Reducing Energy Footprint and Enhancing Profitability: The Role of EPDM Rubber Scrap in Sustainable Manufacturing

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Abstract: ***This study presents an innovative approach to sustainability and profitability in the rubber compounding industry by repurposing waste materials from Ethylene Propylene Diene (EPDM) profiles and weatherstrips. These materials, traditionally considered industrial waste, are integrated up to 30-40% into rubber compounding processes, producing high-quality products like car mats, scooter mats, household mats, and more. One notable application is the use of these waste rubber in children's playgrounds, where it serves as soft flooring, providing safety through its shock-absorbing properties and being non-toxic. This application not only enhances child safety but also contributes to sustainability by reusing waste materials. This methodology also addresses critical challenges such as energy efficiency, waste management, and carbon footprint reduction. By eliminating energy-intensive steps in traditional rubber compounding, energy consumption and emissions are significantly reduced, supporting global sustainability goals. The approach offers substantial economic benefits, with industries realizing a 20-30% increase in profit margins without compromising product quality. This study underscores the potential of circular economy practices to transform waste into valuable resources, fostering both environmental stewardship and financial gains. It provides a compelling case for industries to adopt similar practices, paving the way for a sustainable and economically resilient future, while setting a benchmark for environmental and economic synergy in the rubber industry.***

Keywords: EPDM waste utilization, Sustainable rubber compounding, Circular economy, Carbon footprint reduction, Industrial waste management

1. Introduction

Ethylene Propylene Diene rubber (EPDM) rubber is widely used in automotive, construction, and industrial applications, primarily in weather stripping due to its excellent resistance to environmental factors such as ozone, UV radiation, and extreme temperatures. Other advantageous properties of EPDM include its low density, high filler compatibility, and ability to incorporate process oils, which contribute to cost-effective compounding. EPDM (ethylene propylene diene rubber) is the third most widely produced synthetic rubber (SR) globally, following styrene butadiene rubber (SBR) and butyl rubber (BR). It accounts for approximately 12% of global SR production and 17% of production in Europe[1], [2]. EPDM (ethylene propylene diene rubber) was initially introduced in the USA in 1962, with commercial production commencing in 1963. Since then, EPDM has emerged as the fastest-growing general-purpose elastomer. In automobiles, approximately two-thirds of the total rubber content is utilized in tyres. The remaining rubber components include gaskets, sealing materials, hoses, vibration isolators, and plugs, with EPDM accounting for 25-50% of these non-tyre rubber parts[3]. Additionally, EPDM is extensively used in roofing applications. Consequently, a significant amount of EPDM-based waste is generated daily. According to an estimate conducted in 2006 by the Fraunhofer Institute for Environmental, Safety, and Energy Technology (UMSICHT) in Germany, the annual waste rubber generation was approximately 125,000 tons, accounting for around 14% of the total raw material used. In certain cases, depending on the production process, this percentage can rise to as high as 50% of the raw material consumed[4].

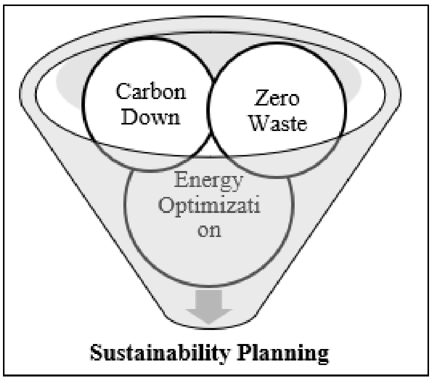

Figure 1: Goals of Sustainability

Conventional methods of reusing these industrial wastes, such as devulcanization, involve energy-intensive and complex processes, including thermomechanical devulcanization, microwave treatment, ultrasonic methods, and biological approaches[5], [6], [7], [8]. While effective, these methods often conflict with the goals of energy efficiency and economic viability. In contrast, the mechanical crushing of waste rubber and its subsequent incorporation into fresh rubber compounds during the mixing stage offers a simpler, more energy-efficient alternative. This method minimizes processing complexity and reduces energy consumption, making it a highly attractive solution for industries aiming to align with environmental and economic objectives.

