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DEVELOPMENT OF FIRE-RESISTANT BEHAVIOUR IN NATURAL RUBBER FOAM VULCANIZATES USING SUSTAINABLE MATERIALS

D. T. J. Jayawardhana[1]*, A. D. Weerakoon[2], and S. G. J. Perera[3]
[1,2,3]Institute of Technology University of Moratuwa, Sri Lanka
tharindujayawardana999@gmail.com[1*], amalidhanu22@gmail.com[2], sudarshana79@gmail.com[3]

ABSTRACT: Fire safety is a critical consideration in foam-based applications, especially with the increasing demand for sustainable, non-toxic materials. This research explores the development of fire-resistant natural rubber foam by incorporating eco-friendly, sustainable materials. The study focuses on enhancing fire resistance while maintaining the foam's mechanical integrity and environmental compatibility. In preliminary experiments, varying concentrations of natural additives were integrated into natural rubber foam to assess their effect on fire resistance. Eggshell powder was identified as particularly effective, with optimised concentrations forming a protective tar layer that slows fire propagation. Further testing demonstrated that samples containing less than 20 parts per hundred rubber (pphr) of eggshell powder achieved optimal fire resistance, offering an effective barrier against ignition. In contrast, concentrations exceeding this threshold showed diminished efficacy due to material accumulation, highlighting the importance of optimal additive loading. This study's findings offer a promising approach for producing safer, more sustainable foam materials, with applications across industries where fire risk is a concern. By replacing conventional flame retardants with bio-based alternatives, this research presents an innovative pathway for enhancing fire safety while supporting green manufacturing. The implications for product safety, environmental sustainability, and cost-effectiveness position this work as a valuable contribution to the advancement of fire-resistant materials.

Keywords: eco-friendly innovation, fire resistance, fire safety, natural rubber foam, sustainable material

1. INTRODUCTION

Natural rubber is highly valued for its elasticity, resilience, and eco-friendly properties, which make it indispensable across industries. However, its flammability presents significant safety risks, especially in contexts where fire hazards are prevalent. Traditionally, chemical flame retardants have mitigated these risks, but they raise environmental and health concerns due to their toxicity and persistence in the environment (Pristine, 2024). As industries shift toward sustainable manufacturing, there is an increased demand for natural, non-toxic alternatives that enhance fire resistance without compromising ecological benefits (Matmake, 2024).

This study explores the potential of bio-based materials, specifically eggshell powder and rice husk silica, to improve fire resistance in natural rubber foam. Derived from agricultural waste, these materials offer promising advantages due to their availability, low cost, and inherent thermal resistance properties as shown in prior studies (Chana Prapruddivongs, 2020) . By analyzing the effects of these materials at different loadings, this research aims to develop an optimized natural rubber foam formulation with enhanced fire resistance, contributing to both product safety and environmental sustainability.

2. METHODOLOGY

2.1 Sample Preparation

Foam samples were prepared using eggshell powder and rice husk silica as fillers and also without any filler (Fig.1 & 2). The filler loadings varied from 1 to 10 parts per hundred rubber (pphr) for both fillers.

Fig. 1. Eggshell Powder added samples

Fig. 2. Rice Husk Silica added samples

2.2 Fire Propagation Testing

To evaluate the fire resistance properties of the natural rubber foam vulcanizates, testing was conducted following the ASTM E1353 standard, specifically for cigarette ignition resistance. This involved placing a smoldering cigarette on the test samples under controlled airflow conditions. According to the standard, to pass the test, any resulting char length must not exceed 2 inches (5.1 cm) from the original ignition point. (E1353)n our tests, the samples containing eggshell powder demonstrated successful performance by self-extinguishing without reaching or exceeding the specified char length, thus meeting the ASTM E1353 criteria. This was further validated through additional fire propagation tests, where 4-inch long, 1 cm² cross-sectional strips of each filler-loaded and control sample were created. The propagation time of fire along these strips confirmed that the eggshell powder-loaded samples exhibited the slowest fire spread, reinforcing their flame-retardant properties.

2.3 Further Experimentation

Based on initial results indicating fire resistance in eggshell powder-added samples, the research shifted focus to increasing the eggshell powder loading up to 25 pphr. No further experiments were conducted with rice husk silica at this stage. Observations noted the accumulation of eggshell powder at the bottom of samples with loadings above 20 pphr.

