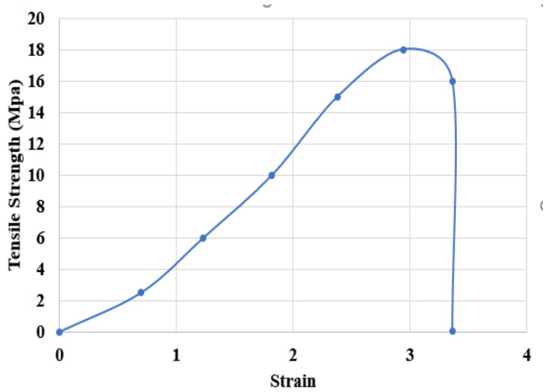

Fig. 19. Curve of stress -strain

Figures 20 and 21 illustrate the tear test specimen's stress distribution and stress-strain curve. The existence of a fracture in the specimen suggests that one of the causes of the specimen's weakness is the stress concentration caused by the crack inclusion. In most cases, the model may be thought of as having homogenous content. The newly formed breaking enhances the irregularity of the inner structure of the specimen and creates weak regions, which interfere with stress transfer and result in greater concentration stress at the point of fracture. At minimal stress, the zone around the crack decreases, as does the ultimate strength of the rubber specimen.

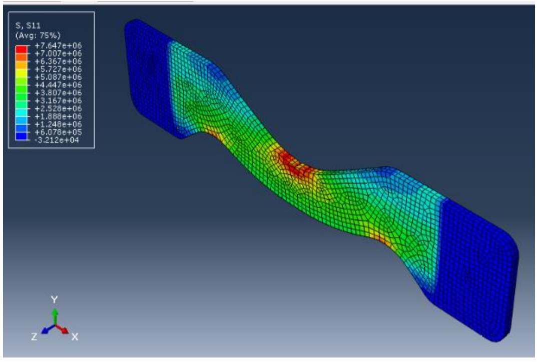

Fig. 20. Stress distribution of Tear specimen

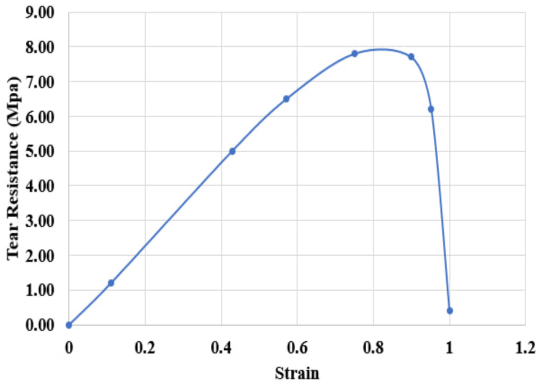

Fig. 21. Stress-strain curve

Figures 22 and 23 demonstrate the flexing test specimen's stress distribution as well as the stress-strain curve. The existence, propagation, and extension of fractures produced by moving and bending the specimen. Greater stress levels, on the other hand, caused a reduction in flex life, which might be attributed to difficulties in achieving homogeneity and uniformity in distribution. Tensile, tear, and flexing test numerical analyses agree with experimental results.

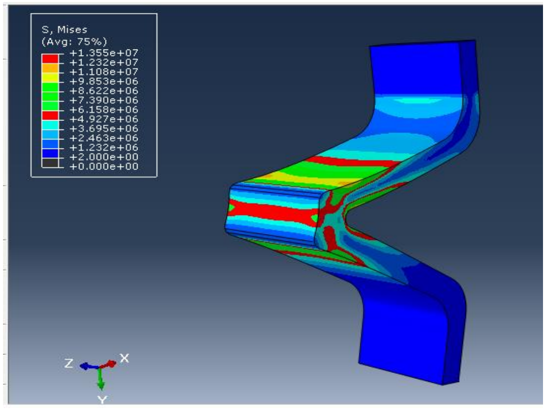

Fig. 22. Stress distribution of flexing specimen

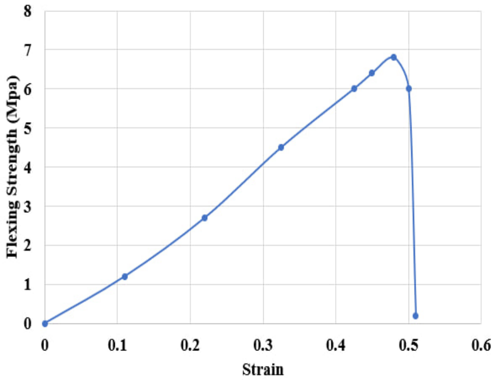

Fig. 23. The stress-strain curve

5. CONCLUSION

Investigated are the mechanical properties of natural rubber composites reinforced with fibers. 1. Tensile strength increased with fibre loading and subsequently decreased.

1. The elongation feature, which often falls off as the additive ratio rises, this is due to the incorporation of fibers in the rubber compound, which causes the blend's decreased flexibility and increased hardness.
2. Tear resistance has improved as the percentage of additional fibres in rubber compounds has increased.
3. The addition of fibres to the rubber compound improved the flex resistance performance. Higher percentages of fibre addition, on the other hand, resulted in a decrease in flex life, which could be related to challenges in maintaining homogeneity and uniform dispersion of the fibres.
4. The performance of the composites to which waste fibre contributes may also be enhanced. In this study, we want to use recycled waste rubber for improved waste management practices and a cleaner environment.
5. Identifying the kinds of damage and the influence of the test type on composite structures may help to choose the best damage detection approach for the structural health monitoring of composites.

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