2. Materials and Methods

2.1 EPDM Waste Processing and Crumb Rubber Production

In the Figure 2 it is shown how EPDM scrap materials, such as off-spec products, trimming wastes, and production residues, were collected directly from manufacturing lines. The collected waste was inspected and sorted to remove any contaminants, such as metal or fabric reinforcements, ensuring the purity of the EPDM material before processing. The sorted EPDM waste was shredded into smaller pieces to facilitate further processing. Industrial shredders were used to ensure consistent particle sizes. The shredded material was processed into crumb rubber using high capacity grinding machines. The final crumb size ranged from 20 to 50 mesh, tailored for compatibility with various formulations. The crumb rubber was passed through sieves to ensure uniform particle size. Any oversized particles were reprocessed to maintain quality standards. Crumb rubber was blended with virgin EPDM rubber compounds in varying proportions (30-40% by weight) depending on the specific application. The blending process was conducted in controlled environments to ensure uniform distribution. Necessary additives, such as curing agents, fillers, and stabilizers, were introduced during the mixing process to optimize the performance of the final product. Specific attention was given to maintaining temperature and shear conditions to prevent degradation of the material.

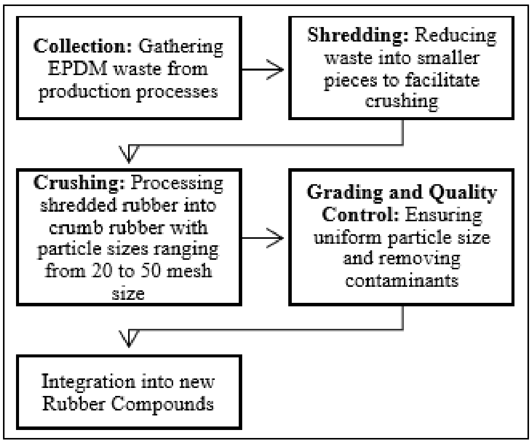

Figure 2: Schematic pathway of EPDM waste processing

2.2 Rubber Compounding Process:

In the rubber compounding process shown in Figure 3, the use of virgin rubber typically involves several energy-intensive steps, including the use of an internal mixer to blend the virgin rubber with other ingredients, a blending mill to thoroughly mix the materials, and a two-roll mill for final homogenization, each contributing significantly to the overall energy consumption. In contrast, when using crumb rubber, these steps are largely eliminated. Crumb rubber can be directly integrated into the compound by a two-roll mill, bypassing the need for an internal mixer, or blending mill resulting in a significant reduction in energy usage. This streamlined process not only enhances efficiency but also offers substantial energy savings compared to traditional virgin rubber processing. The prepared rubber compound was then shaped into desired products using molding techniques.

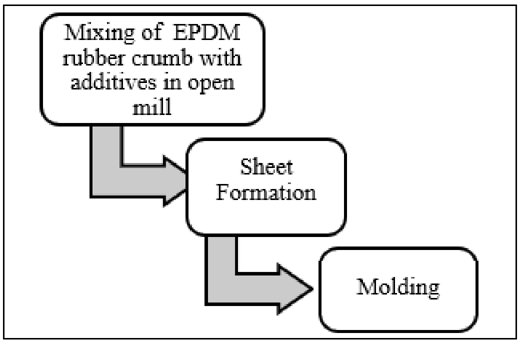

Figure 3: Schematic process of rubber compounding

2.3 Soft Flooring making process

In the process of manufacturing soft flooring for children's playgrounds using crumb rubber shown in Figure 4, these crumb rubber particles are mixed with a binding agent, typically a polyurethane (PU) or other eco-friendly resin, to form a durable, cohesive layer. The mixture is then laid out on designated playground areas and pressurized to form an underlying cushioning layer.

This layer provides a shock-absorbing surface, significantly reducing the impact of falls and ensuring child safety. The rubber's non-toxic nature further enhances its suitability for playground environments, as it poses no harm to children in the event of direct contact. The result is a resilient, eco-friendly flooring solution that not only promotes safety but also contributes to sustainability by reusing industrial waste materials. This method offers a cost-effective and environmentally responsible alternative to traditional playground flooring options while meeting safety standards and providing long-lasting performance.

