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# "Experimental Investigation of Fiber-Reinforced Cement Concrete Design Utilizing Recycled Waste Plastic Aggregate, Fly Ash, and Silica Fumes under Cyclic Loading"

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***Abstract***
*"In the production of lightweight concrete, determining the optimal dosage of substitutes for natural resources, cementitious materials, and mineral admixtures is crucial. This research paper critically reviews the use of plastic aggregates (both coarse and fine) as partial substitutes for natural aggregates, along with the incorporation of fly ash, silica fumes, and GGBS as Substitute Cementitious Materials (SCM). The study investigates the impact of these substitutes on the fresh and hardened properties of fiber-reinforced cement concrete.*
*The findings of this study highlight significant improvements in quality, strength, and workability when using the optimal dosage of substitutes. This research aims to establish guidelines for determining the appropriate dosage of materials to achieve satisfactory and high-quality results. The major outcomes indicate that a combination of 10% SF, 25% FA, and 0–20% plastic waste results in the highest strength and structural stability.*
*Replacing 0%–20% of plastic waste with coarse aggregate enhances the split tensile strength by 12%–15% compared to conventional concrete. However, there is a decrease in compressive and flexural strengths. The design mix concrete weight is 20-30% lighter than nominal concrete. For instance, M25 nominal concrete cube weight ranges from 9 - 9.3 kg, while the design mix M25 weighs 8.3 - 8.5 kg with 10% replacement, 8-8.3 kg with 20% replacement, and 7.4-7.7 kg with 30% replacement, demonstrating a gradual reduction in weight.*
*It is noteworthy that beyond a 20% plastic waste replacement, there is a sudden decline in compressive strength. The research emphasizes the benefits of reducing the use of natural resources, managing waste disposal, preventing pollution, and conserving energy. Additionally, the findings suggest that, for mass concreting purposes, the construction costs will gradually decrease for M25, M45, and M70, respectively.*
***Keywords:*** *Plastic Aggregate (coarse and fine), fly ash, silica fumes, GGBS, SCM, mineral admixture.*

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## I. INTRODUCTION

The utilization of cement concrete commenced with Sir Joseph Aspdin's invention of cement in 1824. Since then, various concrete mixtures with distinct properties have been developed. As infrastructure development gains momentum, the demand for concrete is rapidly increasing. However, traditional concrete has been linked to issues such as excessive weight, diminished durability, lower resistance to chemical attacks, and a shorter design lifespan. To address these challenges and enhance concrete performance, Fiber-Reinforced Cementitious Composites (FRCC) were introduced.

Annually, the concrete industry necessitates significant quantities of aggregates, including naturally occurring gravel and sand. In recent years, there has been a growing trend towards using recycled aggregates to manufacture lightweight concrete, thereby conserving natural resources. Admixtures are commonly incorporated to improve concrete properties and quality, encompassing strength and durability. Various materials such as GGBS, fly ash, silica fume, and rice husk can serve as substitutes for cement. Among these, silica fume, GGBS, and fly ash are the most frequently used cementitious materials to enhance concrete strength parameters. Each material possesses unique characteristics and properties that influence concrete differently.

Extensive experimental studies have been conducted to ascertain the optimum dosage of artificial aggregates and mineral admixtures to achieve optimal results. It has been observed that both excessive and insufficient use of artificial aggregates or mineral admixtures can have adverse effects on the strength, workability, and other factors of concrete. This paper aims to compare and summarize the optimal dosages based on independent research findings.

**Waste Recycled Plastic Aggregate (Artificial Aggregate)**

Artificial aggregates, comprising high-density plastics such as polypropylene, polyethylene, and polyvinyl chloride, are utilized as both coarse and fine aggregates in concrete blends. The inclusion of plastic aggregates serves a dual purpose: reducing the weight of concrete and contributing to the reduction of plastic waste. Recycled plastic waste can be crushed and amalgamated with other materials to craft artificial aggregates for construction applications. Given that plastics generally have lower density than most natural materials, it becomes feasible to produce lightweight aggregates with densities equivalent to those of natural aggregates.

In contrast to traditional lightweight aggregates that often exhibit high shrinkage and excessive water absorption, concrete mixed with recycled plastic aggregates (RPA) has shown promise in completely substituting conventional lightweight aggregates. This substitution results in an approximate 13% reduction in chloride penetration, although it does entail a decrease in compressive strength. Despite this reduction, the achieved strength of 12-15 MPa renders it suitable for non-structural components such as low-rise buildings, cement backfills, and sidewalks.

