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ENHANCING HIGH STRENGTH CONCRETE PERFORMANCE THROUGH THE SYNERGISTICS USE OF FLY ASH AND MICRO SILICA: A FOCUS ON M70 GRADE CONCRETE

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Abstract:

This research paper investigates the synergistic effects of fly ash and micro silica on the performance of M70 grade high strength concrete. The incorporation of these supplementary cementitious materials (SCMs) aims to enhance mechanical properties, durability, and sustainability of the concrete. Comprehensive experimental work is conducted to compare the compressive and flexural strengths, and durability aspects of plain concrete versus concrete with varying proportions of fly ash and micro silica. The results indicate significant improvements in performance metrics, underscoring the potential of these materials to address the limitations of conventional high strength concrete.

Keywords: High-strength concrete, fly ash, micro silica, M70 grade, compressive strength, sustainability, Flexural Strength, Durability, Sustainability.

Introduction:

1.1 Background

High strength concrete plays a vital role in modern construction, demanding continual enhancement of its properties. This study focuses on the combined utilization of Flyash and micro silica to address the challenges associated with conventional high strength concrete, aiming to achieve superior performance in terms of strength, durability, and sustainability. Concrete is a fundamental construction material, and optimizing its properties is crucial for ensuring structural performance. This research focuses on the potential benefits of incorporating Flyash and micro silica into high-strength M70 concrete. These supplementary materials not only enhance strength but also address environmental concerns associated with traditional concrete production.

Microsilica and Flyash are two essential materials in modern construction, offering significant advantages in strength, durability, and environmental sustainability. Microsilica, also known as silica fume, is a byproduct of the production of silicon metal or ferrosilicon alloys and is composed of fine particles of silicon dioxide. Flyash, a byproduct of coal combustion, consists mainly of fine particles that are carried out of the boiler with flue gases.

Their integration into concrete design represents both innovation and pragmatism, leveraging advancements in material science to enhance the performance of concrete structures while addressing environmental concerns. Rapid developments in construction materials technology have empowered civil and structural engineers to achieve remarkable improvements in safety, cost-effectiveness, and functionality of structures serving societal needs. The utilization of microsilica and Flyash in concrete mixtures leads to composite materials with enhanced mechanical properties, improved workability, and increased durability. These materials effectively mitigate common challenges faced by conventional concrete, such as low tensile strength and susceptibility to cracking.

Microsilica and Flyash can be incorporated into various concrete applications, including but not limited to bridges, industrial floors, pavements, overlays, high-rise buildings, and infrastructure projects. Their versatility extends to diverse construction scenarios, from conventional cast-in-place concrete to precast and prestressed elements. Microsilica and Flyash offer distinctive benefits as reinforcing agents for concrete. Microsilica enhances the packing density and particle interaction within the concrete matrix, resulting in higher strength and reduced permeability. Flyash contributes to improved workability, reduced heat of hydration, and increased long-term strength development. Both materials come in various forms and sizes, offering flexibility in design and application. Their incorporation into concrete mixtures requires careful consideration of factors such as particle size distribution, dosage, and compatibility with other admixtures. The integration of microsilica and Flyash represents a paradigm shift in concrete technology, providing engineers and builders with sustainable solutions to meet the evolving demands of modern construction projects.

1.2. Necessity

The advancement of the building industry is associated with continuous research, development, and design of new and improved materials and construction structures. The construction of mega structures requires materials with increasingly improved properties, particularly strength, stiffness, toughness, ductility, durability, and chemical resistance to various aggressive media. Concrete is an inherently brittle material with a relatively low tensile strength compared to compressive strength. Nowadays, research on cement matrix materials is focused on the inclusion of additives, polymeric admixtures, and fibers to improve certain physical and mechanical properties while maintaining strength, low cost, and capacity to fill almost any shape.

Adherence, permeability, ductility, flexural strength, thermal and acoustical insulation, fire performance, and viscous damping are some of the main research lines on cement matrix materials. In recent years, the demand for high-quality cements, concrete, and mortars has greatly increased. This is due to problems with the durability of concrete structures. Environmental conditions play a major role in the deterioration of buildings. Many pollutants present in the environment (i.e., in water, soil, air, etc.) eventually promote concrete deterioration and steel corrosion in industrial and other concrete structures. Concrete made with Ordinary Portland Cement (OPC) possesses certain inherent drawbacks such as poor tensile strength, poor chemical and corrosion resistance, poor bonding with old concrete, etc.

The development of new materials having very high mechanical and durability performances is given considerable attention in high-strength concrete using flyash and microsilica. High-strength concrete using flyash and microsilica is gaining acceptance in the construction industry. Safety, economy, durability, and functionality of structures are mainly considered at the time of design. A number of investigations have been carried out to evaluate the potential of high-strength concrete for structural applications. High-strength concrete has been successfully used for a number of applications over the last four decades. Despite the common usage of concrete, few people are aware of the considerations involved in designing strong, durable, high-quality concrete structures.