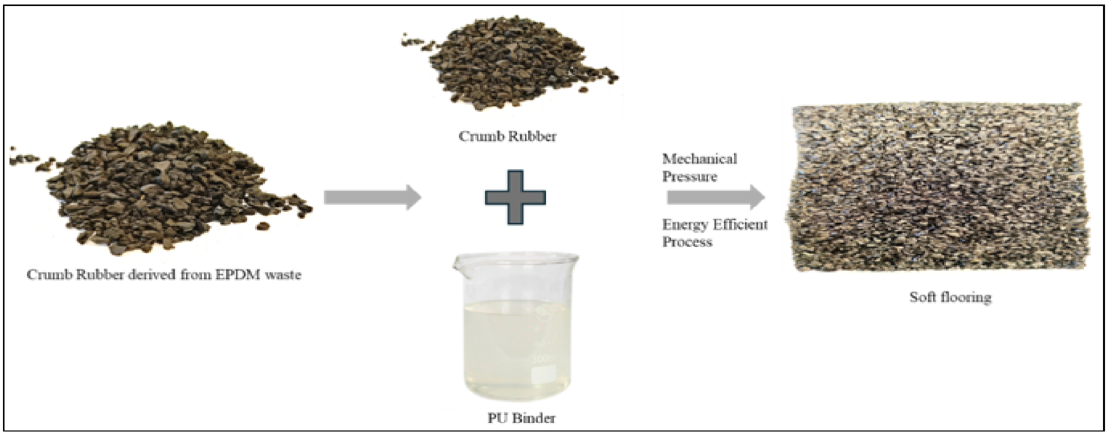

Figure 4: Schematic presentation of making soft flooring with crumb rubber and binder in lab

3. Results and Discussion

3.1 Environmental Benefits: Waste Reduction

By recycling our EPDM waste, we can prevent approximately 200 tons of waste annually from being sent to landfills. If similar practices were adopted globally, a significant reduction in rubber waste could be achieved, mitigating environmental pollution and conserving landfill space.

3.2 Energy Consumption Comparison

The energy required to process virgin EPDM rubber is significantly higher than that for recycled crumb rubber due to energy-intensive polymerization and raw material extraction processes. Virgin rubber processing involves multiple stages such as polymerization, purification, and extensive compounding that utilize high-capacity mixers, two-roll mills, and other processing equipment as per product description, consuming substantial energy. By contrast, recycled crumb rubber bypasses the polymerization process and requires simpler processing steps, including shredding and grinding, which consume comparatively less energy. For example, during rubber compounding, virgin rubber requires an internal mixer followed by a blending mill and a two-roll mill, whereas crumb rubber can integrate directly into the compound in a two-roll mill, eliminating certain steps and saving energy. Breaking down energy consumption further: shredding and grinding in the recycling process consume approximately 1 MJ/kg each, whereas polymerization alone in virgin rubber production accounts for 6 MJ/kg.

Table 1: Comparison data of energy consumption during manufacturing of virgin rubber and crumb rubber

Description	Virgin Rubber (per 100 kg)	Recycled Crumb Rubber (30-40% replacement)
Energy consumption in polymerization (virgin)	600 MJ/kg (for 100 kg)	-
Energy consumption for shredding and grinding	1 MJ/kg × 100 kg = 100 MJ	1 MJ/kg × 30-40 kg = 30-40 MJ (extra energy used)
Energy saving from reduced polymerization (30-40% replacement)	-	180 - 240 MJ (30-40% of 600 MJ)
Total energy saving by using crumb rubber	-	150 - 200 MJ/kg
Percentage energy saving	-	25 - 30%

Table 2: Comparison data of energy consumption during processing of virgin rubber and Crumb rubber

Energy Consumption Category	Virgin Rubber (per 100 kg)	Crumb Rubber (per 100 kg)	Energy Savings (per 100 kg)
Total Energy Consumption	350 MJ	200-220 MJ	130-150 MJ (37%-43% reduction)
Energy Saving (%)	-	-	37% - 43%

