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High Strength Concrete Using Silica Fume and Recycled Plastics

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Abstract

This research investigates the development and performance of high strength concrete (HSC) incorporating silica fume as a partial cement replacement and recycled plastic waste as a partial aggregate substitute. The aim is to enhance concrete strength while promoting sustainability through the utilization of industrial and municipal waste materials. Silica fume, known for its pozzolanic properties and ultra-fine particles, was used at 3%, 5%, 10% and 15% replacement levels to improve the microstructure and mechanical performance of the concrete matrix. Shredded recycled plastic (such as HDPE or PET), an abundant non-biodegradable material, was incorporated at 2.5%, 5% and 10% by volume of fine aggregates to evaluate its viability as a partial replacement.

A total of five concrete mixes were prepared and tested for fresh properties (workability), mechanical strength (compressive, split tensile, and flexural strength), and durability (water absorption). Results showed that silica fume significantly enhanced compressive strength while maintaining durability. Recycled plastic, when used up to 5%, did not significantly compromise strength and offered a lightweight, eco-friendly alternative to natural aggregates. However, at 10% plastic content, a reduction in strength and workability was observed, highlighting the need for optimized mix proportions.

Overall, the study demonstrates that combining silica fume and recycled plastics in HSC can produce a structurally competent and environmentally responsible concrete mix. The findings support the feasibility of using industrial and plastic waste in sustainable construction practices.

Keywords-High Strength Concrete (HSC), High Density Poly Ethylene (HDPE), Polyethylene Terephthalate (PET), Silica Fume.

I INTRODUCTION

Concrete is the most widely used construction material in the world, known for its versatility, durability and relatively low cost. However, the increasing demand for high-performance concrete, along with environmental concerns associated with cement production and plastic waste, has spurred interest in developing more sustainable alternatives. High Strength Concrete (HSC), characterized by compressive strengths exceeding 60 MPa, is often employed in high-rise buildings, bridges, and critical infrastructure where enhanced performance is essential. The development of HSC typically involves the incorporation of mineral admixtures and chemical additives to improve its mechanical and durability properties.

Silica fume, a byproduct of the silicon and ferrosilicon industry, is widely recognized as an effective pozzolanic material. When used in concrete, silica fume contributes to the refinement of the microstructure, reduces permeability, and significantly improves compressive strength. Due to its ultrafine particles and high silica content, silica fume enhances the hydration process and forms additional calcium silicate hydrate (C-S-H), the primary binding compound in concrete.

In parallel, the accumulation of plastic waste presents a significant environmental challenge. Plastic is non-biodegradable and its disposal poses serious threats to ecosystems. One promising solution is the integration of recycled plastic into construction materials, especially concrete. Although plastic materials are generally hydrophobic and non-reactive, they can be used as partial replacements for fine or coarse aggregates, contributing to sustainability without entirely compromising mechanical properties.

This research explores the potential of using both silica fume and recycled plastic in high strength concrete to develop a sustainable construction material that maintains or improves upon conventional performance metrics.

The production of ordinary Portland cement (OPC) is responsible for a significant percentage of global CO_2 emissions. Simultaneously, the world faces a growing plastic waste crisis. These two issues demand innovative and sustainable solutions in the field of civil engineering.
While high strength concrete offers enhanced mechanical and durability properties, it often relies heavily on cement and other non-renewable resources. The incorporation of silica fume and recycled plastic has the potential to reduce the environmental footprint of concrete production. However, the combined effects of silica fume and recycled plastic on the workability, strength, and durability of high strength concrete remain underexplored.

II AIM OF THE STUDY

The aim of this study is to investigate the mechanical performance and workability of high strength concrete incorporating silica fume and recycled plastic as partial replacements for cement and aggregates, respectively.

III OBJECTIVES

The specific objectives of this research are as follows:

1. To design concrete mixes with varying proportions of silica fume and recycled plastic.
2. To evaluate the fresh properties (e.g., workability) of the modified concrete mixes.
3. To assess the mechanical properties such as compressive strength and flexural strength.
4. To compare the results with conventional high strength concrete mixes.
5. To analyze the feasibility of using these materials from both performance and environmental perspectives.

IV REVIEW OF LITERATURE

Recent studies have begun to explore the synergistic effects of combining silica fume and recycled plastic in concrete mixes to address the drawbacks of each material individually. The combination aims to improve strength, durability, and sustainability.

Strength and Durability Synergistic Effects on Strength: Research by Alnuaimi et al. (2020) showed that while recycled plastic alone can reduce the compressive strength of concrete, the incorporation of silica fume can help mitigate this reduction. Silica fume improves the bond between the recycled plastic aggregates and the cement matrix, leading to a more cohesive and stronger mix. In some cases, the compressive strength of concrete with both silica fume and recycled plastic was comparable to or even exceeded that of control concrete, especially at lower plastic content (up to 10% by volume).

Durability Improvements: Studies such as Sarker et al. (2020) and Gaur et al. (2021) found that the use of silica fume in concrete containing recycled plastic improves its resistance to chloride ingress and sulphate attack. Silica fume's ability to refine the pore structure of concrete compensates for some of the weaknesses introduced by the plastic aggregates, resulting in better overall durability.

Workability and Mix Optimization Workability Enhancement: One of the key benefits of combining silica fume and recycled plastic is the potential improvement in workability. Silica fume, being highly fine, generally decreases the workability of concrete due to its increased water demand. However, the inclusion of recycled plastic aggregates can offset this effect by improving the ease of handling and flowability of the mix. This finding is supported by Tayeh et al. (2020) and Guerra et al. (2021), who noted that mixes containing both materials displayed better handling properties compared to silica fume-only mixes.