**Mineral Admixtures: Fly Ash (FA)**

Fly ash is a byproduct resulting from the combustion of coal in coal boilers and furnaces. This material, obtained from such processes, is classified into two categories: Class F and Class C. Class F fly ash is derived from the combustion of older anthracite and bituminous coal. It contains less than 10% lime and is characterized by poor binding properties. In contrast, Class C fly ash is produced by burning younger lignite coal. It contains over 20% lime, imparting superior cementitious properties.

Fly ash serves various purposes across different applications, including soil and road base stabilization, cement production (PCC or Portland Cement Concrete), embankment construction, the manufacture of fly ash bricks, and its use as structural fill. The diverse characteristics of Class F and Class C fly ash make them suitable for different applications, leveraging their unique properties to enhance the performance of various construction materials and processes.

**Silica Fume (SF):** Silica fume is an exceptionally effective pozzolanic material employed to enhance the mechanical properties and durability of concrete. It can be incorporated directly into concrete mixes or used as an additive in conjunction with Portland cement mixes and silica fumes. Initially, silica fume was primarily employed as a substitute for cement and as a water-reducing additive (WRAS). The advent of high-range water admixture reduction (HRWRAS), commonly known as superplasticizers, has opened up new possibilities for harnessing silica fume to achieve high-performance concrete.

Silica fume is applied in a variety of construction scenarios, including high-strength concrete, hydro and nuclear power stations, oil refineries, highway construction, dam and tunnel projects, as well as within the cement industry. Its versatility and impact on concrete properties make it a valuable component in enhancing the performance and longevity of concrete structures in diverse engineering and construction applications.

## II. OBJECTIVES OF THE WORK

- Investigate the properties of fiber-reinforced cement concrete (FRCC), including its advantages, limitations, and mix design.
- Examine the effects of partial cement replacement with industrial waste on strength parameters.
- Evaluate the inclusion of recycled plastic waste and its impact on strength parameters.
- Determine the optimal dosage of mineral admixtures and recycled plastic waste as aggregates.
- Investigate the behavior of FRCC under cyclic loading.
- Establish a common point curve under cyclic loading.
- Define a stability point curve under cyclic loading.

## III. METHODOLOGY

### 1. Selection Of Industrial Waste Material

Material selection is influenced by existing literature and material availability. Fly ash, readily accessible in nearby Indore city areas, boasts favorable cementitious properties. In contrast, GGBS is not locally available. Past research indicates that, as a cement replacement in high-performance concrete, fly ash exhibits superior durability and performance characteristics. Silica fume, a fine powdery material, is employed in concrete to achieve denser packing. Its small particle size of 0.1 micron enables it to fill smaller voids formed between fine sand and cement particles.

### 2. Test For Industrial Waste Material

Fly ash and silica fumes are tested for specific gravity using Le chatelier's flask method conforming to IS 2720-part3. The specific gravities of both the materials are obtained as 2.13 & 2.27. Properties of fly ash and silica fumes are checked conforming to IS:3812-1 (2003) [29] and IS:15388 (2003) [30] respectively.

### 3. Determination of Optimum Dosages

A total of 16 trial mixes were formulated to determine the optimal dosages of mineral admixtures and Recycled Plastic Waste Aggregate (RPWA). Once the materials were selected and their properties tested, the dosages of these materials needed to be determined. In the case of fly ash and silica fume, the consideration primarily focused on compressive strength parameters. However, when establishing the optimal dosages for RPWA, both compressive and tensile strength parameters were taken into account.

### 4. Mix Proportion of Conventional Concrete

**Trial Mix (Both for M25, M45 & M70)**
**Mix 1 -Controlled Nominal Mix**
**Mix 2-FA 20%**
**Mix 3-FA 25%**
**Mix 4-FA 30%**
**Mix 5-FA 35%**
**Mix 6-FA25 + SF05**
**Mix 7-FA25 + SF10**
**Mix 8-FA25 + SF15**
**Mix 9-FA25 + SF10 + RPA10%**
**Mix 10-FA25 + SF10 + RPA20%**
**Mix 11-FA25 + SF10 + RPA30%**
**Mix 12-FA25 + SF10 + RPA40%**
**Mix 13-FA25 + SF10 + RPA50%**
**Mix 14-FA25 + SF10 + RPA60%**
**Mix 15-FA25 + SF10 + RPA75%**
**Mix 16-FA25 + SF10 + RPA100%**