For example, if we use 100 kg of virgin EPDM rubber in compounding, the total energy required during polymerization of 100 kg virgin EPDM rubber is 600 MJ. If 30-40% of virgin rubber is replaced by recycled crumb rubber, the polymerization energy savings range between 180 to 240 MJ (30-40% of 600 MJ). The additional energy required for shredding and grinding the recycled crumb rubber is 30-40 MJ. Therefore, the net energy saving by using recycled crumb rubber is approximately 150 to 200 MJ per 100 kg of compound, which translates to an energy saving of about 25-30% (Table 1). Again, the energy consumption comparison between virgin rubber compounding and crumb rubber compounding

Table 3: Comparison data of energy saving during processing of 100 kg virgin rubber and crumb rubber

Process Step	Virgin Rubber (per 100 kg)	Crumb Rubber (per 100 kg)
Internal Mixer	200 MJ/kg	- (Not required)
Blending Mill	50 MJ/kg	- (Not required)
Two-Roll Mill	100 MJ/kg	100 MJ/kg
Shredding and grinding	-	100-120 MJ (for preparing crumb rubber)
Total Energy Consumption	350 MJ (for 100 kg)	200-220 MJ (for 100 kg)

processes highlight significant efficiency gains in rubber compound production. The virgin rubber process, involving energy-intensive steps like internal mixing (200 MJ), blending (50 MJ), and two-roll milling (100 MJ), consumes a total of 350 MJ per 100 kg of compound. In contrast, the crumb rubber process eliminates internal mixing and blending, reducing energy requirements substantially. While it introduces shredding and grinding (100–120 MJ), the two-roll milling step is less energy-intensive (30–40 MJ), resulting in a total consumption of just 130–150 MJ per 100 kg (Table 2). This represents a 37–43% reduction in energy use, emphasizing the environmental and economic advantages of adopting crumb rubber in sustainable manufacturing practices. Recycling EPDM scrap into crumb rubber reduces energy consumption by approximately 42–47%, shown in Figure 5 offering a highly energy-efficient alternative to traditional rubber processing methods. This significant reduction highlights its potential as a sustainable solution in the rubber industry.

Table 4: Comparison data of Carbon Emission

Parameter	Cost per 100 kg (INR)	Savings per 100 kg (INR)	Annual Savings for 100 tons (INR)	Profit Margin (%)
Virgin EPDM (100%)	22,000.00	0.00	0.00	0.00
30% Crumb Rubber	15,790.00	6,210.00	6210000.00	28.23
40% Crumb Rubber	13,720.00	8,280.00	8280000.00	37.64

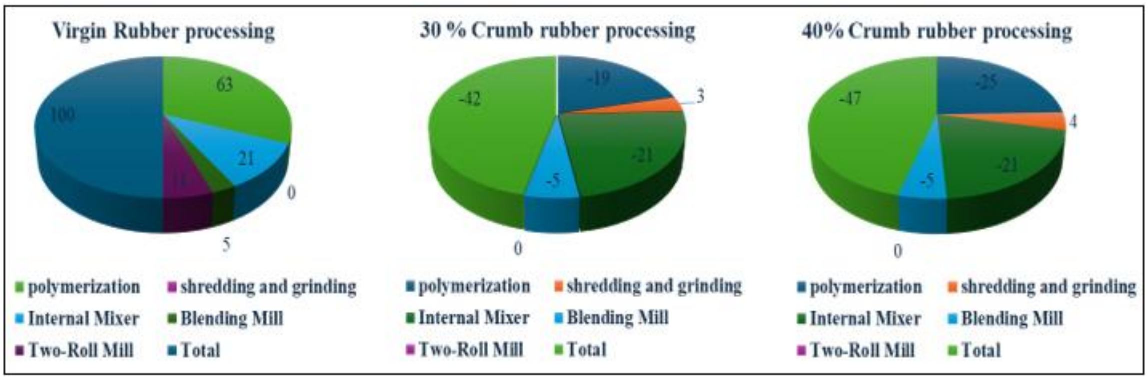

Figure 5: Schematic representation of the comparison for overall power consumption

