Study and Development of a Health-Oriented Shoe Insole Made from Natural Rubber Combined with Carbon Rubber Plate

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Abstract

This study aimed to develop a health-oriented shoe insole from natural rubber materials that can effectively absorb impact and distribute plantar pressure while increasing the value of Thai natural rubber and agricultural waste. Thailand is one of the world's leading producers of natural rubber; however, declining rubber prices continue to affect farmers' income and quality of life. Therefore, value-added applications of natural rubber are of great importance. The insole was designed as a three-layer sandwich structure consisting of a latex foam top layer for shock absorption, an EVA foam middle layer for pressure distribution and structural stability, and a bio-carbon rubber plate made from coconut-shell-derived carbon black as the bottom layer to improve durability and wear resistance. Different formulations of latex foam and carbon rubber plates were prepared and evaluated. The carbon rubber plate was fabricated through sulfur vulcanization, in which sulfur and accelerators were used to create crosslinks within the rubber matrix, thereby enhancing its mechanical strength and elasticity. The materials and the assembled insole were characterized through tensile, compression, and simple drop-impact tests. The results showed that the latex foam exhibited excellent softness and resilience, while the carbon rubber plate enhanced load-bearing capacity and pressure distribution. The developed insole significantly reduced peak impact forces and localized pressure, demonstrating strong potential as a health-oriented footwear material and providing an alternative approach for adding value to natural rubber and agricultural by-products in Thailand.

keywords : Natural rubber, Sandwich structure, Orthopedic insole, Shock absorption

Introduction

Thailand is one of the world's leading producers and exporters of natural rubber, playing a significant role in the country's agricultural economy and export sector (Office of Agricultural Economics [OAE], 2022). However, in recent years, the natural rubber industry has faced challenges due to price fluctuations and oversupply in the global market, resulting from an imbalance between production volume and market demand. These issues have directly affected the income of rubber farmers in many regions (Food and Agriculture Organization [FAO], 2021). Therefore, the development of value-added products from natural rubber has become an important strategy for increasing farmers' income and promoting the sustainability of Thailand's agricultural sector (Department of Agriculture, 2020).

Shoe insoles play an important role in promoting foot health and overall musculoskeletal well-being. Biomechanical studies have shown that insoles with effective shock absorption and pressure distribution properties can reduce ground reaction forces and lower the risk of ankle and knee injuries (Nigg et al., 2015). This is particularly beneficial for individuals who stand or walk for extended periods, athletes, and older adults, who often experience excessive pressure accumulation on the plantar surface of the foot (Landorf & Keenan, 2000).

Natural rubber is a highly elastic material with excellent elastic recovery and shock-absorbing capabilities, making it suitable for manufacturing load-bearing products such as shoe insoles (Ismail & Poh, 2014). In addition, the incorporation of reinforcing fillers such as carbon black can significantly improve the strength, wear resistance, and mechanical properties of rubber products (Mark et al., 2013). Carbon black derived from biomass materials, such as coconut shells, also aligns with the principles of the circular economy and sustainable resource utilization (Sirisinha, 2018).

Based on these concepts and supporting information, this project was developed to investigate the feasibility of designing and producing natural rubber shoe insoles reinforced with carbon rubber inserts at key load-bearing areas. The project focuses on enhancing pressure distribution, durability, and practical usability. Furthermore, it aims to promote the utilization of domestic resources, increase the value of agricultural products, and support the development of innovative products with future commercial potential.

Methodology

1. A Study of Formulation Ratios for Natural Rubber Latex Foam Sheet Production

1.1 A Study of Formulation Ratios for Natural Rubber Latex Foam Sheet Production

A total of five latex foam formulations were prepared by varying the proportions of key chemical additives affecting the foaming and vulcanization processes, including sulfur and diphenyl guanidine (DPG), as well as the foaming time. The objective was to investigate their effects on the foam cell structure and mechanical properties of the resulting foam sheets. The preparation process of the natural rubber latex foam sheets was adapted from the methodology developed by the Rubber Technology Research Centre (RTEC).

Table 1 Formulations for Natural Rubber Latex Foam Sheet Production

Materials and Chemicals	Natural Rubber Latex 60% (g.)	Sulfur (g.)	DPG (g.)
1	250	15	20
2	250	10	20
3	250	20	20

Materials and Chemicals	Natural Rubber Latex 60% (g.)	Sulfur (g.)	DPG (g.)
4	250	15	18
5	250	15	22

1.2 Preparation of Materials for Natural Rubber Latex Foam Production

1. Each ingredient was weighed according to the formulation ratios specified in Table 1.
2. Natural rubber latex and chemical additives were prepared separately according to the designated formulations.

