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Research article

Flooring Material from Thermoplastic Elastomer Based on Natural Rubber and Recycled Plastic Waste

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Abstract: This study investigates the preparation of thermoplastic elastomer flooring materials using a blend of recycled polyethylene (Re-PE) and natural rubber (NR) through simple blending and dynamic vulcanization techniques. This study aims to provide a sustainable alternative to conventional flooring by converting plastic waste into thermoplastic elastomers (TPEs) with tailored properties suited for elderly safety. This research addresses the gap in designing flooring materials with high flexibility, shock absorption, and slip resistance, essential for fall prevention among the aging population. It was observed that the flowability of TPEs decreases as NR content increases. Thermal stability of TPEs exhibits two degradation stages: NR phase degrades at 380-400°C, and the plastic phase at 490-500°C. The degradation temperature increases with increasing plastic content. Mechanical properties of TPEs show that 100% modulus, tensile strength, impact strength, and hardness decrease as the proportion of NR increases. However, the elongation at break increases with increased NR content. Comparing the simple blending technique to dynamic vulcanization, the former yields higher impact strength while the latter results in higher values for the 100% modulus and tensile strength. The preparation of TPEs with a textured surface is obtained through the simple blending technique with a Re-PE/NR ratio of 25/75 due to its superior flowability, which allows for easier texturing. The material exhibits lower hardness and higher friction than other surfaces, reducing accident risk and injury severity. These findings highlight its potential as a practical alternative to conventional flooring, especially in elderly care where slip resistance and cushioning are critical.

Keywords: Flooring material; thermoplastic natural rubber; simple blending; dynamic vulcanization

1. Introduction

According to the United Nations (UN) report World Population Ageing 2020, Thailand faces a rapid demographic shift, with a significant increase in the elderly population. In 2020, older people accounted for 13% of Thailand's total population, which is predicted to rise to 20% by 2030 and 30% by 2050. Thailand is aging fast and has become the 2nd most aged society in ASEAN after Singapore. Currently, 20 percent of Thais are older than 60 years old. About one-third of the Thai population will be over 60 by 2030, a level not far behind what Japan is facing today [1]. As the aging population increases, so does the predominance of age-related challenges, one of the most critical of which is the risk of falling injuries. Falls among the elderly are a leading cause of severe injuries, including fractures and internal trauma, often resulting in reduced mobility, loss of independence, and significant healthcare costs. In this context, developing safer flooring materials tailored for older people becomes a critical area of focus. TPEs derived from plastic waste offer beneficial properties such as softness, elasticity, and slip resistance, which are directly linked to minimizing fall severity and enhancing safety in elderly environments. The severity of fall-related injuries is closely linked to the type of surface on which the falls occur. Hard surfaces can exacerbate the impact of a fall, leading to more severe injuries. In contrast, surfaces with a high coefficient of friction can help reduce the risk of slipping and falling altogether. Therefore, developing flooring materials from thermoplastic elastomers (TPEs) derived from recycled waste is a promising approach to address environmental concerns and improve surface safety simultaneously.

Plastic waste has become a significant and pressing environmental issue due to the convenience and fast-paced lifestyles that generate this waste. Plastic waste is causing major environmental impacts, especially when it ends up in oceans and water sources. Technologies and materials that can replace plastic, particularly thermoplastic elastomers, are very interesting. Thermoplastic elastomers are modern materials with favorable properties, and they have garnered significant attention in current research. The advantage of thermoplastic elastomers is their combination of strength and flexibility, like rubber, but they can be reshaped like plastics [2]. These materials can be recycled and reused, making them a potential solution to the plastic waste problem. Currently, a popular research focus is thermoplastic elastomers derived from blending rubber and plastic materials. This blending can be achieved using two main techniques: simple blending and dynamic vulcanization [3, 4]. The study explores blending various rubber materials, including natural rubber [5, 6], EPDM rubber [7-9], and nitrile rubber [10-12], with different plastic materials such as polyethylene [13-15] and polypropylene [16, 17]. These thermoplastic elastomers have gained popularity for their favorable properties, and their applications extend to various fields. One notable application is the production of flooring materials, particularly in environments where safety is paramount, such as facilities for the elderly or young children. For elderly flooring, properties such as moderate softness to absorb shock and a high coefficient of friction to reduce slips are especially critical. Thermoplastic elastomers offer several advantages over traditional materials like concrete or ceramic tiles. They are less susceptible to breaking, provide flexibility, and reduce the risk of injury in case of falls. Furthermore, these materials are environmentally friendly because they can be recycled and reused. This contributes to addressing the growing environmental issues associated with plastic waste. In summary, the research aims to recycle plastic waste into thermoplastic elastomers, offering a versatile and eco-friendly solution to the plastic waste problem, particularly in applications where safety and durability are essential.

