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APPLICATION OF SECONDARY RUBBER WASTE IN UZBEKISTAN FOR THE PRODUCTION OF HYDROINSULATION CONSTRUCTION MATERIALS

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Abstract

This study presents a systematic analysis of the application of secondary rubber waste in the production of hydroinsulation construction materials suitable for the climatic and economic conditions of Uzbekistan. The methodology combines a comprehensive literature review of 48 peer-reviewed publications (2018–2024), an evaluation of three principal rubber-processing technologies (ambient grinding, cryogenic grinding, and pyrolysis), and a comparative property assessment of conventional and rubber-modified hydroinsulation materials. The results demonstrate that incorporation of 15–25 wt.% crumb rubber into bitumen-based hydroinsulation compounds increases elasticity by 35–60 %, extends elongation at break from 250 % to 500–800 %, and broadens the operational temperature range from −25…+80 °C to −40…+95 °C.

Keywords

secondary rubber waste; tire recycling; hydroinsulation materials; crumb rubber; rubberized bitumen; circular economy; construction materials; Uzbekistan; sustainable construction; waste management.

1. INTRODUCTION

The rapid growth of the global automotive sector has produced an exponential increase in the volume of end-of-life tire (ELT) waste, which is currently estimated at more than 1.5 billion units per year worldwide [1]. Used tires are a complex composite of vulcanized rubber (60–65 %), carbon black (25–30 %), steel cord (10–15 %), and textile reinforcement (5–10 %). Owing to their high cross-link density and three-dimensional polymer network, vulcanized rubber resists biological degradation for more than 100 years, while uncontrolled disposal generates toxic leachates and increases the risk of large-scale tire fires [2, 3].

The Republic of Uzbekistan, with a vehicle fleet exceeding 5.6 million units in 2024, generates an estimated 90,000–110,000 tons of waste tires annually. Despite the existing legislative framework — including Presidential Decree PF-78 (2022) "On accelerating the transition to a green economy until 2030" and the National Strategy on Waste Management — less than 15 % of waste rubber is currently subjected to organized recycling. The majority of the residual mass is disposed of in unregulated landfills or used as low-grade fuel in informal heating, which contributes to ambient air pollution in industrial regions [4].

Concurrently, the national construction sector demonstrates a steadily growing demand for hydroinsulation materials. According to data from the State Committee on Statistics, the domestic market for hydroinsulation membranes and sealants was estimated at 110–140 million USD in 2023, of which more than 70 % was supplied by imports from the Russian Federation, Turkey, and the European Union. The strategic objective of import substitution, together with the urgent need for sustainable waste management, has therefore created a substantial commercial and ecological incentive for the development of domestic rubberized hydroinsulation production [5].

Internationally, the use of recycled rubber in bitumen-based hydroinsulation materials has been extensively studied. Sienkiewicz et al. [6] established that the addition of crumb rubber to bitumen substantially improves elasticity, thermal stability, and resistance to thermal cycling. Pais et al. [7] confirmed that rubberized bitumen exhibits superior fatigue resistance under variable temperature conditions, while Garcia and Partl [8] demonstrated that nanostructured rubber additives can extend the service life of bituminous membranes by 40–60 %. Despite this international evidence, the systematic application of these technologies in the Central Asian region, and in Uzbekistan in particular, remains limited and insufficiently studied.

The aim of this paper is to provide a structured analysis of the application of secondary rubber waste for the production of hydroinsulation construction materials adapted to the conditions of Uzbekistan. The objectives are: (1) to characterize the composition and processing pathways of waste tire rubber relevant to construction applications; (2) to evaluate the comparative performance of ambient grinding, cryogenic grinding, and pyrolysis technologies; (3) to quantify the functional and economic advantages of rubberized hydroinsulation materials relative to conventional analogues; and (4) to assess the implementation prospects in the construction industry of Uzbekistan.