3.3 Carbon Footprint Reduction

The production of virgin EPDM rubber involves substantial carbon emissions due to energy-intensive polymerization processes and the transportation of raw materials. During polymerization, the production of synthetic polymers consumes substantial amounts of energy and emits greenhouse gases, accounting for approximately 2.5 kg CO_2/kg of emissions. Additionally, the transportation of raw materials, often sourced from distant locations, contributes an additional 1.5 kg CO_2/kg, resulting in a total carbon footprint of 4.0 kg CO_2/kg for virgin EPDM rubber. In contrast, recycled crumb rubber production eliminates the need for polymerization and significantly reduces transportation-related emissions as the waste materials are often processed in-house or locally. The carbon emissions for recycled crumb rubber amount to only 0.8 kg CO_2/kg, mainly due to the energy required for shredding and grinding stages (Table 4).

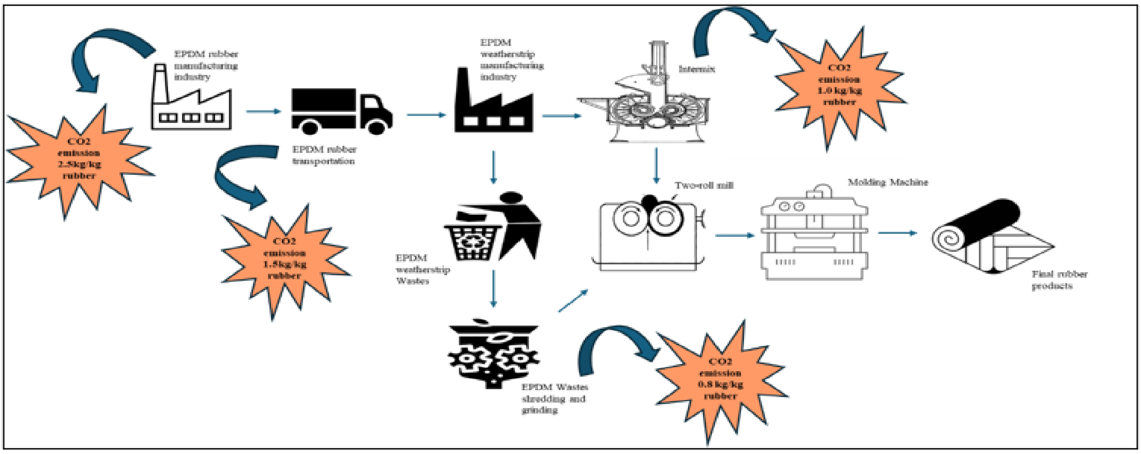

Figure 6: Schematic illustration of CO2 emission during different manufacturing and processing steps

Table 5: Comparison data of raw material cost saving

Processing Method	Carbon Emissions (kg CO_2/kg)	Details
Virgin EPDM Rubber	4.0	High emissions from polymerization (2.5 kg CO_2/kg) and transportation (1.5 kg CO_2/kg).
Recycled Crumb Rubber	0.8	Emissions primarily from shredding and grinding stages.
Reduction Achieved	3.2	Recycling reduces emissions by approximately 80%, aligning with global sustainability benchmarks.

3.4 Raw Material Cost Savings

By replacing virgin EPDM rubber (costing 220 INR/kg) with crumb rubber (costing 13 INR/kg) in compounding processes, manufacturers can achieve significant raw material cost savings. Table 5 shows, replacing 30% of virgin rubber with crumb rubber reduces the cost per 100 kg from 22,000 INR to 15,790 INR, resulting in savings of 6,210 INR per 100 kg. At a 40% replacement ratio, the cost drops further to 13,720 INR per 100 kg, yielding savings of 8,280 INR. For an annual consumption of 100 tons, this translates to annual savings of

6210000 INR at 30% replacement and 8280000 INR at 40% replacement. These cost savings correspond to profit margins of 28.23% and 37.64%, respectively, underscoring the economic advantages of integrating crumb rubber into EPDM formulations.

3.5 Product Performance

Physical property tests indicate that the performance of rubber compounds with 30% and 40% crumb rubber replacement closely matches that of virgin rubber compounds. Key parameters, such as tensile strength, elongation at break, compression set, and hardness, were measured and compared, as shown in Figure 7. Heat aging tests conducted revealed excellent performance for compounds with crumb rubber replacements. After 70 hours at 70°C heat aging, all samples exhibited minimal changes in tensile strength and elongation, confirming their thermal stability and durability (Figure 8).