## IV. RESULTSAND DISCUSSION

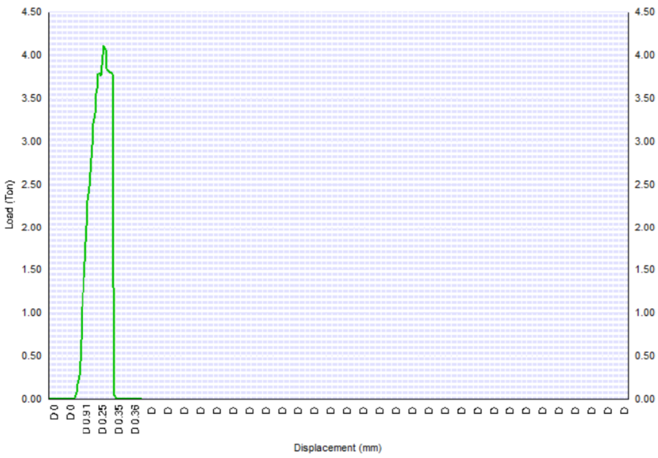


**Figure 1:** Nominal M25 Grade under monotonic loads.

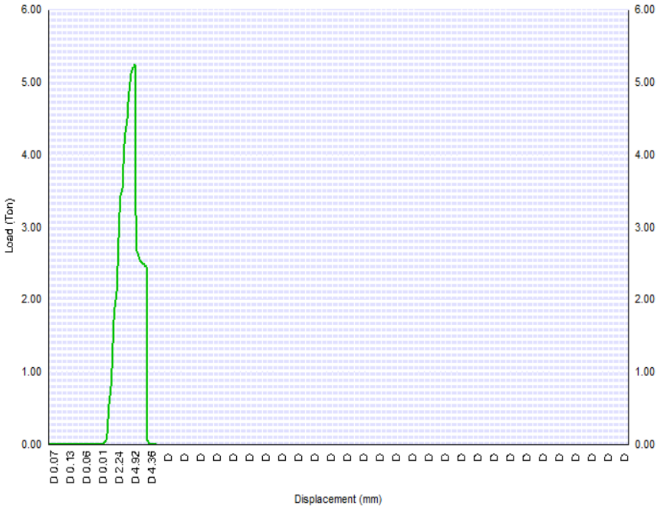


**Figure 2** M25 DM Grade under monotonic loads.

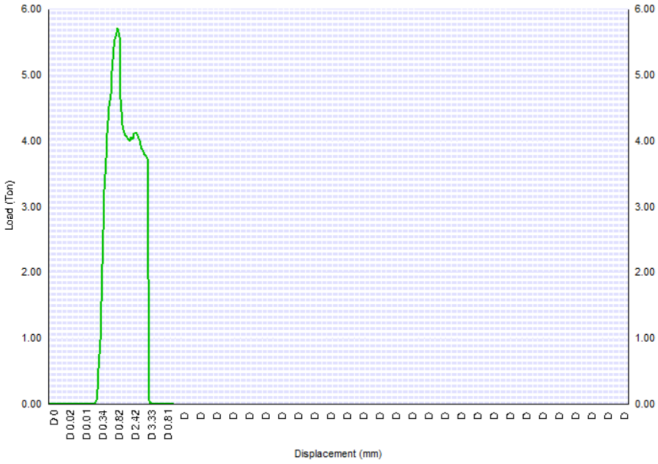


Figure 3. Nominal M45 Grade

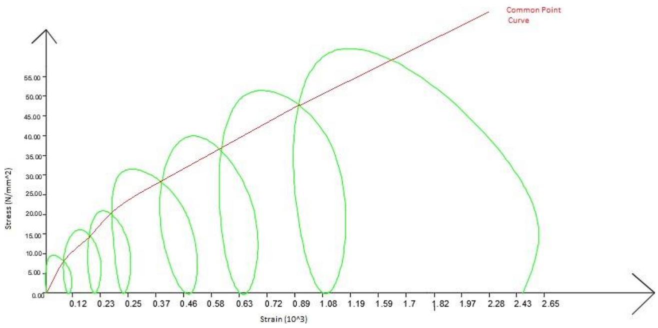


Figure 4. Common point curves for M25 DM cylinders.

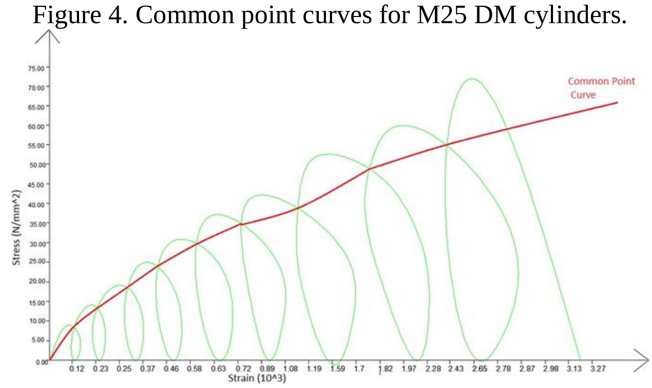


Figure 5 Common point curves for M70 DM cylinders.