2.4 Testing of Optimized Samples

Fire tests were then conducted on the optimized samples with eggshell powder loadings below 20 pphr, as these were determined to be the most effective based on previous results. Significant findings included the formation of a protective tar layer in these samples, which effectively halted fire propagation.

3. RESULTS AND DISCUSSION

Egg shell and rice husk incorporated foam samples (Fig 3) exhibits difference in propagation time for ignition due to structural difference in two materials.

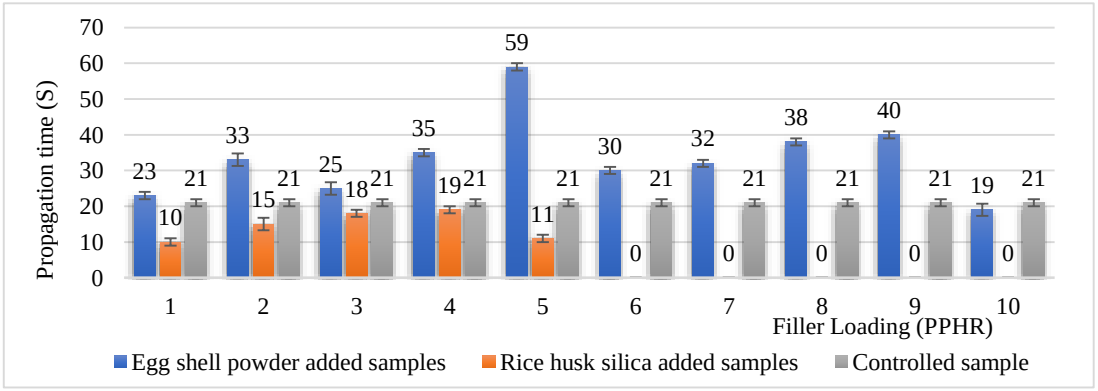

Fig. 3. Propagation time for ignition of eggshell and rice husk added foam rubber samples

The samples containing eggshell powder exhibited significantly better fire resistance than those with rice husk silica. This finding highlighted the effectiveness of eggshell powder as a natural flame retardant

The increase in eggshell powder loading beyond 10 pphr led to further improvements in fire resistance. The formation of a protective tar layer (Fig 4) was observed in samples with loadings below 20 pphr, which acted as a barrier to fire propagation

Fig. 4. Formation of a Protective Tar Layer

The accumulation of eggshell powder at higher loadings (above 20 pphr) suggests a potential limit to its effective incorporation in the foam matrix. This accumulation may hinder uniform distribution, which is crucial for optimizing fire resistance.
The findings emphasize the potential application of eggshell powder in the mattress and foam-related industries, offering a sustainable and effective solution for enhancing fire safety. The use of natural materials not only improves product safety but also reduces environmental impact, making it a viable alternative to conventional flame retardants.

4. CONCLUSION

This study demonstrates the successful enhancement of fire resistance in natural rubber foam vulcanizates through the incorporation of sustainable fillers, specifically eggshell powder. Experimental results revealed that samples containing eggshell powder exhibited significantly better fire resistance than those with rice husk silica, highlighting the superior effectiveness of eggshell powder as a natural flame retardant. A key discovery was that increasing the eggshell powder loading up to 25 parts per hundred rubber (pphr) led to the formation of a protective tar layer. This layer acted as a physical barrier, effectively halting fire propagation in samples with loadings below 20 pphr. The presence of calcium carbonate ($CaCO_3$) in eggshell powder plays a pivotal role in enhancing fire retardancy. Upon heating, calcium carbonate decomposes to release carbon dioxide (CO_2) gas, which cools the material and dilutes combustible gases, thereby reducing the risk of ignition. The residue left after decomposition further aids in creating an insulating barrier that limits heat transfer and sustains the structural integrity of the foam under high temperatures (Pondelak, 2021).

These findings underscore the potential of eggshell powder as a sustainable, cost-effective flame retardant, offering a viable alternative to conventional, chemical-based retardants. This innovation not only enhances the safety profile of rubber foam products but also aligns with the industry's shift toward eco-friendly manufacturing processes. By incorporating eggshell powder as a natural flame retardant, this research provides valuable insights into sustainable material design, contributing to safer and greener solutions for the mattress and foam industries.

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