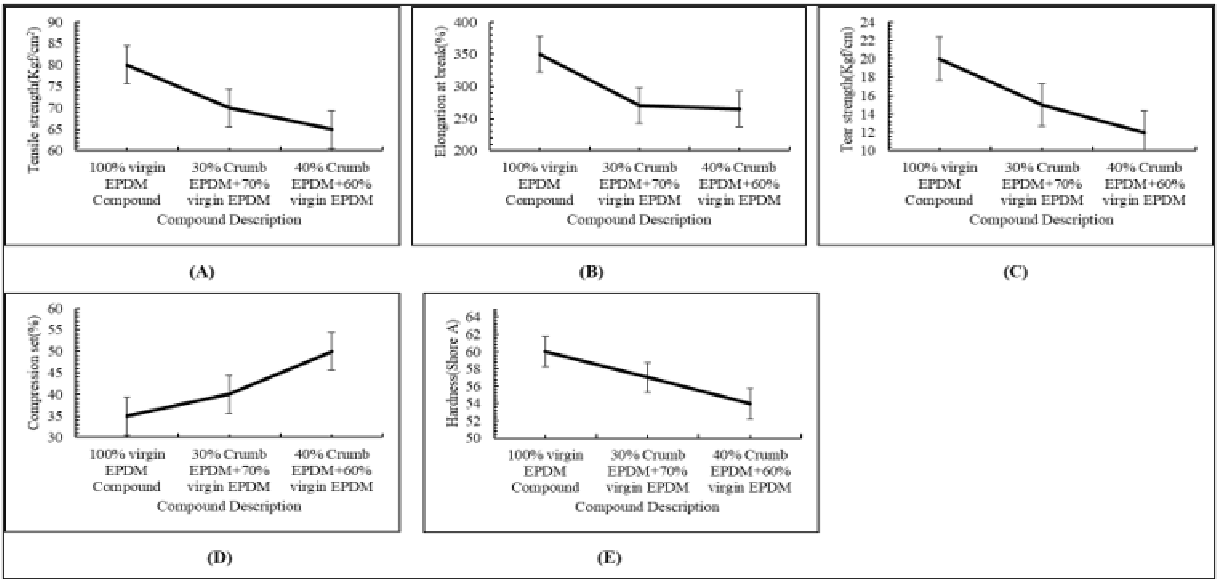

Figure 7: Comparison of various physical properties of rubber compounds;(A) Tensile strength, (B) Elongation at break, (C) Tear strength, (D) Compression set, and (E) Shore A Hardness

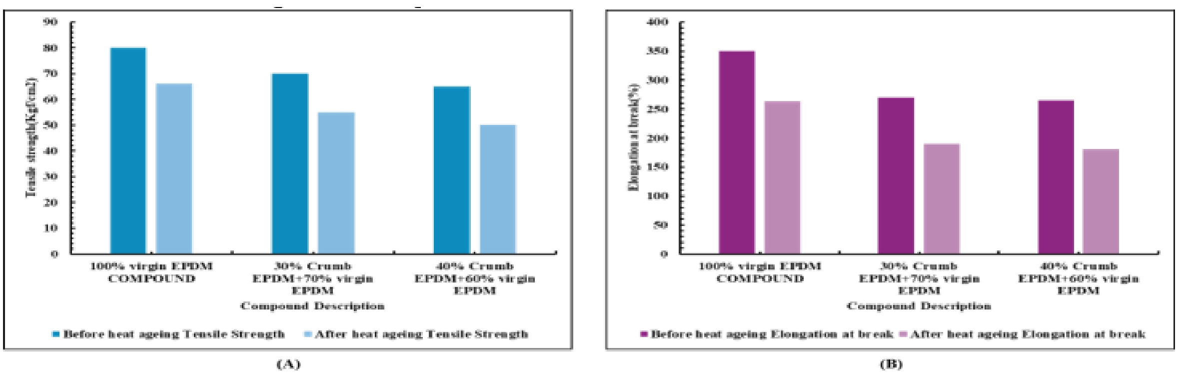

Figure 8: Comparison data of various properties before and after aging;(A) Tensile strength comparison, (B) Elongation at break comparison