2. Materials and Methods

2.1 Materials

Natural rubber (block rubbers STR 20) was used as a blend component, produced by the Rubber Authority of Thailand (RAOT) in Nakhon Si Thammarat province, Thailand. Two cure activators for sulfur vulcanization were used, including zinc oxide (ZnO) from Lanxess, Leverkusen, Germany, and stearic acid, manufactured by Unichema International B.V., Gouda, the Netherlands. Trimethylhydroquinoline (TMQ) was used as an antioxidant obtained from Shenyang Sunnyjoint Chemicals, China. N-Cyclohexyl-2-benzothiazole sulfenamide (CBS) was obtained from Lanxess, Leverkusen, Germany. Dibenzothiazyl disulfide (MBTS) was used as an accelerator obtained from Asia Pacific Specialty Chemicals Limited, Australia. Pergan GmbH, Bocholt, Germany, manufactures sulfur curing agents.

2.2 Preparation of thermoplastic elastomer

Various blending ratios are explored to examine the effects of different compositions, including 0/100, 25/75, 50/50, 75/25, and 100/0. These proportions were chosen to represent a full spectrum of rubber-to-plastic content, enabling mechanical and thermal behavior analysis at extreme and intermediate blend ratios. This allows the identification of an optimal formulation for flooring applications. Two blending methods are compared: simple blending and dynamic vulcanization. A schematic flowchart summarizing the two preparation processes is provided in Figure 1 to illustrate the key steps involved in each method. The study begins by preparing thermoplastic elastomers by blending natural rubber with plastic bottle waste (Re-PE). The first step for the dynamic vulcanization process involved preparing the rubber compound based on the formulation shown in Table 1. The compounding was done using a melt-mixing method in an internal mixer at a rotor speed of 60 rpm and a temperature of 60°C. The rubber was masticated for 3 minutes, followed by the sequential addition of compounding ingredients (ZnO, stearic acid, TMQ, CBS, MBTS, and sulfur), each mixed for 1 minute. The mixing process continued for an additional 2 minutes to ensure homogeneity. The resulting rubber compounds were then sheeted out using a two-roll mill and left at room temperature for at least 12 hours before further processing. Thermoplastic elastomers with various blend ratios were prepared. Before compounding, recycled polyethylene (PE) obtained from disposable plastic bottles was shredded into small pieces using a shredding machine. Thermoplastic elastomers were prepared in an internal mixer at 160°C with a rotor speed of 60 rpm. Initially, the PE was preheated in the mixing chamber without rotation for 5 minutes. It was then melted by mixing at 60 rpm for 2 minutes. Subsequently, either rubber compounds (for dynamic vulcanization) or natural rubber (for simple blending) were added to the molten PE, and the mixing was continued until the mixing torque reached a plateau, indicating the completion of blending. Finally, the blended materials were cut into small pieces. The test specimens were prepared using a compression molding machine.