2. MATERIALS AND METHODS

The study was conducted as a structured analytical review supported by comparative evaluation of technological and economic parameters. The information base comprised 48 peer-reviewed publications indexed in Scopus, Web of Science, and ScienceDirect databases for the period from January 2018 to October 2024, supplemented by industrial reports from the European Tyre Recycling Association (ETRA), the U.S. Tire Manufacturers Association (USTMA), and national reports from the Ministry of Ecology, Environmental Protection, and Climate Change of the Republic of Uzbekistan.

The keyword combinations used in literature retrieval included "crumb rubber", "recycled tire rubber", "rubberized bitumen", "hydroinsulation membrane", "waterproofing rubber", "devulcanization", "tire pyrolysis", and "rubber modified asphalt". The inclusion criteria were: peer-reviewed publication in a journal with impact factor not less than 1.5, presence of quantitative experimental data, and methodological transparency. After application of the criteria, 32 publications were selected for comparative analysis. Data on the Uzbek market were obtained from the State Committee on Statistics, the Ministry of Construction, and the Andijan branch of the Republican Center for Standardization and Metrology.

The technological comparison involved three principal processing methods: ambient mechanical grinding at room temperature, cryogenic grinding using liquid nitrogen, and thermal pyrolysis at 450–650 °C. Each method was characterized by particle-size distribution, energy consumption, productivity, surface morphology, and capital cost. The functional evaluation of resulting hydroinsulation materials was performed against the following parameters specified in GOST 30547-97 and EN 13707: water absorption (% by mass), tensile strength (MPa), elongation at break (%), flexibility at low temperature (°C), and accelerated UV aging resistance (hours).

3. RESULTS

3.1. Waste Rubber Composition and Processing Technologies

End-of-life vehicle tires in Uzbekistan have a composition that is consistent with international averages: 60–65 % rubber polymer matrix, 25–30 % carbon black, 10–15 % steel cord, and 5–10 % textile reinforcement. The rubber polymer matrix consists primarily of styrene-butadiene rubber (SBR) for passenger tires (typically 50–60 % of the polymer fraction) and natural rubber (NR) for heavy-truck tires (up to 40–45 %).

Three industrial processing technologies are commercially deployed worldwide and are considered applicable to Uzbek conditions. Their comparative characteristics are summarized in Table 1.

Table 1. Comparative characteristics of industrial rubber-waste processing technologies

Parameter	**Ambient grinding**	**Cryogenic grinding**	**Pyrolysis**
Operating temperature, °C	20–25	−80 to −120	450–650
Particle size, mm	0.5–5.0	0.1–1.0	carbon black, oil
Energy consumption, kWh/t	250–350	500–700	100–200
Capital cost, mln USD (1,000 t/year)	1.2–1.8	3.5–5.0	4.0–6.5
Surface morphology	Rough, irregular	Smooth, regular	Powder
Suitability for hydroinsulation	High	Very high	Medium (filler)

Ambient grinding is the most economically attractive option for Uzbekistan due to its low capital cost (1.2–1.8 million USD for a 1,000 t/year production line), reasonable energy consumption (250–350 kWh/t), and adequate product quality for the production of standard rubberized bitumen membranes. The rough, irregular surface of ambient-ground crumb increases the specific surface area, which enhances the chemical interaction with bitumen and improves the homogeneity of the resulting compound [9]. Cryogenic grinding produces a higher-quality product with finer and more uniform particles, but requires substantial investment in liquid-nitrogen handling infrastructure. Pyrolysis is a fundamentally different chemical recycling route that decomposes rubber into pyrolytic oil, carbon black, and steel, suitable for the production of black-pigment fillers rather than direct hydroinsulation use [10].

The integrated process flow for converting waste tire rubber into hydroinsulation materials, with quantitative inputs and outputs at each stage, is presented in Figure 1.