3.6. Sustainability Impacts

The integration of recycled crumb rubber into EPDM production aligns seamlessly with global sustainability goals, particularly UN SDG 12 (Responsible **Consumption and Production) and UN SDG 13 (Climate Action). By utilizing in-house EPDM waste, manufacturers significantly reduce the reliance on virgin** raw materials, contributing to the conservation of finite resources. Furthermore, the reduction in carbon emissions—approximately 80% lower compared to virgin rubber production—directly supports global efforts to combat climate change. This transition also embodies a circular economy model, transforming waste into valuable resources. Recycling reduces landfill waste, minimizes energy-intensive polymerization and transportation processes, and curtails environmental pollution. By adopting this approach, manufacturers not only achieve tangible environmental benefits but also reinforce their commitment to sustainable industrial practices, strengthening their competitive position in an environmentally conscious market. These impacts illustrate the critical role of EPDM recycling in fostering a more sustainable and circular economy.

Table 6: Testing Results of Product Performance Testing

Test name and Condition	Observation type	100% virgin EPDM COMPOUND	30% Crumb EPDM+70% virgin EPDM	40% Crumb EPDM+60% virgin EPDM
Weathering Properties Irriadance:0.55 W/m^2 at 340 nm, BPT:70 °C for 1500 hours	GSR value	>4	>4	>4
Ozone Resistance 50 pphm at 40°C, 20% elongation for 72 hours	Visual	No crack	No crack	No crack
Low-Temperature Properties at -30°C	Visual	No crack	No crack	No crack
Fire Resistance Properties	Burning Rate	Compliance	Compliance	Compliance

3.7 Profitability

The use of crumb rubber in soft flooring applications for children's playgrounds presents a significant opportunity for companies to generate substantial income by tapping into various sectors. By repurposing industrial waste into high-quality, shock-absorbing playground flooring, companies can cater to a wide range of markets, including schools, colleges, athletic playgrounds, and community parks. This product not only meets safety standards but also offers a cost-effective, eco-friendly alternative to traditional flooring options. The growing demand for sustainable and safe playground surfaces, coupled with the scalability of this process, positions crumb rubber flooring as a profitable venture. Companies can benefit from recurring sales in these diverse sectors, ensuring steady revenue streams while contributing to environmental conservation. Additionally, the non-toxic, durable nature of the flooring makes it a highly attractive option for government and private institutions, further expanding **its** commercial potential. Thus, the adoption of this innovative approach provides a dual benefit: driving economic growth through increased sales and fostering sustainability through the effective repurposing of waste materials.

Figure 7: Soft flooring application in children's playground (Source: https://rubbercal.com/playground-surfacing-tiles)

Conclusion

The integration of recycled crumb rubber into EPDM rubber production represents a significant advancement in sustainable manufacturing. By replacing up to 40% of virgin rubber with crumb rubber, manufacturers achieve considerable raw material cost savings—reducing expenses from 220 INR/kg to 13 INR/kg, resulting in a potential annual cost reduction of over 6-8 million INR for a 100-ton operation. Additionally, this substitution reduces energy consumption by bypassing energy-intensive processes such as polymerization and excessive mixing, leading to energy cost savings.

Environmental benefits are equally compelling, with carbon emissions reduced by 80% from 4.0 kg CO_2/kg for virgin rubber to 0.8 kg CO_2/kg for recycled rubber. Physical property evaluations confirm that the performance of rubber compounds with 30–40% crumb rubber replacement, including tensile strength, elongation, and weather resistance, remains comparable to virgin compounds, with minimal impact on durability. Accelerated aging tests further validate the long-term viability of recycled products.

This innovative approach aligns with global sustainability goals, including UN SDG 12 (Responsible Consumption) and SDG 13 (Climate Action), by fostering a circular economy and reducing dependency on finite resources. Overall, recycling EPDM rubber waste offers a comprehensive solution that enhances profitability, reduces environmental impact, and supports global sustainability efforts.

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