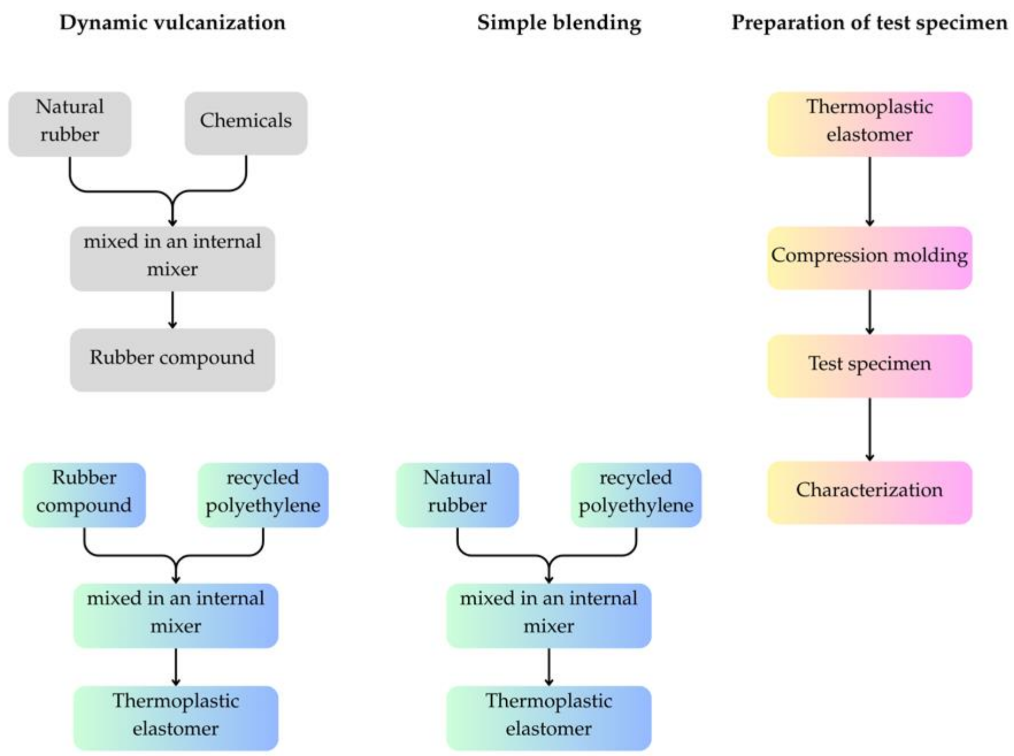


Figure 1. A schematic flowchart summarizing the two preparation processes and preparation of test specimens.

Table 1. Formulation of rubber compound.

Ingredients	Amount (phr)
Natural rubber	100
ZnO	5
Stearic acid	1
TMQ	1
CBS	1
MBTS	0.5
Sulfur	2.5

2.3 Characterization

The physical properties of thermoplastic natural rubber are studied to understand its behavior. This includes measuring hardness, tensile strength, elongation at break, 100% modulus, flow properties, and thermal decomposition using Thermogravimetric Analysis (TGA). All experimental results were analyzed using standard deviation and one-way ANOVA to determine statistical significance among formulations, with a confidence level of 95%. The tensile properties were characterized with a universal tensile testing machine (Testometric Co., Ltd.). All samples were conditioned at 25°C and 50% relative humidity for 48 hours before testing to minimize environmental variability. The samples of rubber vulcanizates were tested at room temperature according to ASTM D412 with an extension speed of 500 mm/min. The hardness of rubber vulcanizates was tested using a durometer Shore A (Rex Gauge Co., Ltd.) according to ASTM D2240, the impact resistance as per ISO180 standard by using a Zwick Roell impact tester, Germany, and the melt flow index as per ASTM D1238 standard by using a Zwick Roell Mflow, Germany. The TGA was performed using Perkin Elmer STA600 (New Shelton, USA). The samples were first placed in the platinum pan under a nitrogen atmosphere. The test was then performed with a heating rate of 10°C/min in the 30-600(C temperature range. The static friction coefficient was evaluated using the sliding angle friction method, following the ASTM D202. For elderly care flooring suitability, performance benchmarks were referenced against slip resistance values (>0.6) and Shore A hardness (<70 for comfort) as desirable for impact absorption, based on criteria outlined by Petdee et al. (2023) [18]. This method measures static friction, the force required to keep an object stationary. The specimens were mounted in this test with a sliding block featuring 3 mm of additional padding. The specimens were lifted at the incline angle of 1.5° ± 0.5° per second and held for 10 seconds. The inclination was stopped when the specimens began to move, and the angle was recorded to the nearest 0.5°. The static friction coefficient was calculated using the equation [18]: $\mu s = \tan \theta$ where μs was the coefficient of static friction, and θ was the angle of testing (degree).

