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A STUDY ON INCREASEING RECYCLED RUBBER CONTENT IN SOLID TYRE TREAD COMPOUNDS BY INCORPORATING BALLOON AND FOAM RUBBER WASTE

U. U. C. D. Chandrasena[1*], D. T. D. Weerathunga[2] and J. C. Jayawarna[3]
[1,3] LAUGFS Corporation (Rubber) Ltd, Sri Lanka
[2]University of Sri Jayewardenepura, Sri Lanka
cdevinda025@gmail.com[1*], dhammikaweerathunga@sjp.ac.lk[2], janadara@laugfs.lk[3]

ABSTRACT: The solid tyre and latex industries face significant economic and environmental challenges due to their reliance on virgin rubber and waste materials. This study examines the integration of recycled latex balloon and foam rubber waste into solid tyre tread compounds. The aim is to formulate a compound that optimizes the use of recycled materials while adhering to the quality standards required for solid tyres. The experimental design included a control formulation (Test 1) comprising only natural rubber, and a test formulation (Test 2) incorporating natural rubber mixed with reclaimed balloon waste at a 70:30 ratio. Further tests (Tests 3-6) introduced varying proportions of latex foam waste, starting from 10 phr and increasing in 5 phr increments up to 25 phr, to the Test 2. (Virgin to Recycled ratio T3- 64:36, T4-60:40, T5-58:42, T6-56:44). Results reveal that incorporating recycled latex affects cure characteristics and physical properties. Specifically, increased recycled latex content reduces cure and scorch time while enhancing the cure rate. Torque properties relatively remain stable. The addition of recycled latex foam waste improves rebound resilience but results in decreased tensile strength, modulus, elongation at break, tear strength, and hardness. Notably, the aging performance in terms of hardness and modulus is comparable to virgin rubber, whereas elongation at break, tensile strength, and tear strength show improvements over the virgin compound. In conclusion, a formulation with 70:30 ratio of natural rubber to balloon waste and 20 phr of latex foam waste meets acceptable quality levels though it reduces modulus and tensile strength. This offers a viable, cost-effective alternative for sustainable solid tire tread compounds, addressing high raw material costs and supporting recycling and sustainability goals.

Keywords: balloon waste, foam waste, recycled latex, solid-tire tread, sustainability

1. INTRODUCTION

In 2020, major rubber consumers included China, the USA, and Japan, with Thailand as the top natural rubber producer. Sri Lanka emerged as a key exporter of solid tyres, while the USA led in imports (Rodrigo 2021). The rubber industry in Sri Lanka has seen a shift in recent years, with a notable increase in local utilization of natural raw rubber for value-added products. According to the 2021 annual review by the Rubber Research Institute of Sri Lanka, raw rubber exports slightly declined from 15,766 tons in 2020 to 15,490 tons in 2021, while export earnings rose from Rs. 5.6 billion to Rs. 8.3 billion. This growth rise in waste generation. Waste rubber management various strategies are employed to handle discarded rubber materials. These strategies include recycling, reusing, recovering energy, and landfilling (Markl and Lackner 2020). Among these options, the predominant approach to waste rubber management is energy recovery. Rather than disposing waste rubber in landfills, which can contribute to environmental concerns (Ali Shah et al. 2013). Recycling and reusing rubber waste are essential for sustainability and reducing environmental impact. This thesis aims to develop a solid tire tread compound using recycled latex balloon and foam waste while maintaining quality standards, promoting sustainable tire production in Sri Lanka by addressing waste disposal and raw material costs.

2. METHODOLOGY

Preparation of latex foam waste, latex balloon waste, and solid tire tread compound latex foam waste was air-dried to a constant weight and then milled using an XKP-560 two roll rubber shredder, followed grinding to achieve fine crumbs, which were separated into 30-mesh sizes. Latex balloon waste was reclaimed through a mechanical and chemical process using a two-roll mill at 60–70°C with a 1:1.25 friction ratio and a 100:1 ratio of balloon waste to IPPD. For the solid tire tread compound, natural rubber was mixed with reclaimed balloon waste and ground latex foam waste on a two-roll mill, with increasing amounts of foam waste (5 to 25 phr) added in successive tests to evaluate the effects on the compound.

The experimental design included a control formulation (Test 1) comprising only natural rubber, and a test formulation (Test 2) incorporating natural rubber mixed with reclaimed balloon waste at a 70:30 ratio, as established by Jayawarna (2015). Further tests (Tests 3-6) introduced varying proportions of latex foam waste, starting from 10 phr and increasing in 5 phr increments up to 25 phr, to the Test 2. (Virgin to Recycled ratio T3- 64:36, T4-60:40, T5-58:42, T6-56:44). Three compound samples were prepared for each formulation, followed by characterization of each sample.

