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*Original Article*

# From Waste to Resilience: A State-of-the-Art Review on Fly Ash-Based Rubberized Geopolymer Concrete

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***Abstract*** *- The construction sector remains heavily dependent on Ordinary Portland Cement (OPC) and natural aggregates worldwide, making it one of the largest contributors to carbon emissions and resource depletion. At the same time, industries still have challenges in properly disposing of fly ash and tires with a minimum useful life, both of which are produced in enormous quantities annually. Fly Ash-Based Rubberized Geopolymer Concrete (FRGC) presents a suitable alternative to replace cement, natural aggregates used in conventional concrete, and reduce carbon footprint by utilizing waste products. A geopolymer binder made from low-calcium fly ash is used in place of OPC in FRGC, and rubber fragments recovered from used tires are used in place of some of the natural aggregates. An extensive review is therefore performed in this study to highlight the research gaps to be addressed in the future and potential challenges in achieving the goal. The present study also examines the effects of rubber size/content, curing regime, silicate-to-hydroxide ratio, and alkaline activator molarity on the mechanical, fresh, and durability characteristics of FRGC. Results from previous studies show that adding rubber by 6% can lower compressive strength by 10–25%. However, it significantly improves ductility, impact resistance, and energy absorption by more than 50%. However, the geopolymer binder lowers the carbon footprint of concrete by 60–80% as compared to OPC and offers great early strength and exceptional durability in harsh settings. This consolidated literature reveals that while the alkaline chemistry of geopolymer binders and the toughness benefits of rubber are individually well studied, their combined influence under elevated curing and fire exposure remains critically underexplored. Furthermore, long-term durability and corrosion studies of FRGC are scarce, and no comprehensive datasets exist for machine learning-based prediction. Addressing these gaps will define the trajectory for future research and standardization.*

***Keywords*** *- Geopolymer Concrete, Rubberized Concrete, Fly Ash, Sustainable Construction, Lifecycle Assessment.*

## 1. Introduction

Climate change and unsustainable resource consumption are the two crises that define the twenty-first century. As the biggest user of natural resources and a major generator of greenhouse gas emissions, particularly from the manufacture of Ordinary Portland Cement (OPC), the building industry is at the center of both [1]. With over one tonne of $CO_2$ generated for every tonne of cement produced, the production of cement is responsible for around 8% of anthropogenic $CO_2$ emissions worldwide [2, 3]. At the same time, solid waste production keeps increasing.

With an estimated 1.2 billion units produced each year globally, tires from end-of-life vehicles represent a particularly hazardous waste stream. Due to their longevity and lack of biodegradability, disposing of them in landfills is both environmentally and financially unsound and frequently results in hoarding and illegal dumping, which increases the risk of fire and spreads disease [4, 5].

The core of sustainable construction is founded on two issues- utilization of waste products and mitigation of environmental impact. Rubberized Concrete (RuC) and Geopolymer Concrete (GPC) have been separately studied by many researchers in the past as a solution to sustainable construction. Davidovits [6] investigated the performance of GPC and compared it with OPC-based concrete [7, 8]. Utilizing the chemical reaction between aluminosilicate sourced from fly-ash or slag and high-alkali solution, an inorganic polymer binder is formed. It is estimated that using industrial waste in GPC can reduce $CO_2$ emissions by up to 80% [9, 10]. RuC, on the other hand, uses granulated tire rubber to make the material more resistant to impact, more flexible, and better at controlling fractures by partially replacing natural aggregates. It also serves as a repository for discarded rubber [11-13]. However, RuC, due to the weak bond between the cement paste and hydrophobic rubber in the Interfacial Transition Zone (ITZ), results in the reduction of compressive strength [14, 15].

# Chapter 28
# Study for the Development of Fly Ash Based Concrete


**Anupam Saha, Bidhan Ghosh, and Hasim Ali Khan**

**Abstract** Concrete is extensively used sustainable structural material. Control concrete consists of cement, sand and stone-chips. But 1 kg $CO_2$ is generated for producing 1 kg of cement, resulting pollution. The use of industrial byproducts such as fly ash can be beneficial to the production of friendly concrete. Present study is an attempt to identify the characteristics of Portland Pozzolana Cement (PPC) based fly ash mixed concrete. The study has been taken up for the designed mix M40 grade and M60. The mechanical nature of concrete were experimented at seven days and twenty eight days in which cement is partly substituted with fly ash ranging from 15 to 35%. To maintain the slump and water cement ratio Sikament 600 (SD) super plasticizer was used in the study. The optimal percentage of replacement of fly ash was found 30% in cement concrete from the study.

**Keywords** Sustainable · Eco friendly · Fly ash · Mechanical properties · Super plasticizer

## 28.1 Introduction

Concretes are changing day by day according to the rheological and mechanical performance intended to be used in a particular structure, its environment, construction method and to enhance its performance criteria known as High Performance concretes (HPC). Now-a-days, cement industry is major manufacturers of carbon dioxide. Coal is used as fuel in factory and burning of coal turn out huge fly ash daily (MORTH 2013; ASTM D 2006). Due to pozzolana nature of fly ash, it can be of use in concrete. The utilisation of fly ash is also a step to reduce the use of natural resources as one of the main challenges now confronting the concrete industry in the countries that are developing countries like India. For the study, fly ash was obtained from Bandel thermal power plant, Tribeni, West Bengal. Various literature on physical

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(57) Abstract :

The present invention introduces a groundbreaking method for enhancing the durability and longevity of concrete infrastructure through the integration of advanced nanomaterials capable of self-healing. By incorporating self-healing agents at the nanoscale level, the proposed approach enables autonomous repair of cracks and damage within concrete structures, mitigating the need for costly and disruptive maintenance interventions. The invention harnesses the unique properties of nanomaterials, including self-assembly, reactivity, and mechanical reinforcement, to improve the resilience and sustainability of concrete infrastructure in various applications, including buildings, bridges, roads, and tunnels. This innovative method not only extends the service life of concrete structures but also reduces maintenance costs and enhances safety, contributing to more sustainable and resilient infrastructure development

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