3. Results and Discussion

3.1 Flow Properties

Figure 2 shows the flow properties of thermoplastic natural rubber material derived from blending NR with Re-PE at various proportions (Re-PE/NR: 100/0, 75/25, 50/50, and 25/75). The flow rate of thermoplastic natural rubber is compared between simple blending and dynamic vulcanization. It was observed that the flowability of thermoplastic natural rubber decreased as the proportion of natural rubber increased. This decline in flowability is attributed to the lower plastic phase content in natural rubber, which results from the decrease in the proportion of polyethylene (PE). Polyethylene exhibits better flow properties than natural rubber, which reduces the overall flowability of thermoplastic natural rubber as the proportion of polyethylene decreases. Quantitatively, for the simple blending method, the melt flow rate (MFR) decreased from approximately 1.8 g/10 min at a 100/0 Re-PE/NR ratio to 0.9 g/10 min at 25/75, indicating a substantial reduction in flowability as the natural rubber content increased. For the dynamic blends, MFR values were consistently lower across all compositions, which can be attributed to the formation of crosslinked rubber networks that restrict polymer melt flow. Thermoplastic natural rubber obtained through simple blending exhibited better flow properties than those derived from dynamic vulcanization. This is because the natural rubber remains in its raw rubber state in simple blending, while in dynamic vulcanization, the natural rubber phase becomes vulcanized. Therefore, thermoplastic natural rubber obtained through dynamic vulcanization exhibits lower flowability. Specifically, Sobrinho et al. (2024) [19] reported that SBR/PP blends typically exhibit MFI values around 4.2 g/10 min due to the non-melting behavior of SBR, which restricts the flowability of the PP matrix. Similarly, Tasdemir et al. (2010) [20] demonstrated that dynamically vulcanized EPDM/PP blends have MFI values ranging from 1.5 to 2.2 g/10 min depending on EPDM content and vulcanization level. In contrast, our Re-PE/NR blends showed MFI values between 1.80 and 0.90 g/10 min as NR content increased, indicating reduced flowability similar to traditional TPEs. Despite this limitation, the Re-PE/NR system provides notable environmental benefits by incorporating recycled polyethylene and bio-based natural rubber. These advantages offer a sustainable alternative to petrochemical-based TPEs while still delivering essential mechanical and functional properties for applications such as slip-resistant flooring. Notably, when the proportion of natural rubber exceeds 50%, those derived from dynamic vulcanization cannot be tested for flow properties. This is because the dispersed rubber phase, which increases with a higher proportion of natural rubber, obstructs the polymer flow [21]. Even at elevated temperatures, rubber, a thermoset, cannot flow.

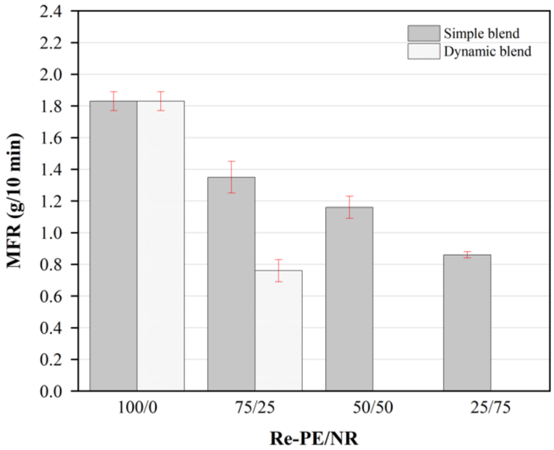


Figure 2. The flow rate of thermoplastic natural rubber at various Re-PE/NR ratios was prepared using simple blending and dynamic vulcanization methods.

3.2 Thermogravimetric Analysis

As shown in Figure 3, the thermal gravimetric analysis (TGA) results reveal that thermoplastic natural rubber undergoes a two-stage decomposition process at different temperature ranges. The first stage occurs at 380-400°C), representing the natural rubber phase decomposition. The second stage takes place around 490-500°C and corresponds to the decomposition of the plastic phase. Re-PE contributes to improved thermal stability due to its higher decomposition temperature and semi-crystalline structure, which resists breakdown at elevated temperatures. The increased presence of Re-PE in the blend delays the onset of mass loss, indicating that the plastic phase plays a crucial role in sustaining the structural integrity of the composite under thermal conditions. Notably, thermoplastic natural rubber elastomers obtained through dynamic vulcanization demonstrate higher thermal stability than those derived from simple blending. The remaining portion of thermoplastic natural rubber obtained from the dynamic vulcanization process exhibits higher residual mass than the simple blending technique. This residual mass primarily consists of inorganic compounds such as sulfur and zinc oxide, in addition to chemical components used in the vulcanization recipe specific to the rubber phase of the dynamic vulcanization system. Thermoplastic elastomer prepared via dynamic vulcanization exhibited higher residual mass, suggesting improved thermal stability due to the vulcanized rubber phase and crosslinking agents. This is because vulcanized rubber forms a stable crosslinked network that resists thermal decomposition better than unvulcanized rubber. This enhanced thermal stability makes dynamically vulcanized composites suitable for applications exposed to high temperatures.

