Performance Evaluation of Sustainable Concrete Pavements with Utilization of Reusable Waste Material

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***Abstract** - The constant need for infrastructure development in the building industry brought about by population growth led to increased use of aggregates and cement. Ultimately boosting carbon emissions and resource extraction in greater depths. The focus here is to create sustainable concrete using partially replacing cement with supplementary cementitious material like Fly Ash (FA), Silica Fume (SF), and Recycled Coarse Aggregates (RCA) with virgin aggregate so that FA, SF, and RCA, can be used widely in construction.*

Concrete was produced for the study in various batches while maintaining a constant water-cement ratio of 0.4. Compressive strength and flexural strength tests are used to determine the hardened properties of the specimens after 3, 7, and 28 days of curing. Batches were altered based on the constituents that were substituted, adding 5%, 10%, and 15% for Fly Ash, 3%, 6%, and 9% for Silica Fume, and 0%, 6%, 12%, and 18% for Recycled Coarse Aggregates.

The utilization of Fly Ash at 15%, Silica Fume at 9%, and Recycled Coarse Aggregates at 18% demonstrated to have achieved significant outcomes after 28 days of testing. Numerous batches had notable results in the compressive test but struggled in the flexural test. Some batches including Fly Ash at 10%, Silica Fume at 6%, and Recycled Coarse Aggregates at 12% reached early age strength and did not improve as age grew, whereas batches containing Fly Ash at 15%, Silica Fume at 9%, and Recycled Coarse Aggregates at 18% greatly improved over time.

***Keywords** - Fly Ash; Silica Fume; Recycled Coarse Aggregate; virgin Aggregates; Compressive Strength; Flexural Strength*

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INTRODUCTION

Concrete pavements are extensively used in infrastructure development due to their strength and durability. However, the production of conventional concrete involves the consumption of a significant number of natural resources and the emission of greenhouse gases, contributing to environmental degradation and climate change. To address these concerns, sustainable alternatives in pavement construction have gained increasing attention in recent years.

The utilization of reusable waste materials in concrete construction offers a promising path for achieving sustainability objectives while maintaining the performance and structural integrity of pavements. Reusable waste materials, such as fly ash, blast furnace slag, silica fumes, and other industrial by-products, can potentially replace a portion of the cementitious binder and recycled coarse aggregate as natural aggregates in concrete mixtures. This reduces the demand for virgin materials and diverts waste from landfills, leading to a more environmentally friendly construction approach.

This topic explores the use of waste materials in concrete pavements for improved sustainability. Research findings indicate that incorporating reusable waste materials can affect pavements' mechanical properties and durability while reducing environmental impact. However, research gaps exist in terms of long-term performance evaluation, waste material optimization, standardization, economic feasibility, climate resilience, and field monitoring. Addressing these gaps will advance knowledge of sustainable pavement construction practices.

LITERATURE

Chore et al. [1] present experimental investigations for assessing the strength properties of concrete made using pozzolanic waste materials. They evaluated the compressive strengths corresponding to the curing period of 7, 28, 40, and 90 days and the flexural and indirect tensile strengths corresponding to 7, 28, and 40 days. The study concludes that industrial waste materials can be used as a partial replacement for cement and can render sustainable concrete for use in rigid pavement construction.

Aggarwal et al. [2] reviewed the superior alternative materials that they may utilize to replace cement and aggregates in concrete. The potential of alternatives such as coal ash, silica fume, Nano- silica, fly ash, slag, and recycled concrete aggregate is investigated. For example, fly ash improves essential mechanical properties of the concrete, such as compressive strength and abrasion resistance, when used in combination with silica fume, but can be undesirable when used alone.

Mehta et al. [3] represent an issue on a global scale the massive release of greenhouse gases from industrial wastes. The severity of the issue is made worse by the fact that industrial wastes including silica fume, glass, bottom ash, and rubber tires are not biodegradable. According to earlier research, recycling waste materials for use in the cement and building industries might be a practical way to save natural resources from extinction. The cement and concrete industries are being drawn in as a sustainable option by the chemical makeup of waste glass and silica fume. Although green concrete is still in its infancy, it has recently gained a lot of attention from academics and researchers. This essay investigates how waste glass and silica fume affect the workability, durability, and strength of concrete.

OBJECTIVE

To determine the optimum replacement ratio of supplementary cementitious material and reusable aggregates in concrete.

There is a growth in the amount and type of waste materials across the population increment. Most of the waste materials have remained not decayed in the environment for long years causing a waste disposal crisis and environmental pollution specifically in dense population areas. So, this waste material should be used in the concrete pavements. The data related to this topic should be collected from the existing literature. So, we use this waste material in the concrete as reusable concrete waste materials. From the study, we will find the optimum replacement ratio of supplementary cementitious material and reusable aggregates in concrete.

METHODOLOGY

- **Percentage of Replacement of Constituent Material:**

Table 1: Percentage replacement of fly ash, silica fume, and recycled coarse aggregates in concrete.