1.3 Preparation of Natural Rubber Latex Foam Sheets

1) Natural rubber latex was placed in a laboratory mixer and stirred at speed level 3 for 20 seconds to remove ammonia.

2) Potassium Oleate, Sulfur, ZMBT, ZDEC, and Wingstay-L were added sequentially.

3) The mixing speed was then increased to level 4 and continued for 30 seconds.

4) The speed was increased to level 5 and mixing continued for 2 minutes to generate foam.

5) After foaming, the mixing speed was reduced to level 3 and continued for 90 seconds to obtain a finer and more uniform foam structure.

6) ZnO, DPG, and SSF were subsequently added, and the mixture was stirred for an additional 30 seconds.

7) The latex foam was poured into an aluminum mold (14.00 g) and a glass Petri dish (13.50 g).

8) The foam was allowed to stand for 15 minutes and then cured in steam at 100°C for 40 minutes to stabilize the foam structure.

9) The cured foam sheets were removed from the molds and air-dried before being used for subsequent testing.

1.4 Physical Property Testing of Natural Rubber Latex Foam Sheets

1) Compression properties were evaluated using a compression test.

2) Resilience was determined using a Ball Rebound Tester.

3) Tensile properties were evaluated using a Tensile Strength Test.

2. Study of Formulation Ratios for Carbon Rubber Sheet Production

2.1 Production of Carbon Black from Coconut Shells

1) Mature coconut shells with good structural integrity were selected. Shells showing mold contamination or remaining outer husk were excluded. The selected shells were washed with clean water to remove dust and impurities, and then sun-dried for 1–2 days.

2) The dried shells were cut or crushed into small pieces (approximately 1–3 cm) and placed in a furnace. The furnace was tightly sealed to limit air exchange. The material was carbonized at 850°C for 2 hours.

3) After completion, the furnace was allowed to cool naturally without opening the lid. The resulting char was collected and ground into a fine powder.

4) The carbon powder was sieved through a 75-micron mesh screen and stored in a dry, sealed container for further use.

2.2 Preparation of Carbon Rubber Compounds

Carbon powder was mixed with natural rubber latex and chemical additives according to the formulations

Table 2 Formulations for Carbon Rubber Sheet Production

Materials and Chemicals	Natural Rubber Latex 60% (phr)	Coconut Shell Biochar (phr)
1	100	0
2	100	5
3	100	10
4	100	15
5	100	20

2.3 Carbon Rubber Sheet Forming Process

1) Chemicals and carbon black powder were weighed according to the formulations specified in Table 2

2) The materials were thoroughly mixed with natural rubber latex until a homogeneous mixture was obtained.

3) The mixture was then poured into molds.

4) The molded samples were cured at 120°C for 24 hours, following the method referenced from Patent Publication No. 17178.

5) The cured rubber sheets were demolded and prepared for further testing.

2.4 Testing of Carbon Rubber Sheet Properties

The tensile properties of the carbon rubber sheets were evaluated using a tensile strength test.

3. Study of Physical Properties of a Health-Oriented Shoe Insole Model

3.1 Fabrication of Shoe Insole Model

The materials used for the shoe insole structure were cut into square specimens with dimensions of 3 × 3 cm.

3.2 Assembly of the Shoe Insole Structure

1) A thin layer of rubber adhesive was applied, or a hot press machine was used, to bond the three layers together.

The multilayer structure consisted of:

Top layer: EVA foam

Middle layer: Natural rubber latex foam

Bottom layer: Carbon rubber sheet

2) The assembly was left to cure until the adhesive was fully set, or pressed using a hot press machine under appropriate time and pressure conditions.

3.3 Testing Procedures

1) Impact resistance was evaluated using a simple drop test.

2) Load distribution behavior was assessed using a simplified drop test method.

3) Compressive properties were evaluated using a tensile strength test.

Result and Discussion

1. Tensile Testing of Carbon Rubber Shock-Absorbing Sheets

The carbon rubber shock-absorbing sheets were molded into rectangular specimens with dimensions of 1 cm in width, 7 cm in length, and a thickness ranging from 5 to 6 cm.