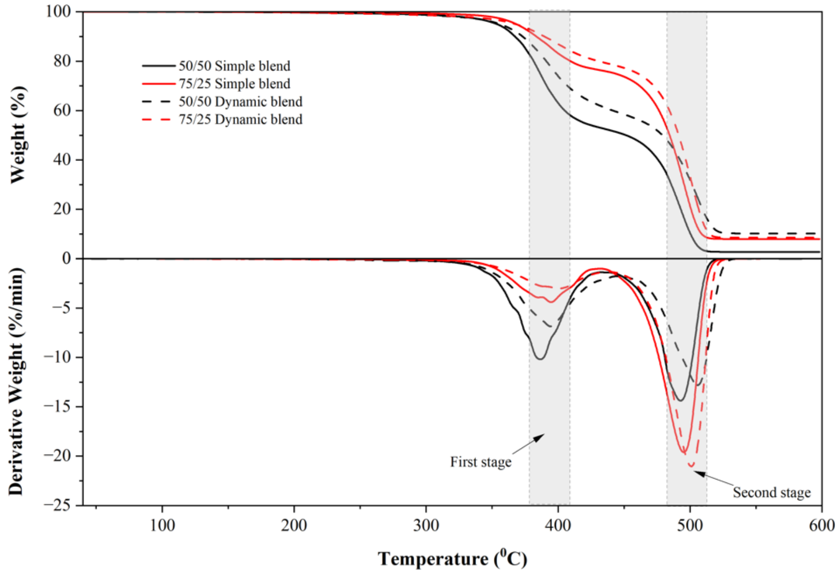


Figure 3. TGA curve of thermoplastic natural rubber at various Re-PE/NR ratios prepared using simple blending and dynamic vulcanization methods.

3.3 Mechanical Properties

The mechanical properties, including 100% modulus, tensile strength, elongation at break, and hardness, are presented in Figures 4–7, respectively. In Figure 4, it was found that the 100% modulus decreases when the proportion of natural rubber increases. It should be noted that for the 100/0 composition, the modulus was not measurable due to the extremely low flexibility and early break of specimens. This happens because the 100% modulus is influenced by the plastic continuous phase, which is stiffer than the rubber phase. At Re-PE/NR ratios of 100/0 and 75/25, the 100% modulus could not be measured due to the high plastic content, which leads to low elongation. The high hardness of Re-PE reduces flexibility, causing the test specimens to break before achieving the specified stretch, as shown in Figure 6. The elongation at break increases sharply as the proportion of natural rubber increases from 75/25 to 50/50. It increases from approximately 10% to 450%, indicating a significant increase in material elasticity. However, at 25/75, the elongation decreases slightly compared to 50/50 due to poor rubber-plastic interaction and insufficient plastic matrix for deformation. The tensile strength of thermoplastic natural rubber material is shown in Figure 5. The dynamic vulcanization process enhances the tensile strength due to the formation of crosslinked structures, whereas simple blending results in lower strength but better elongation. The plastic phase exhibits higher strength compared to the rubber phase. Several studies have indicated that higher plastic phase content improves tensile strength [22]. Then, thermoplastic natural rubber materials with a higher plastic content demonstrate increased tensile strength as the proportion of plastic increases. The mechanical properties observed in this study are consistent with previous research on PP/rubber blends. For instance, Bendjaouhdou and Bensaad (2013) [23] reported that adding 10 wt% NR to PP decreased tensile strength from 29.5 MPa to 22.1 MPa, while elongation at break increased from 6% to 20%, indicating enhanced ductility. Similarly, Kakroodi et al. (2012) [24] found that incorporating SBR into recycled PP reduced tensile strength due to interfacial incompatibility, although compatibilizer use improved it by 30%. Furthermore, Scagliusi et al. (2021) [25] noted that increasing EPDM content in PP/EPDM blends led to lower tensile strength but higher elongation. These trends align with our findings, validating the mechanical behavior of Re-PE/NR blends.