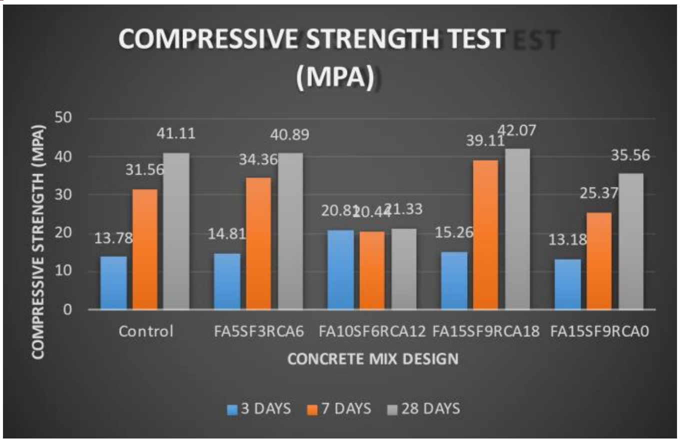
Mix	Fly Ash (%)	Silica Fume (%)	Natural Aggregates (%)	Recycled Coarse Aggregates (%)
Control	0	0	100	0
FA5SF3RCA6	5	3	94	6
FA10SF6RCA12	10	6	88	12
FA15SF9RCA18	15	9	82	18
FA15SF9RCA0	15	9	100	0

- **Compressive test result and analysis:**

Table 2: Average of 3 specimens for compressive strength test result

Test Result Hardened Concrete (MPa) (Average of 3 observations)			
Mix	Compression test		
	3	7	28
Control	13.78	31.56	41.11
FA5SF3RCA6	14.81	34.36	40.89
FA10SF6RCA12	20.81	20.44	21.33
FA15SF9RCA18	15.26	39.11	42.07
FA15SF9RCA0	13.18	25.37	35.56

- **Graph For Average of Compressive Strength:**



Graph No.1: Average Compressive Strength Test (MPA)

At 3 days, all mixes show higher strength compared to the control mix. Among them, FA10SF6RCA12 exhibits the highest strength (20.81 MPa), followed closely by FA15SF9RCA18 (15.26 MPa), FA5SF3RCA6 (14.81 MPa), and FA15SF9RCA0 (13.18 MPa).

At 7 days, FA15SF9RCA18 achieves the highest strength (39.11 MPa), followed by FA5SF3RCA6 (34.36 MPa), FA15SF9RCA0 (25.37 MPa), and Control mix (31.56 MPa). FA10SF6RCA12 exhibits the lowest strength (20.44 MPa).

At 28 days, FA15SF9RCA18 records the highest strength (42.07 MPa), followed by FA5SF3RCA6 (40.89 MPa), Control (41.11 MPa), and FA15SF9RCA0 (35.56 MPa). FA10SF6RCA12 shows the lowest strength (21.33 MPa).

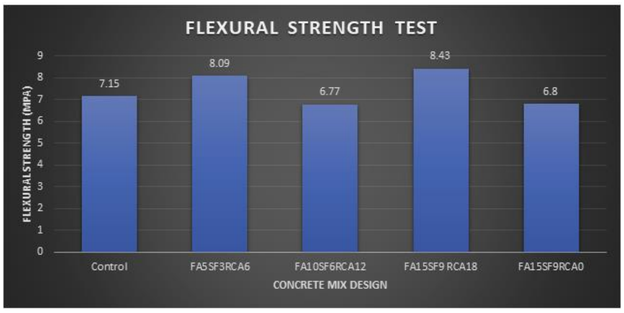
- **Flexural test result and analysis:**

The flexural test result for 28 days is analyzed and a comparative analysis is done:

Table 3: Average of Flexural strength test result for 28 days

Test Result Hardened Concrete (MPa) (Average of 3 observations)	
Mix	Flexural test result
	28 Days
Control	7.15
FA5SF3RCA6	8.09
FA10SF6RCA12	6.77
FA1518F9RCA18	8.43
FA15SF9RCA0	6.8

- **Graph For Average of Flexural Strength:**



Graph No.2: Average of Flexural Test (MPa)

The flexural test results for hardened concrete at 28 days indicate variations in flexural strength among different mixes. The Control mix demonstrates a flexural strength of 7.15 MPa. Among the tested mixes, FA1518F9RCA18 exhibits the highest flexural strength at 8.43 MPa, followed by FA5SF3RCA6 at 8.09 MPa. FA15SF9RCA0 and FA10SF6RCA12 show lower flexural strengths at 6.80 MPa and 6.77 MPa, respectively. These findings highlight the influence of mix composition on the flexural strength properties of concrete.

CONCLUSION

The compressive strength test indicates that different mixes exhibit varying levels of strength at different ages. Mixes with 10% fly ash, 6% silica fume, and 12% recycled aggregate perform well in terms of early-age strength at 3 days. However, for 7-day and 28-day compressive strength, mixes containing 5% fly ash, 3% silica fume, and 6% recycled aggregate show superior performance, and 15% fly ash, 9% silica fume, and 18% recycled aggregates demonstrate the highest overall compressive strength.

Regarding the flexural strength test 15% fly ash, 9% silica fume, and 18% recycled aggregates exhibit the highest flexural strength among the tested mixes, followed by the control mix, 5% fly ash, 3% silica fume, and 6% recycled aggregate; 10% fly ash, 6% silica fume, and 12% recycled aggregates; and 15% fly ash, 9% silica fume, and 0% recycled aggregates show comparatively lower flexural strengths. These findings underline the influence of mix composition on both compressive and flexural strength properties of hardened concrete.

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