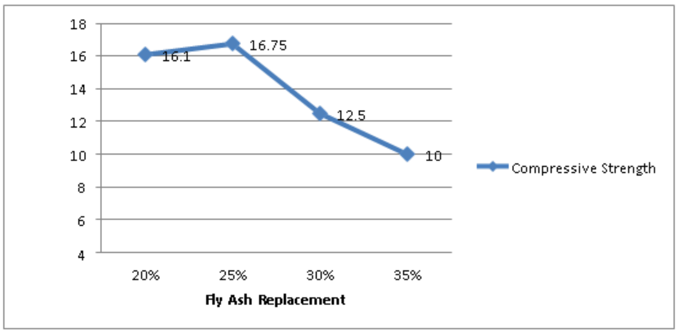


Figure 6 Optimum Dosage Curve of FA

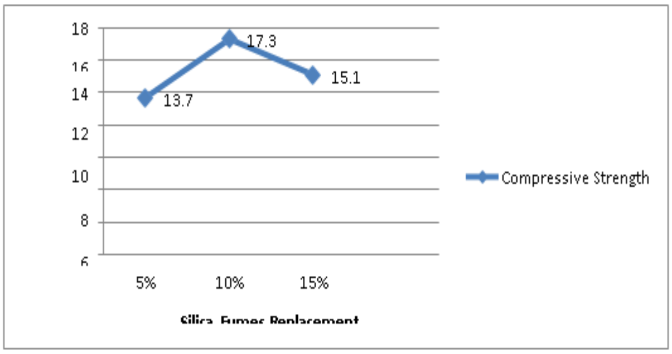


Figure 6 Optimum Dosage Curve of SF

## V. CONCLUSION

1. Based on the results obtained from the various trials, it can be concluded that the mixture containing 10% silica fume (SF), 25% fly ash (FA), and 20% plastic waste exhibits the highest strength and structural stability.
2. The replacement of coarse aggregate with 0% to 20% plastic waste leads to an improvement in the split tensile strength of concrete by approximately 12% to 15% compared to conventional concrete.
3. The weight of the lightweight concrete (DM concrete) is 20-30% lighter than nominal concrete. For example, the weight of M25 nominal concrete cubes ranged between 9.0-9.3 kg, while DM M25 cubes weighed around 8.3-8.5 kg with 10% replacement, 8-8.3 kg with 20% replacement, and 7.4-7.7 kg with 30% replacement. This demonstrates a significant reduction in weight as desired.
4. The incorporation of mineral admixtures leads to an increase in the compressive and tensile strength of the concrete by approximately 12% to 15%.
5. The study reveals that as the percentage of mineral admixtures increases, the workability of the concrete is adversely affected, necessitating a higher demand for superplasticizers.
6. When the plastic waste content exceeds 20%, the concrete experiences a sudden decrease in compressive strength.
7. All the specimens exhibited a parabolic relationship in their stress-strain curves until failure.
8. The stress-strain curve obtained under monotonic loading and the stress-strain curve obtained under cyclic loading almost coincide at their peaks.
9. The results indicate that as the grade of concrete increases from M25 to M45 and M70, the cost of construction gradually decreases.
10. Utilizing plastic waste in construction applications provides long-term sustainability compared to short-term recycling into new products that would eventually become waste.
11. The peak stresses corresponding to the common point and stability point range from 75% to 83% of the envelope curve.
12. Experimental measurements yielded an envelope stress-strain curve, a locus of common points, and a locus of stability points, which were used to develop block shear diagrams for the FRCC mixture containing 110% SF, 25% FA, and 20% plastic waste.
13. The cyclic stress-strain curve was utilized to determine the positions of the common point and stability points, which facilitated the development of block shear diagrams for the FRCC mixture.
14. The stress-strain envelope curve, common point curve, and stability point curve can be mathematically represented using polynomial and logarithmic functions. The correlation regression index for this curve ranges from 0.73 to 0.92, indicating good performance in the tests.
15. The peak stresses corresponding to the common point exceed 82% of the envelope curve.

16. The peak stresses corresponding to the stability points exceed 73% of the envelope curve.
17. The load cycles with peak stresses from the stability point curve clearly demonstrate the accumulation of plastic strain, below which the strain stabilizes and the model does not fail..

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