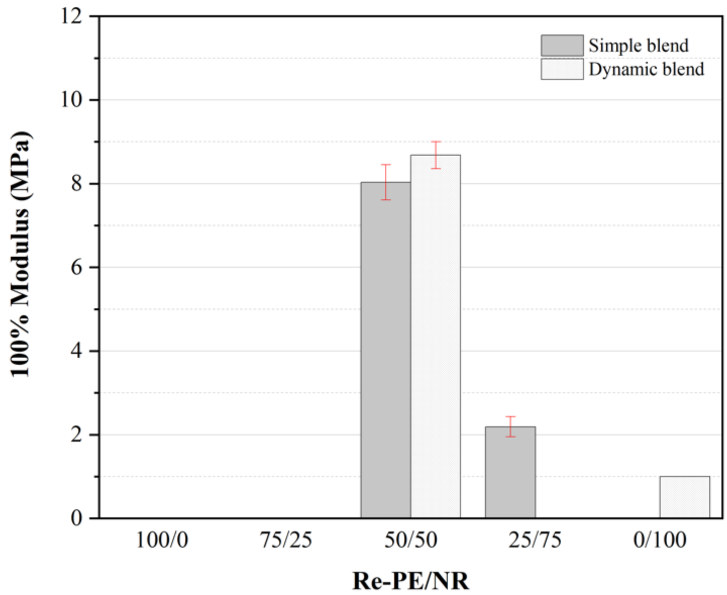


Figure 4. 100% modulus of thermoplastic natural rubber at various Re-PE/NR ratios prepared using simple blending and dynamic vulcanization methods.

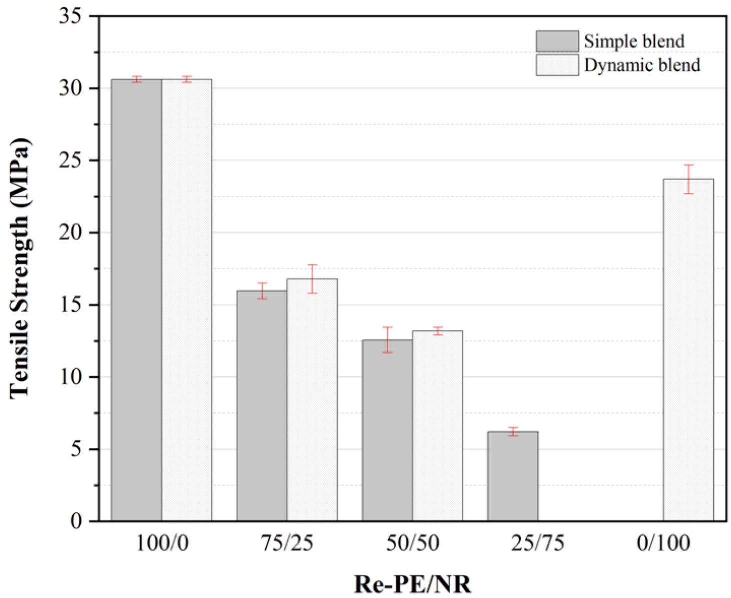


Figure 5. Tensile strength of thermoplastic natural rubber at various Re-PE/NR ratios prepared using simple blending and dynamic vulcanization methods.

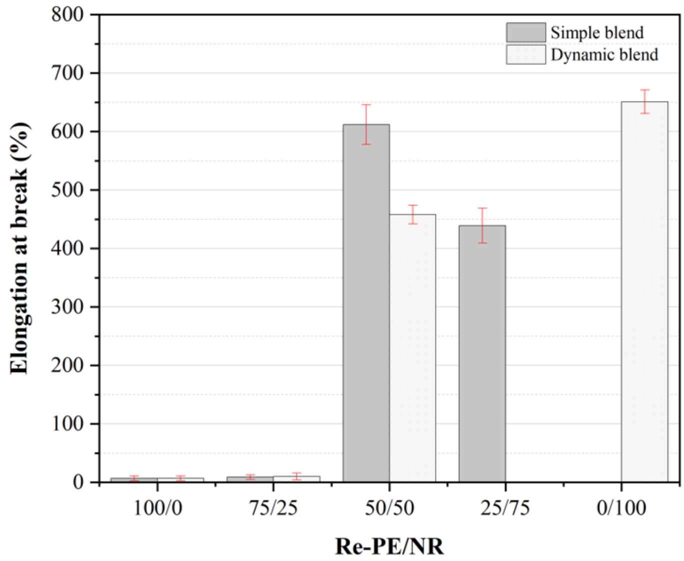


Figure 6. Elongation at break of thermoplastic natural rubber at various Re-PE/NR ratios prepared using simple blending and dynamic vulcanization methods.

Figure 7 shows that at Re-PE/NR ratios of 100/0,75/25, and 50/50, the hardness values are relatively similar, measuring around 99 Shore A. This similarity is attributed to the influence of the plastic phase on the material's properties. Figure 8 shows the impact strength properties of thermoplastic natural rubber, comparing the simple blending and dynamic vulcanization methods. It is found that the impact strength decreases with an increase in the proportion of natural rubber. It is worth noting that polyethylene is known for its excellent impact resistance properties [26]. Therefore, the impact strength depends on the material's hardness, and the values obtained correlate with the hardness values, as seen in Figure 7. In the tested samples, no signs of sample breakage occurred after testing. Thus, the test results are influenced by the decrease in hardness when the proportion of natural rubber increases.