Characterization

The cure characteristics of the compound were analysed using an Oscillating Disk Rheometer (ODR) EKT-100H, which provided data on scorch time (TS2), 90% cure time (TC90), minimum torque (ML), and maximum torque (MH). Hardness was measured using a Shore A durometer following ASTM D2240 standards to assess indentation resistance. Modulus, tensile strength, and elongation at break were tested with a Gotech tensile testing machine (GT-7010-AEP) per ASTM D412, while tear strength was evaluated per ASTM D624. The DIN abrasion test, per ASTM D5963, measured abrasion resistance, and rebound resilience was tested using the GTKB18 according to ASTM D7121. Glass transition temperature (Tg) was measured using a Dynamic Mechanical Analyzer (PerkinElmer DMA 8000), and swelling tests were performed using the equilibrium swelling method in accordance with ASTM D471 standards.

3. RESULTS AND DISCUSSION

Properties of tire tread compound

Cure characteristics

Minimum torque (ML), maximum torque (MH), and the torque difference indicate the stock's viscosity and processability. Increasing amounts of latex foam waste raised the ML, as the filler restricts molecular movement. min-max torque values remained stable, indicating consistent crosslink density (Chuan and Siang 2017; Ismail, Nordin, and Noor 2002; Jayawarna 2015). Treating latex foam as a filler. Scorch time (TS2) and cure time (TC90) decreased with increased latex foam, indicating that unreacted curatives migrate into the rubber chains, affecting sulphur curing (Formela and Haponiuk 2014; Kim et al. 2007). Despite reduced scorch safety and cure time, which benefits production throughput. The lowest scorch safety achieved was 200 seconds, aligning with industry standards. T1 and T2 show no significant change in cure rate index, while T3 to T6, with ground latex foam waste, display an increasing trend. This suggests unreacted accelerators in the foam speed up curing without increasing crosslink density.

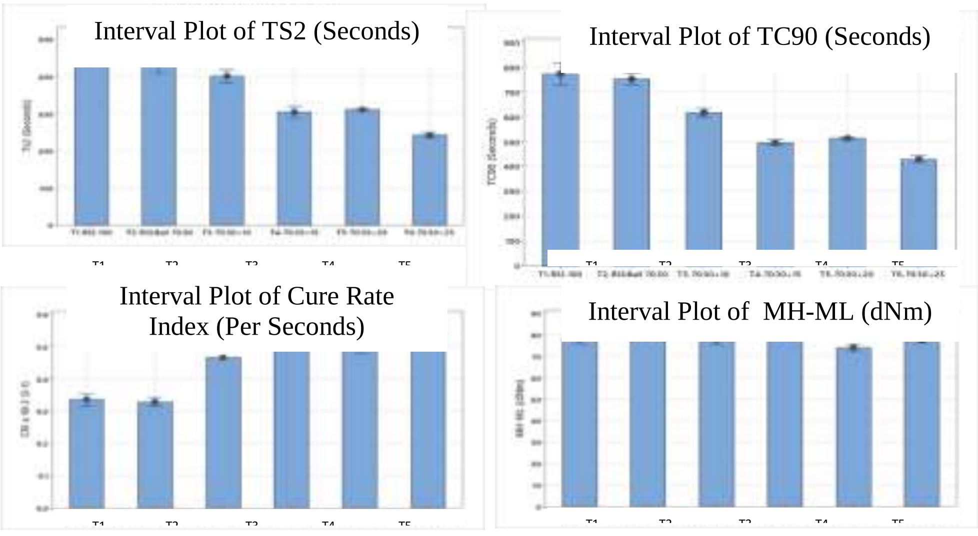

Fig. 1. Impact of Recycled Rubber Content on the Curing Characteristics of Solid Tire

Physico-mechanical properties

Evaluation of Tensile Strength, Tensile Modulus at 300% Elongation, Elongation at Break, and Tear Strength.

When compounded with ground latex foam waste, increasing foam content slightly reduces tensile strength due to weak bonding between foam particles and the natural rubber matrix, with agglomeration further weakening particle interactions (Fig. 2). Despite this, 90% of tensile strength is retained even with 25 phr foam (Ramarad et al. 2015; Sonnier et al. 2007; Sreeja and Kutty 2000). Modulus increases with reclaimed balloon waste (T2) but decreases as latex foam is added, reflecting reduced stiffness (Chuan and Siang 2017; Jayawarna 2015; Najib et al. 2011). Elongation at break and tear strength decrease with rising foam content, attributed to weak interfaces and crack propagation (Ismail et al. 2002), though tear strength stabilizes beyond a certain point (Chuan and Siang 2017), meeting industry standards for solid tire tread applications.

