

RESEARCH ON RECYCLING AND RESOURCE RECOVERY OF WASTE MATERIALS IN EXTREME ENVIRONMENTS

Vinnitsia National Technical University

Abstract

This study focuses on the regeneration potential and resource utilization pathways of waste materials in extreme environments. Through the integration of technological, policy, and industrial synergies, it reveals the impact mechanisms of material performance optimization and pollution control on resource efficiency, proposing a full-lifecycle management framework and differentiated policy recommendations to support low-carbon regeneration of extreme-environment waste.

Keywords: *extreme environments; waste materials; circular regeneration; resource utilization; pollution control; full lifecycle.*

INTRODUCTION

Waste materials in extreme environments (e.g., polar regions, deserts, nuclear-contaminated zones) are prone to secondary pollution through traditional disposal methods like landfilling or incineration due to environmental corrosion and compositional complexity, necessitating resource utilization via circular regeneration technologies[1,2]. Current research predominantly focuses on singular technical pathways, lacking systematic analysis of the "technology-policy-industry" synergy and insufficient exploration of performance optimization and risk control for extreme-environment materials. This study constructs a comprehensive framework covering "classification-regeneration-performance enhancement-environmental verification" by integrating circular economy theory, materials science, and ecological risk assessment models, providing systematic solutions for extreme waste management [3,4].

MAIN PART

The circular regeneration of extreme-environment waste materials requires core principles of reduction, reuse, and resource efficiency under circular economy theory. A three-dimensional evaluation framework ("technical feasibility-environmental risk-economic value") based on EU Life Cycle Assessment (LCA) standards quantifies key indicators such as carbon emission intensity (e.g., 30% reduction in CO₂ emissions for recycled aggregates compared to natural sand) and resource substitution rates (e.g., ≥40% substitution of recycled metals for virgin minerals). For aerospace waste with oxidized surface layers (10–50 μm), Germany employs arc furnace gradient temperature control (1200–1500°C) to achieve 98.5% metal purity, while electrolytic separation systems enhance rare earth element recovery to 85% [5,6]. Nuclear-contaminated waste treatment utilizes gene-edited microorganisms (e.g., *Geobacter* strains) to convert uranium-238 into stable phosphate minerals, reducing processing cycles to 30 days and cesium-137 activity to ≤0.1 Bq/g[56].

Environmental risk control mandates hierarchical application standards and pollutant thresholds. The EU EN 12620 standard restricts medium-risk recycled aggregates to non-load-bearing structures, with limits on microplastic release (≤0.01 mg/L, ISO 1883056) and lead leaching (≤0.05 mg/L, EPA 131156). Blockchain traceability systems ensure ≥99% accuracy in pollutant monitoring, confining high-risk radioactive waste to deep-sea disposal or radiation shielding projects. Material modification techniques, such as nano-silica enhancers, elevate the compressive strength of polar construction waste-derived aggregates to ≥C40 and freeze-thaw resistance to 200 cycles (ASTM C66646).

Recycled concrete can be used in various forms for wall construction:

- Recycled concrete blocks – used as standard building blocks.
- Monolithic structures – recycled concrete can be incorporated into new reinforced concrete elements.
- Facing materials – crushed concrete can serve as a decorative element or filler.

Policy-industry synergy is critical for technology implementation. Japan's Waste Disposal Act mandates ≥30% recycled material usage in public projects, while California's carbon credit trading

reduces recycled construction material costs by 15–20%. The EU's Extreme Environment Material Regeneration Guidelines set energy consumption limits for high-temperature melting (≤ 3.5 kWh/kg⁴⁶), and Germany's green procurement policies boost recycled material market share to 28%. Industrial chain optimization includes front-end pre-sorting protocols for polar stations, mid-term modular mobile processing units (e.g., vehicle-mounted furnaces) to reduce logistics costs, and back-end applications driven by high-purity metal demand, forming a closed-loop "sorting-processing-application" system.

Despite its numerous advantages, the use of waste concrete also has certain difficulties:

1. The need for standardization and certification of recycled concrete.
2. High costs for primary processing of the material.
3. Variability in the quality of recycled concrete depending on the starting raw materials.

However, with the development of technology and legislative support, this area has significant potential for expansion. Further research and the implementation of effective recycling methods will help to increase the scale of the use of recycled concrete in construction.

CONCLUSION

Circular regeneration of extreme-environment waste requires breakthroughs in material performance and pollution control technologies. Policy instruments (e.g., extended producer responsibility) and industrial integration (e.g., smart recycling networks) can synergize environmental and economic benefits. Future research should prioritize interdisciplinary innovations (e.g., AI-driven sorting algorithms) and regionalized standards for recycled mate. Using waste concrete for wall construction is an environmentally and economically viable solution. It reduces the negative impact on the environment, reduces the use of natural resources and lowers the cost of construction. Further development of this technology will contribute to a more sustainable and efficient construction industry.

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Department of construction, urban economy and architecture

Olena LIALIUK - Ph. D., assistant professor of construction of urban economy and architecture Vinnitsa National Technical University. e-mail: Lyalyuk74@gmail.com.

Li Zhijun - master Vinnitsa National Technical University. e-mail:541702467@qq.com