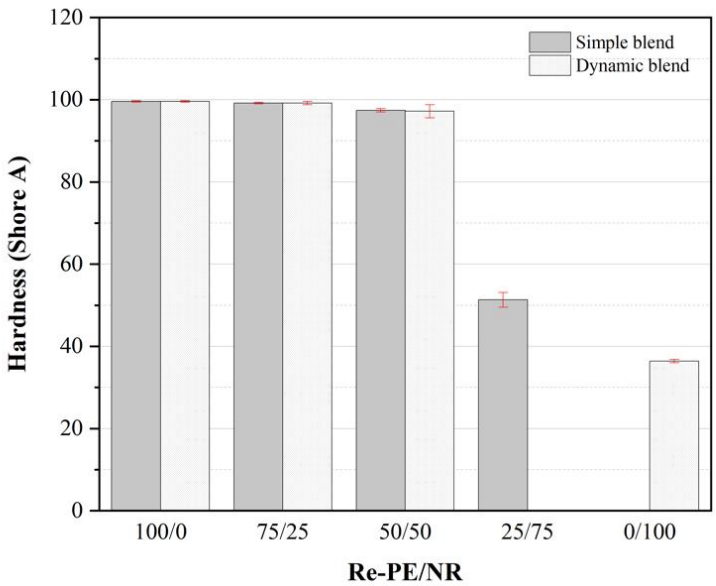


Figure 7. The hardness of thermoplastic natural rubber at various Re-PE/NR ratios prepared using simple blending and dynamic vulcanization methods.

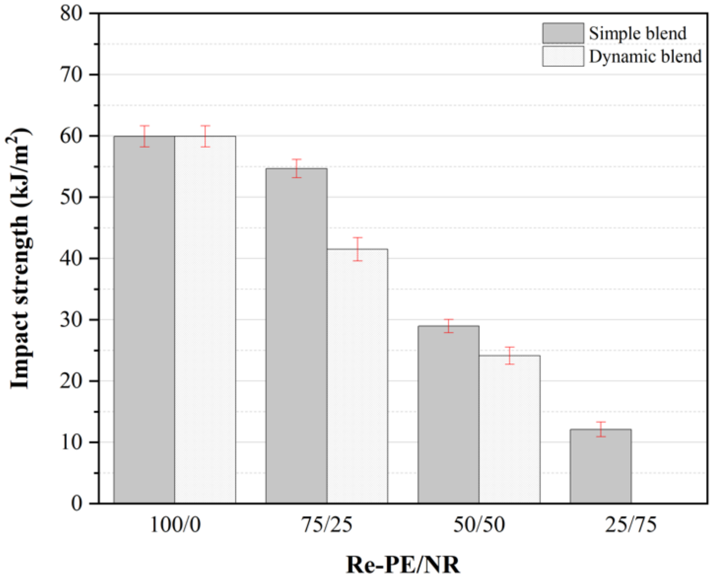


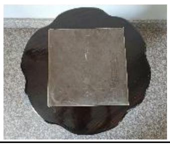
Figure 8. Impact strength of thermoplastic natural rubber at various Re-PE/NR ratios prepared using simple blending and dynamic vulcanization methods.