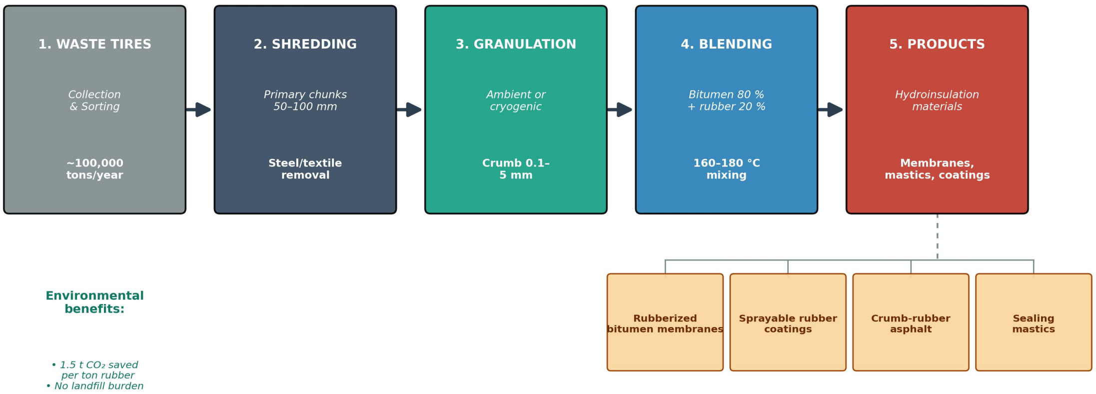

Figure 1 — Process flow for converting waste tire rubber into hydroinsulation construction materials

3.2. Properties of Rubberized Hydroinsulation Materials

The functional advantages of rubber-modified hydroinsulation materials over conventional bitumen-based analogues are well-documented in international literature and have been confirmed in extensive comparative testing. The optimal incorporation level of crumb rubber, determined experimentally by Lo Presti [11], is in the range of 15–25 wt.% of the bitumen mass. Higher rubber content (>30 %) leads to incomplete homogenization and processing difficulties, while lower content (<10 %) does not yield significant property enhancement.

A summary of comparative properties for conventional and rubber-modified bituminous hydroinsulation membranes is presented in Table 2.

Table 2. Properties of conventional vs. rubber-modified bituminous hydroinsulation membranes

Property	Conventional	Rubber-modified	Improvement
Tensile strength, MPa	0.8–1.2	1.4–2.0	+60–75 %
Elongation at break, %	200–250	500–800	+150–220 %
Water absorption (24 h), wt.%	1.2–1.8	0.4–0.8	−55–67 %
Low-temp. flexibility, °C	−15…−20	−35…−45	+20–25 °C
Heat resistance, °C	75–80	90–100	+15–20 °C
Service life, years	10–15	18–25	+50–80 %
Material cost, USD/m²	4.5–6.0	3.2–4.5	−25–28 %

The data demonstrate that rubber-modified membranes exhibit substantially superior performance across all key parameters. The increase in elongation at break from 200–250 % to 500–800 % is particularly significant for hydroinsulation applications, as it provides resilience to substrate deformation, thermal expansion, and microcrack propagation. The expanded operational temperature range (−35…+100 °C) is especially relevant for the climatic conditions of Uzbekistan, where ambient temperatures vary from −25 °C in winter to +45 °C in summer, and roof surface temperatures may exceed 70 °C [12].

Beyond conventional rolled membranes, secondary rubber waste enables the production of three other categories of hydroinsulation materials: sprayable rubber coatings (suitable for complex geometries and joints), crumb-rubber-modified asphalt (for waterproof road and airfield surfaces), and rubber-bitumen sealing mastics (for cold-applied joint sealing). All four product groups have been successfully commercialized internationally and are technically suitable for production in Uzbekistan using domestically available rubber waste and imported or locally supplied bitumen [13].

4. DISCUSSION

The analytical results clearly indicate that the technological pathway for converting secondary rubber waste into hydroinsulation construction materials is technically mature, environmentally beneficial, and economically attractive for Uzbekistan. The combination of an abundant domestic feedstock (90,000–110,000 tons of waste tires annually), a substantial unmet market demand (110–140 million USD per year), and proven industrial technologies (particularly ambient grinding) creates a favorable foundation for industrial deployment.