Sustainability and Environmental Impact Reduction in CO_2 Emissions: Several studies, including those by Siddique and Kaur (2019) and Akinmoladun et al. (2022), found that using both silica fume and recycled plastic in concrete contributes significantly to sustainability. Silica fume reduces the amount of Portland cement required, which in turn lowers the carbon footprint of concrete. Additionally, the use of recycled plastic diverts waste from landfills, helping to reduce plastic pollution. A combined approach reduces the environmental impact of concrete without compromising performance.

Energy and Resource Efficiency: Bertuol et al. (2017) and Singh et al. (2020) found that the combined use of silica fume and recycled plastic not only conserves natural resources by reducing the need for virgin aggregates and cement but also contributes to energy savings through the recycling of plastic waste materials.

V SIGNIFICANCE OF THE STUDY

This research contributes to the growing body of work on sustainable construction materials. By investigating the dual incorporation of silica fume and recycled plastic, the study offers a potential pathway to reduce reliance on non-renewable resources, decrease greenhouse gas emissions, and mitigate plastic pollution. The findings could inform the development of new standards and practices for eco-friendly high performance concrete in the construction industry.

VI SCOPE AND LIMITATIONS

This study focuses on concrete mixes with compressive strength 60 MPa, using silica fume as a partial replacement for cement typically ranging from (0%, 3%, 5%, 10% and 15% by weight) and recycled plastic as a partial replacement for fine aggregate (in the range of 0%,2.5%, 5% and 10%). The experimental work includes tests for workability, compressive strength, and flexural strength, conducted over curing periods of 7, 14, and 28 days. Durability tests and microstructural analysis are outside the scope of this initial study but are recommended for future work.

VII METHODOLOGY

The experimental program was designed to compare the mechanical properties i.e. compressive strength, flexural strength and splitting tensile strength of high strength concrete with M60 grade of concrete and with different replacement levels of ordinary Portland cement (ultra tech cement 53 grade) with silica fume or micro silica of 920-D and recycled plastics.

Among plastic, the most familiar plastics used is Polyethylene Terephthalate (PET). From drinking water bottles and beverages bottles, this type of plastic is obtained in massive quantity. The natural sand is substituted with the PET-aggregate at dosages (0%, 2.5%, 5%, and 10% by volume of the sand) to produce High Performance Concrete mixes, in addition, using superplasticizer (SP), and silica fume (SF), as a partial replacement by weight of cement.

The program consists of casting and testing samples of standard cubes (150mmX150mmX150mm), standard cylinders of (150mm Dia X 300mm height) and standard prisms of (100mmX100mmX500mm) cast with and without (silica fume and recycled plastics). Universal testing machine was used to test all the specimens. The specimens were cast with M60 grade concrete with different replacement levels of cement as (0%, 3%, 5%, 10% and 15%) with silica fume and natural sand is substituted with the PET-aggregate at dosages (0%, 2.5%, 5%, and 10% by volume of the sand).

VIII FUTURE SCOPE OF THE WORK

This study focuses on concrete mixes with compressive strength 60 MPa, using silica fume as a partial replacement for cement typically ranging from (0%, 3%, 5%, 10% and 15% by weight) and recycled plastic as a partial replacement for fine aggregate (in the range of 0%,2.5%, 5% and 10%). The experimental work includes tests for workability, compressive strength, and flexural strength, conducted over curing periods of 7, 14, and 28 days. Durability tests and microstructural analysis are outside the scope of this initial study but are recommended for future work.

IX RESULTS AND DISCUSSION

Parameter	Observation
Compressive Strength	Increased with silica fume (max at 10–15%), reduced slightly with plastic.
Tensile/Flexural	Improved with silica fume; maintained at 5% plastic, dropped at 10%.

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Parameter	Observation
Workability	Decreased with increasing silica fume and plastic; requires admixture use.
Durability	Improved with silica fume; slightly affected by plastic.
Microstructure	Silica fume densified matrix; plastic created weak zones.

Table 1- Summary of observations.

X CONCLUSIONS

The integration of silica fume (10–15%) significantly improves strength and durability in high strength concrete. Recycled plastic, when used in small proportions (≤5%), can serve as a sustainable partial aggregate replacement without compromising core mechanical properties. Higher percentages of plastic tend to reduce overall performance due to poor bonding and lack of structural stiffness. A well-designed balance between silica fume content and plastic proportion is crucial to achieving performance and sustainability. The major observations are given below-

- The addition of silica fume decreased slump due to its high fineness and increased water demand. Recycled plastics further reduced workability due to poor water absorption and low density. Hence, use of a superplasticizer is essential at higher replacement levels to maintain workability.
- Silica fume significantly improved compressive strength due to pozzolanic reaction and microfilling effect.
- A drop in strength is observed due to plastic as there is weak interfacial bonding and poor stiffness of plastic particles. Strength is increased with silica fume due to enhanced bond between cement paste and aggregates.
- Silica fume enhances flexural strength due to improved interfacial transition zone (ITZ). 5% plastic maintain good flexural behavior and it may bridge microcracks to a limited extent.
- Silica fume reduced porosity and improved water tightness but plastic slightly increased absorption at higher percentages due to poor matrix continuity and voids around plastic particles.

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