3.4 Floor Molding

The experimental results indicated that thermoplastic natural rubber, in its simple blending form, is easier to mold into floor tiles than the dynamic vulcanization method. Simple blending can be molded easily in all proportions, although molding becomes more challenging as the proportion of natural rubber increases. In contrast, thermoplastic natural rubber produced through dynamic vulcanization can only be successfully molded at a 50/50 Re-PE/NR ratio, which aligns with its flowability properties shown in Figure 2. Consequently, for molding floor tiles, a decision was made to use the 50/50 and 25/75 blends from simple blending and the 50/50 blend from dynamic blending, as they were easier to mold. Table 2 shows the potential of Re-PE/NR thermoplastic elastomer as flooring materials compared to commercial flooring options (i.e., para-wood, ceramic, and granite). The hardness of Re-PE/NR dynamic blending at a 50/50 ratio is 97.2 ± 1.6 shore A, close to the hardness of ceramic and granite flooring materials, measuring 100 Shore A. In contrast, the simple blending at a 25/75 Re-PE/NR ratio displayed a significantly lower hardness of 51.3 ± 1.8. This reduced hardness enhances flexibility, making the material suitable for applications that require softer surfaces, such as flooring for elderly care facilities, where minimizing fall impact is critical. These findings are consistent with previous work by Petdee et al. (2023) [18], who optimized stair tread covers from natural rubber and wood sawdust composites and reported high slip resistance (friction coefficient ~0.63). These characteristics were validated against safety expectations for stair surfaces in elderly care environments. Therefore, this study's Re-PE/NR composites meet the safety-related material performance benchmarks for elderly flooring systems. These findings align with previous research that indicates increasing the proportion of rubber enhances flexibility while reducing hardness due to the inherent elasticity of NR [27]. As a result, the material exhibited higher flowability and softness, which facilitated molding into flooring tiles. However, the lack of vulcanization also reduced mechanical strength and hardness. This characteristic makes the unvulcanized NR blend suitable for applications that require flexibility and shock absorption, such as flooring in elderly care facilities.

The static friction coefficient indicates the slip resistance, which is important for determining surface safety. The simple blend with a 25/75 ratio exhibited the highest static friction coefficient (0.68) when compared to conventional materials such as para-wood (0.51) and ceramic (0.52). In contrast, the dynamic blend with a 50/50 ratio showed a lower slip resistance of 0.25, comparable to granite (0.33). Therefore, slip resistance is limited. The thermoplastic elastomer has a lower friction coefficient, which may result from smoother surface finishes and reduced elasticity in composites with higher plastic content.

Table 2. Comparison of the developed floor tiles with commercial materials.

Properties	Para-wood	ceramic	granite	Simple blend Re-PE/NR:25/75	Simple blend Re-PE/NR:50/50	Dynamic blend Re-PE/NR:50/50
Hardness (shore A)	100	100	100	51.3 ± 1.8	97.4 ± 0.4	97.2 ± 1.6
θ(degree)	27.17 ± 0.79	27.25 ± 0.54	18.42 ± 0.63	34.38 ± 1.10	18.10 ± 0.33	14.24 ± 0.48
Static Friction Coefficient (μ_s)	0.51	0.52	0.33	0.68	0.33	0.25
Physical appearance						

4. Conclusions

The flowability properties of thermoplastic natural rubber show that the flowability of the material decreases as the natural rubber increases. When comparing simple blending with dynamic vulcanization, dynamic vulcanization blending results in lower flowability properties than materials obtained from simple blending. Flowability properties are indicated by the material's ability to undergo deformation. Therefore, thermoplastic elastomers of natural rubber prepared from simple blending exhibit easier deformability than those prepared from dynamic vulcanization. The decomposition temperature, 100% modulus, tensile strength, hardness, and impact strength of thermoplastic natural rubber decrease as the content of natural rubber increases. While the elongation at break increases with the increasing content of natural rubber. Dynamic vulcanization blending provides materials with a higher 100% modulus and tensile strength than simple blending, indicating superior mechanical properties. However, the ability to stretch, which reflects material flexibility, is higher in simple blending. In this study, the thermoplastic elastomer was prepared by simple blending, and a Re-PE/NR ratio of 25/75 was found to be the most suitable flooring material. It has excellent processability and a high coefficient of friction. Additionally, its significantly lower hardness helps minimize the severity of injuries in the event of an accident. The results of this study are supported by previous research, including Petdee et al. (2023) [18], who reported that natural rubber-based stair tread composites exhibited impact force resistance and slip resistance, consistent with our Re-PE/NR materials. Quantitatively, the Re-PE/NR blends showed MFI between 0.90–1.8 g/10 min, elongation at break reaching 450%, and coefficient of friction up to 0.63, indicating good processability, mechanical flexibility, and slip prevention. These properties align with standards for elderly flooring, where high friction and soft underfoot cushioning are essential for preventing slips and absorbing impact. The improved tensile strength and modulus in dynamically vulcanized blends are attributed to the crosslinked network formed during vulcanization, which enhances the load-bearing capacity. In contrast, lower hardness values in simple blends offer better shock absorption, which can help mitigate fall-related injuries. This is particularly beneficial in elderly care facilities, where material compliance reduces the impact force transferred to the body upon accidental falls. These insights support the application of Re-PE/NR composites as sustainable and safe flooring materials.

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