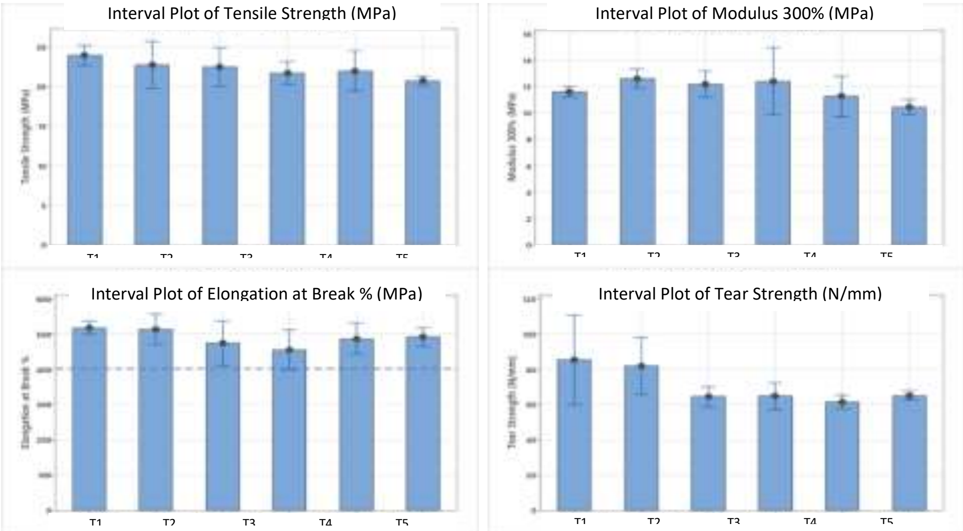

Fig. 2. Impact of Recycled Rubber Content on the Tensile Strength, Tensile Modulus at 300% Elongation, Elongation at Break, and Tear Strength.

Evaluation of Hardness, Rebound resilience, Abrasion resistance and Density:

The study examines the effects of adding reclaimed balloon waste and ground latex foam waste to solid tire tread compounds. Hardness increases slightly with the addition of reclaimed balloon waste (Chuan and Siang 2017; Jayawarna 2015) but decreases marginally with latex foam, remaining within acceptable industry standards and remained stable (Fig. 3). Rebound resilience improves by up to 6% due to the foam's microcellular structure (Dick 2014; Phiri et al. 2019), reducing energy loss and heat buildup. Abrasion resistance decreases with increased foam waste, though results remain acceptable for tire performance. The compound's density shows a slight increase with reclaimed balloon waste (Chuan and Siang 2017) but decreases as more ground latex foam is added due to its low-density properties.

Evaluation of Aging Properties, Measurement of swelling ratio & Glass transition temperature:

Aging properties of compounds are evaluated by measuring changes in hardness, tensile strength, elongation at break, and tear strength. The results indicate that hardness remains within a 6-8% range, with tensile strength retention being higher in compounds containing reclaimed balloon and latex foam waste compared to pure natural rubber (T1). Modulus variations do not exceed 40%, and elongation and tear strength improve across all test compounds. The swelling ratio remains consistent in T1 and T2 compounds, while T4 to T6 show an increase due to the foam's microcellular structure, which absorbs more toluene as foam waste content rises.

The crosslink density remains stable, with the increased swelling ratio resulting from the foam's absorption properties. The glass transition temperature (Tg), crucial for tire performance in cold conditions, shifts from a flexible to a brittle state, affecting traction. The Tg of the T6 compound (with maximum filler load) is measured at -44.2°C, compared to -64.5°C for T1, demonstrating the impact of ground latex foam. Understanding Tg is key for assessing low-temperature behaviour and tire safety.

4. CONCLUSION

In conclusion, grinded latex foam waste can be effectively incorporated with latex balloon waste to manufacture natural rubber solid tire tread compounds. While cure and scorch times decrease with higher recycled content, the cure rate slightly increase. Min-max torque values and hardness remained stable, rebound resilience improves, but tensile strength, modulus, elongation at break, tear strength decrease. Aging performance shows that hardness and modulus remain stable, while tensile strength, elongation at break, and tear strength surpass virgin compounds. A 70:30 ratio of natural rubber to balloon waste with 20 phr of latex foam waste is a sustainable, cost-effective solution for solid tire tread production.

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