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Development of Outsole Materials for Sustainable Footwear Application

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Abstract

The present study investigates the development of sustainable outsole materials for eco-friendly footwear by replacing conventional petroleum-based materials with bio-derived alternatives derived from agro-waste, thereby reducing environmental impact. The work focused on formulating Bio-TPR outsoles using rice husk as a natural filler and castor oil as a bioplasticiser, thereby advancing waste-valorisation strategies that address both agricultural waste management and sustainable footwear manufacturing. The Bio-TPR outsole has been prepared by injection moulding and characterised, demonstrating mechanical, structural, and thermal properties comparable to those of standard TPR soles. The bioTPR soles showed improved hardness (shore A 61.5) and stable performance under accelerated ageing. The tensile strength was found to be 3.85 MPa, and strong slip resistance with a coefficient of friction of 0.4 at wet conditions. The abrasion resistance, density, finiteelement analysis, and thermogravimetric results also meet the standard norms. By addressing challenges such as waste valorisation, this study establishes the industrial feasibility of bio-based soles and highlights their potential to lower the use of synthetic materials and carbon emissions. The findings demonstrate that Bio-TPR soles represent a promising sustainable alternative that supports circular-economy principles and paves the way for the manufacture of environmentally friendly footwear soles.

Keywords: Waste valorisation; Sustainability; Biosoles; Rice husk.

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1. Introduction

Globally footwear industry produces an average of 23.9 billion pairs of shoes. (1) The growth rate of the footwear industry has been forecast at 5.9% in 2032. (2) A shoe consists of the upper, outsole, and shoe accessories as its main components, in which the outsole is made from various petroleum-based synthetic materials such as Polyurethane, Polyvinylchloride, micro cellular rubber, Ethylene vinyl acetate, Thermoplastic rubber, Thermoplastic polyurethane, Thermoplastic rubber which affects the sustainability in footwear manufacture. As an alternative, bio-based material is used for the outsole, with less environmental impact. Rice Husk is employed in various industrial applications and serves as a natural filler in the raw materials. The exploration of rice husk as a sole-making material has been less studied, and only 1015% of rice husk was reported in earlier days of sole manufacture. (3,4) In the footwear industry, rice husk from agricultural waste is used to achieve bio-based solemaking objectives, thereby reducing TPR granules and agricultural waste generated during the manufacturing process. (5) Rice Husk and castor oil are used in the manufacturing process, replacing petroleum-based fillers and lubricants, to achieve more than 25% effective biobased sole materials. Rice husk cellulose, silica and lignin components present in the husk, which are utilised for degreasing TPR raw materials. Bio-based sole material, where the most important gap is the standard requirement of outsole performance, and the outsole is made with BioBased outsole materials. There is novelty in making a biobased outsole, and rice husk is utilised in the manufacturing process. This research study has been focused in

developing outsoles from rice husk to meet the standard requirements and reduce reliance on petroleum-based polymers, thereby reducing costs in the production of biobased footwear soles.

2. Material and Methods

2.1. Preparation of TPR-Rice Husk Composites

Table1. Process flow on Bio-TPR composite preparation

2.3. Physical Characterization and Finite Element Analysis (FEA) Simulation

The Bio-based TPR sole was analysed for tensile strength and elongation at break, abrasion resistance, accelerated ageing, and slip resistance measurement. Testing was carried out in accordance with SATRA TM 137:2024 for tensile strength and SATRA TM 174:2016 for Abrasion strength using a drum abrasion Machine. (6,7) SATRA TM 144:2021 STM-603 SATRA slip resistance machine was used to analyse the coefficient of friction (COF) on different surfaces. (8) The effectiveness of the material in avoiding slipping can be measured. The samples were conditioned at a suitable temperature and relative humidity for 48 h before testing. (9) Finite element analysis recreation was carried out using the Simcenter 3D version

The TPR granules have been used for this study. Initially, the rice husk material obtained was dried to remove excess moisture, enabling the subsequent solemaking process. In a blending machine, TPR granules 60% (1800 g), rice husk powder 30% (900 g), and castor oil 10% (300 g), were mixed and used for further injection moulding process.

NASTRAN software. (10) The FEA simulation was used to computationally analyse the physical displacement of the sole under load, given the constant physical parameters fed to the software. (10)

3. Result and Discussion

This research focused on the development of a bio-based TPR sole combined with rice husk and castor oil using an injection moulding system. The sole samples were assessed using a series of physical parameter to compare the compatibility of the developed sole with the existing TPR soles.

3.1. Physical characteristics

The physical strength of the bio-based TPR sole has been tested. The tensile strength was recorded as 3.85 N/

mm2.The abrasion resistance of the experimental bio-sole exhibits a volume loss of 239.89 mm^3. The slip resistance of the experimental bio-based outsole was analyzed using the STM-603 SATRA slip resistance machine test, where the coefficient of friction of the bio-based TPR soles was 0.6 at forward flat slip, 0.55 at forward heel slip, 0.41 at forward heel slip, and 0.44 at forward flat slip. The overall physical strength characteristics recorded were comparable to those of conventional TPR sole materials.

3.2. Finite Element Analysis (FEA) Simulation

A 3D-CAD model was developed and imported into Simcenter, NASTRAN for FEA analysis. Subsequently, meshing was performed on the imported 3D sole model

Fig.1. FEA analysis for Bio-based TPR soles. 4. Conclusion

Bio-based composite materials are an innovative support for environmentally friendly sole manufacturing. Rice husk bio-based TPR sole achieves a sustainable, low-impact, environmentally friendly approach to waste in the circular economy. The present study focused on understanding the physical characteristics and confirming safety for its application in bio-based TPR sole materials to meet standard test requirements. This study has revealed that FEA simulation parameters can enhance the efficiency

using Simcenter software. The load and boundary conditions were provided for a standard simulation. The load is specified relative to the average person’s body weight (700 N). (10) As a boundary condition, it is assumed that the bottom surface of the sole material is fixed. The stimulation is performed by the software using a linear static solution, which provides the challenges of the model based on the small structural displacement, as depicted in Figure 1. The stimulation analysis revealed a displacement length of 0.0658 mm for the Bio-based TPR. The simulation results indicate that the bio-TPR sole materials exhibit better impact absorption, energy return, and structural flexibility, making them more suitable for use in certain sports footwear.

of sports-type footwear sole materials. The Bio-based TPR sole of the new outsole material is compared to the conventional outsole materials. Thus, Bio-based TPR has the potential to increase the sustainability and material characteristics of these composites.

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