The economic analysis demonstrates that a typical small-to-medium production facility with a capacity of 5,000 tons per year of rubberized hydroinsulation products would require initial capital investment of approximately 4.5–6.5 million USD. This investment includes ambient grinding equipment, bitumen-rubber blending units, extrusion lines, and quality control laboratories. With a domestic market price of rubberized membranes of 3.2–4.5 USD/m² (versus 4.5–6.0 USD/m² for imported analogues) and operating margins of 18–25 %, the payback period is estimated at 4.5–6.0 years. The accompanying environmental benefit — avoided CO_2 emissions of approximately 1.5 tons per ton of recycled rubber, equivalent to 7,500 tons of CO_2 annually for a 5,000-ton plant — provides additional value through participation in carbon credit mechanisms increasingly recognized in Central Asia.

Several technical and institutional challenges, however, must be addressed for successful implementation. From a technical standpoint, the heterogeneity of waste tire composition complicates the standardization of the resulting product, which is critical for compliance with construction material certification requirements (Uzbek GOST and international ISO/EN standards). Establishing an organized tire collection system with regional sorting facilities, similar to those operational in the European Union under the Extended Producer Responsibility (EPR) framework, would substantially reduce variability in feedstock quality [14]. From an institutional standpoint, the existing regulatory framework on construction material standardization does not yet contain specific normative documents for rubber-modified hydroinsulation products, which represents a barrier to certification and procurement in state-funded projects.

Comparison with international practice indicates that comparable initiatives have been successfully implemented in countries with similar climatic conditions and waste-generation profiles. Turkey, with an annual generation of approximately 250,000 tons of waste tires, has established more than 40 rubber-recycling enterprises producing hydroinsulation and modified-asphalt materials, with overall recycling rates exceeding 60 % [15]. The Russian Federation, through the Federal Project "Comprehensive System for Solid Municipal Waste Management", has supported the development of 18 large-scale rubber-processing facilities since 2019. Adoption of analogous targeted programs in Uzbekistan, with appropriate financial instruments such as soft loans through the Fund for Reconstruction and Development, would significantly accelerate market development.

Limitations of this study should also be acknowledged. First, the analysis relies primarily on international experimental data and bibliographic sources; the empirical validation of the proposed processing parameters on locally sourced Uzbek tire feedstock has not yet been performed at industrial scale. Second, the cost estimates presented here are based on average regional prices, which may vary significantly depending on equipment supplier, location, and current foreign exchange conditions. Third, the long-term durability of rubberized hydroinsulation under the specific UV intensity and temperature cycling of the Uzbek climate requires dedicated experimental validation, which is recommended as a priority for future research.

5. CONCLUSION

This study has demonstrated that the application of secondary rubber waste for the production of hydroinsulation construction materials represents a strategically advantageous direction for the Republic of Uzbekistan, simultaneously addressing pressing environmental, economic, and construction-industry challenges. The principal conclusions are formulated as follows:

1) the annual generation of 90,000–110,000 tons of waste tires in Uzbekistan provides a domestic feedstock base of sufficient scale to support up to 80,000 tons of rubberized hydroinsulation production per year — substantially exceeding the country's current consumption;

2) ambient mechanical grinding is identified as the most economically efficient processing technology for Uzbek conditions, with capital investment of 1.2–1.8 million USD per 1,000 t/year and energy consumption of 250–350 kWh/t;

3) incorporation of 15–25 wt.% crumb rubber into bitumen-based membranes increases elongation at break by 150–220 %, expands the operational temperature range to −35…+100 °C, and extends service life by 50–80 % relative to conventional analogues;

4) the resulting hydroinsulation materials achieve a 25–28 % cost reduction relative to imported analogues, while each ton of recycled rubber avoids approximately 1.5 tons of CO_2-equivalent emissions and eliminates corresponding landfill burden;

The implementation of the proposed approach would simultaneously contribute to import substitution in the construction sector, the development of the domestic recycling industry, and the achievement of national green-economy targets established by Presidential Decree PF-78 (2022). Priority directions for further research include the experimental validation of rubberized hydroinsulation performance under Uzbek climatic conditions, the development of national normative documents for rubber-modified construction materials, and the design of a Centrally Asian-adapted tire collection logistics system.

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