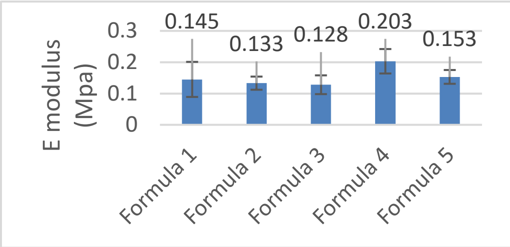

Fig. 1 Elastic Modulus (E) of Carbon Black Rubber Sheets (MPa)

2. Tensile Testing of Natural Rubber Latex Foam Using a Universal Testing Machine (UTM)

The natural rubber latex foam sheets were molded into rectangular specimens with dimensions of 1 cm in width, 7 cm in length, and 0.9–1.0 cm in thickness.

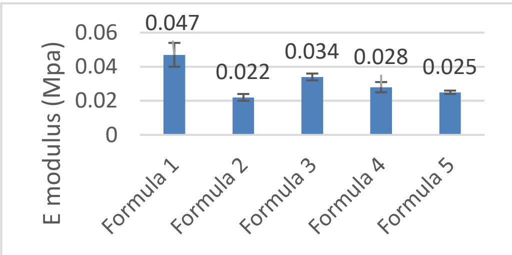

Fig. 2 Elastic Modulus (E) of Natural Rubber Latex Foam (MPa)

3. Compression testing of natural rubber latex foam using a Universal Testing Machine (UTM).

The natural rubber latex foam samples were molded into square specimens with dimensions of 3 × 3 cm and a thickness of 2.0 cm.

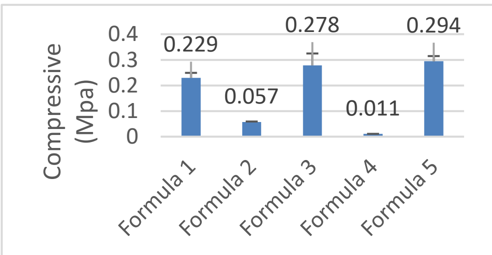

Fig. 2 Elastic Modulus (E) of Natural Rubber Latex Foam (MPa)

Conclusions

From the tensile testing of carbon rubber sheets, the results indicated that formulation 3 exhibited the best performance in terms of tensile strength and elongation behavior. During testing, this formulation withstood a higher tensile load before failure compared to the other formulations, indicating a stronger internal structure and improved interfacial bonding between natural rubber and carbon black. In addition, formulation 3 demonstrated a balanced elongation behavior without becoming brittle or easily fractured under continuous loading. This suggests that the material possesses an appropriate balance between toughness and elasticity. It is assumed that the carbon black content in formulation 3 is optimal, effectively reinforcing the rubber matrix without causing excessive stiffness or brittleness. In comparison, formulations with lower carbon black content exhibited lower mechanical strength, while those with excessive carbon black tended to become overly stiff and prone to fracture. Therefore, formulation 3 represents the best balance between strength and flexibility and is considered the most suitable formulation for further development in load-bearing or health-related applications.

For natural rubber latex foam, the mechanical properties including tensile strength, elongation, elastic modulus (E-modulus), compressive behavior, and impact resistance showed distinct differences among formulations. Overall, formulation 1 demonstrated the best overall performance, exhibiting a balanced combination of strength and flexibility.

It showed good tensile and compressive resistance, appropriate elastic recovery, and effective deformation control. Impact testing using a drop-weight method revealed that formulation 1 had the lowest average thickness change, indicating superior energy absorption capability. The carbon sheet marking pattern also showed a wide and uniform stress distribution without localized stress concentration, confirming efficient impact dispersion.

Formulations 2 and 5 exhibited high softness and high elongation, but lower structural strength, resulting in slightly reduced load distribution performance. Formulation 3 showed moderate properties in terms of strength, elasticity, and force distribution. Meanwhile, formulation 4 was the softest and exhibited significant deformation; although it could absorb impact energy, it showed poor deformation control and clear stress concentration areas.

Overall, formulation 1 was identified as the most suitable for applications requiring load support, impact absorption, and effective stress distribution.

When formulation 1 was further developed into a three-layer structure consisting of formulation 3 carbon rubber as the bottom layer, EVA foam as the middle layer, and formulation 1 latex foam as the top layer, the mechanical performance improved significantly. Drop-weight impact testing showed an average deformation of approximately 1.07 mm. Although this value indicates greater deformation compared to single-layer samples, it is considered beneficial in engineering terms, as it reflects enhanced energy absorption capacity. Furthermore, the system demonstrated good rebound behavior, with the impactor bouncing back to a relatively high position, indicating good elastic recovery and energy return. No permanent deformation or structural instability was observed, confirming the effectiveness of the multilayer structure in improving overall mechanical performance.

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