Geopolymer Pavements with Recycled Aggregates: A Sustainable Solution

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Introduction

Across India, pavements shape how cities grow, how people move, and how economies thrive. Yet, as infrastructure expands, the pressure on natural aggregates continues to rise, pushing the search for materials that can support the next generation of pavement construction. With natural resources being finite, the need for credible, sustainable alternatives has become increasingly apparent. At the same time, according to the Building Material Promotion Council, India estimates that the generation of massive volumes of construction and demolition waste (CDW) is around 150 million tonnes annually, while formal recycling accounts for barely one percent of this amount. A similar challenge exists with fly ash, which thermal power plants generate in excess of 300 million tonnes each year, much of it remaining unused. Together, CDW and fly ash represent an underutilised resource stream with significant potential. Our research explores how these secondary materials can be combined and transformed through geopolymer stabilisation to create robust, sustainable pavement base layers that reduce reliance on natural aggregates and pave the way for greener infrastructure.

From Debris to Design: Strengthening Recycled Aggregates with Geopolymers

Natural aggregates have high environmental and economic costs. At the same time, materials like fly ash continue to accumulate as by-products of power generation, and CDW continues to build up due to increasing urbanization. Geopolymer stabilization offers a way to address these challenges simultaneously. Instead of relying on traditional cement, which contributed roughly 1.7 billion metric tonnes of CO_2 emissions globally in 2021, fly ash can be chemically activated to form a strong, low-carbon binder. When this binder is used to stabilize recycled aggregates, such as CDW, it transforms them into reliable pavement base materials, reducing reliance on natural aggregates. Put simply, industrial by-products, rich in silica and alumina, when chemically activated, form geopolymers that improve the performance of recycled aggregates, making them suitable for pavement construction. In our laboratory studies, varying proportions of CDW and natural aggregates are blended and stabilised using fly ash–based geopolymers. This binder significantly improves the mechanical performance of these materials, making them suitable as a stabilized base material for road construction. By turning underutilized industrial and construction residues into engineering-grade pavement layers, this approach reduces pressure on natural aggregates while advancing a more sustainable and resource-efficient future for pavement infrastructure.\

Why It Matters

Conventional pavement construction relies heavily on natural aggregates and cement, both of which are associated with significant environmental and economic costs. The findings of this study indicate that geopolymer-stabilized base layers can save approximately 60–100% of natural aggregates by incorporating recycled materials such as construction and demolition waste, consistent with trends reported in previous studies. In addition, previous studies [1] indicate that the use of fly ash–based geopolymers instead of cement results in carbon dioxide emissions of only about 20–30% of those from cement-treated mixes, while also reducing construction costs by approximately 17–25%. At scale, this approach conserves natural resources, lowers embodied carbon, and promotes circular, cost-effective pavement infrastructure.

Summary:

Geopolymer-stabilised recycled aggregates offer a practical and environmentally responsible pathway for constructing durable pavements. This research highlights how new approaches in pavement construction can contribute to greener and more sustainable infrastructure, providing solutions that are locally adapted, resource-efficient, and low-carbon. As India continues to expand its road networks, approaches like this could redefine how infrastructure is conceived and built.

References

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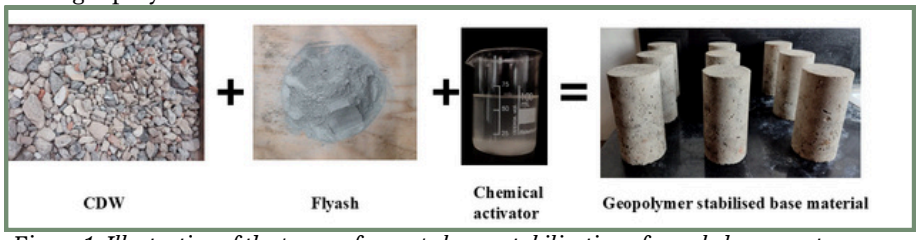

Figure 1. Illustrative of the process for geopolymer stabilisation of recycled aggregates

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