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Durability and Environmental Performance Evaluation of Eco-Friendly Construction Materials under Accelerated Weathering Tests

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Abstract: The construction sector is a major contributor to global resource consumption and environmental degradation, necessitating the development and adoption of eco-friendly construction materials with reduced environmental impact and long-term durability. While sustainable materials such as geopolymer concrete, recycled aggregate composites, bio-based binders, and natural fiber-reinforced materials have demonstrated promising environmental benefits, their long-term performance under harsh environmental conditions remains insufficiently understood. This study presents a comprehensive durability and environmental performance evaluation of selected eco-friendly construction materials subjected to accelerated weathering tests. Materials were exposed to controlled cycles of ultraviolet radiation, moisture ingress, thermal fluctuations, and chemical attack to simulate long-term aging. Mechanical strength retention, microstructural stability, water absorption, and surface degradation were systematically assessed. Results indicate that eco-friendly materials exhibit varying resistance to environmental stressors, with geopolymer-based systems demonstrating superior durability and lower degradation rates compared to bio-composites. The findings provide critical insights into material selection, lifecycle performance, and sustainable construction practices, supporting the wider adoption of environmentally responsible materials in infrastructure development.

Keywords: Eco-Friendly Materials, Accelerated Weathering, Durability Assessment, Sustainable Construction, Environmental Performance

1. Introduction

The global construction industry accounts for significant consumption of natural resources and energy while contributing substantially to greenhouse gas emissions. Conventional construction materials such as Portland cement concrete and fired clay bricks are associated with high embodied energy and carbon emissions. In response, eco-friendly construction materials have gained attention due to their potential to reduce environmental impact while maintaining functional performance [1]. Eco-friendly materials include geopolymers, recycled aggregate concrete, bio-based composites, and industrial by-product-based binders. Despite their sustainability advantages, concerns regarding durability and long-term performance under environmental exposure remain a barrier to widespread adoption. Environmental stressors such as ultraviolet radiation, moisture cycling, temperature variation, and chemical exposure can significantly affect material integrity. This study aims to evaluate the durability and environmental performance of selected eco-friendly construction materials under accelerated weathering conditions to simulate long-term service behavior.

2. Eco-Friendly Construction Materials Overview

Eco-friendly construction materials are designed to minimize environmental impact while achieving acceptable structural and functional properties. Geopolymer concrete utilizes industrial by-products such as fly ash and slag as binders, significantly reducing carbon emissions compared to cement-based systems [2]. Bio-based materials incorporate natural fibers, agricultural residues, or bio-polymers to enhance sustainability. Recycled aggregate

materials reduce dependence on virgin aggregates and mitigate construction waste disposal issues. However, their performance under prolonged environmental exposure requires systematic evaluation.

3. Sensor Accelerated Weathering Test Methodology

Accelerated weathering tests are widely used to simulate long-term environmental exposure within shorter timeframes. In this study, specimens were subjected to cyclic exposure involving ultraviolet radiation, wet-dry cycles, thermal variation, and chemical exposure. Ultraviolet radiation simulated solar degradation effects, while moisture cycling replicated rainfall and humidity variations. Thermal cycles induced expansion and contraction stresses, and chemical exposure assessed resistance to acidic and alkaline environments.

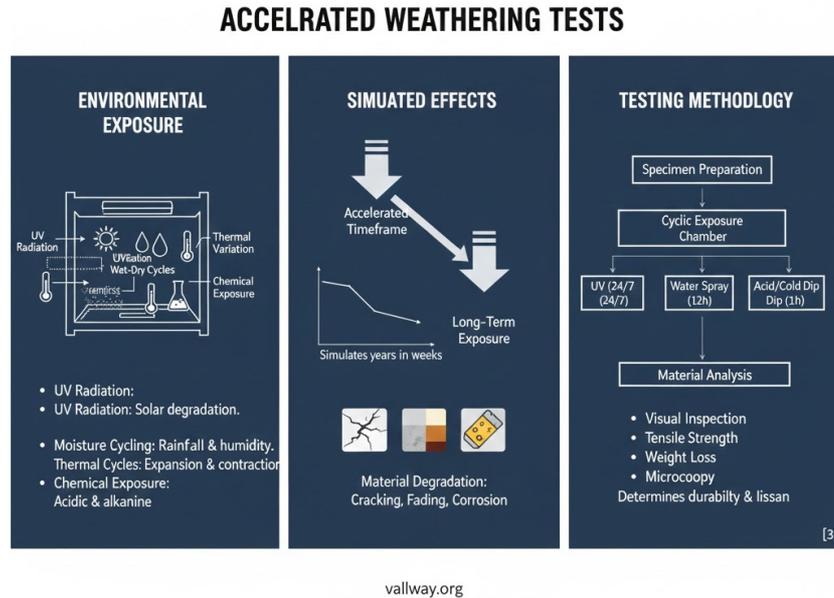


Fig. 1 Accelerated Weathering Test

4. Experimental Program and Sample Preparation

Material specimens were prepared following standardized procedures to ensure uniformity. Geopolymer concrete samples were cured under controlled conditions, while bio-composites were fabricated using natural fiber reinforcement and eco-friendly binders. Specimens were exposed to accelerated aging cycles for durations corresponding to multiple years of natural exposure. Mechanical testing and physical characterization were conducted at predefined intervals.

5. Mechanical Performance under Weathering

The Compressive strength, flexural strength, and surface hardness were evaluated before and after weathering exposure. Results showed that geopolymer materials retained a higher percentage of their initial strength compared to bio-based composites. Strength degradation in bio-composites was attributed to moisture absorption and fiber degradation, highlighting the importance of protective treatments and material design [3].

6. Physical and Microstructural Analysis

Water absorption, porosity, and density changes were measured to assess physical degradation. Microstructural analysis using microscopy revealed crack formation, surface erosion, and fiber debonding in certain materials. Geopolymer matrices exhibited dense microstructures with limited crack propagation, contributing to enhanced durability.

7. Environmental Performance Evaluation

The Environmental performance was assessed through embodied energy analysis, carbon footprint estimation, and recyclability potential. Eco-friendly materials demonstrated significant reductions in embodied carbon compared to conventional materials, even when durability considerations were included. Lifecycle assessment indicated that longer service life substantially improves sustainability outcomes.

8. Comparative Performance Analysis

A comparative evaluation highlighted trade-offs between environmental benefits and durability. While bio-based materials offered superior sustainability metrics, geopolymer systems achieved better long-term performance under harsh conditions. The results emphasize the need for application-specific material selection.



Fig. 2 Comparative Chart

9. Implications for Sustainable Construction

Durability is a critical factor influencing the overall sustainability of construction materials. Premature degradation can offset environmental benefits by increasing maintenance and replacement requirements. The findings support the use of geopolymer and hybrid eco-friendly materials in applications requiring long service life.

10. Challenges and Limitations

Challenges include variability in raw material quality, limited standardization, and higher initial costs. Accelerated weathering tests, while informative, may not capture all real-world degradation mechanisms.

11. Conclusion

This study demonstrates that eco-friendly construction materials exhibit diverse durability responses under accelerated weathering conditions. Geopolymer-based materials showed superior resistance to environmental degradation, while bio-based composites require further optimization. The results contribute valuable insights for sustainable material selection and long-term infrastructure planning.

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