1.3. Objectives

The objectives of the present experimental work are to develop a methodology and evolve contributions with reference to the following:

1. To compare the results between plain concrete and high-strength concrete using microsilica and flyash.

2. To determine the compressive strength of the concrete.

3. To determine the flexural strength and toughness.

4. To prepare load versus deflection curves.

5. To decide and suggest the suitability and use of high-strength concrete using microsilica and flyash.

1.4. Theme

With the advancement of material technology, many materials, such as micro silica and fly ash, are introduced as construction and repair materials. Therefore, one valid approach is to improve the concrete itself, and another is to combine micro silica and fly ash with concrete to create new components and develop new technologies. Micro silica and fly ash play a role at two different levels in the cracking process of concrete. At the material level, they can improve the strength and the ductility of the concrete. At the structural level, they can enhance the load-bearing capacity and the ductility of the structures.

The mechanical properties of these materials depend on various factors such as volume fraction, particle size, shape, type, orientation, and aspect ratio of micro silica and fly ash. Additionally, preparation, vibration, and placement procedures influence the properties of the resulting concrete.

The addition of micro silica and fly ash to concrete can increase its strength, stiffness, ductility, and resistance to adverse environmental conditions. Micro silica and fly ash modified concrete exhibits excellent bonding to steel reinforcement and old concrete, good ductility, resistance to penetration of water and aqueous salt solutions, and resistance to freeze-thaw damage. It has been effectively used as a suitable repair material.

In experimental work, for each mix of composite, a total of six specimens of various types are prepared:

(a) For compressive strength test, cubes of size 150 mm x 150 mm x 150 mm are prepared.

(b) For flexure test, prism specimens of size 150 mm x 150 mm x 700 mm are prepared.

All the above specimens are prepared with various volume fractions of micro silica and fly ash, ranging from 6% to 10% of the weight of cementitious material.

1.5 Scope

This research focuses on the M70 grade concrete, exploring various mix proportions of fly ash and micro silica to identify the optimal combination for enhanced performance. The study includes preparing and testing concrete specimens for compressive and flexural strengths, analyzing the results to recommend the best practices for using these SCMs in high-strength concrete applications.

2. Literature Review

The literature review on the utilization of fly ash and silica fume in concrete spans various research studies focusing on their effects on the mechanical and durability properties of concrete. Chai Jaturapitakkul's work investigates the impact of fly ash particle size and combustion conditions on the strength development of concrete, finding that certain fly ash fractions can enhance early strength [1]. Thanongsak Nochaiya's study explores Portland-fly ash cement with silica fume, highlighting that silica fume's fine particles increase water demand but improve concrete's overall properties [2].F.U.A. Shaikh examines high-volume fly ash concrete incorporating nano-silica, demonstrating that nano-silica can enhance both compressive strength and durability against harsh environmental conditions[3].Deng-Deng Zheng's research on magnesium-potassium phosphate cement shows how fly ash and silica fume combinations can improve the setting times and mechanical properties of this novel binder[4].L. Ponraj Sankar's investigation into finely ground fly ash and silica fume reveals significant improvements in concrete's fresh and hardened states, promoting high-performance concrete applications[5].Mehran Khan assesses coconut fiber-reinforced concrete with fly ash and silica fume, finding enhanced toughness and crack resistance[6].Daniel Hatungimana's work indicates that the inclusion of silica fume and fly ash in mortar improves its resistance to chloride ion penetration, crucial for reinforced concrete structures[7].V.V. Sai Chand’s study on chloride ion ingress concludes that higher fly ash content significantly reduces chloride diffusion, enhancing concrete durability in corrosive environments[8]. Sathi Kranthi Vijaya's research emphasizes the role of mineral admixtures like fly ash and silica fume in increasing flexural and compressive strength, thus promoting the use of sustainable materials in concrete[9].Liaqat Ali Qureshi explores recycled aggregate concrete incorporating silica fume and fly ash, demonstrating that these additions can significantly improve the mechanical and durability properties of recycled concrete aggregates[10].Suseela Alla's study on robosand, fly ash, and silica fume shows that these materials enhance the durability and strength of concrete, making it more sustainable and cost-effective[11].Shaswat Kumar Das investigates ambient curing of fly ash geopolymers with lime and silica fume, showing improvements in strength and durability under ambient conditions[12].M.D. Ikramullah Khan evaluates the effect of fly ash and polypropylene fibers on micro-cracks in concrete, finding that these additions can reduce shrinkage cracks and enhance durability[13].Sachin Patil’s research on fly ash, silica fume, glass, and polypropylene fibers demonstrates their combined effect on improving acid resistance and mechanical properties of concrete[14].Rakesh Choudharys study on self-compacting high-strength concrete indicates that the combined use of silica fume and fly ash can achieve high strength and durability, making it suitable for advanced construction needs[15].Thanongsak Nochaiya’s second study focuses on organic acid corrosion resistance in pig farm environments, showing significant improvements in concrete durability with fly ash and silica fume[16].Qiang Fu investigates erosion behavior in lining concrete, concluding that fly ash and silica fume significantly enhance erosion resistance, critical for structures exposed to aggressive environments[17].Dheeresh Kumar Nayak explores sustainable development in concrete, highlighting fly ash’s role in reducing the carbon footprint of cement production while improving concrete properties[18]. Dashdondog Oyunbileg’s research on freeze-thaw resistance finds that silica fume and fly ash significantly improve high-strength concrete's performance under freeze-thaw cycles, making it more durable in cold climates [19]. Ganesh Prabhu Ganapathy studies vegetation porous concrete, showing that the incorporation of fly ash and silica fume enhances permeability and durability, beneficial for green infrastructure projects [20].

3. Methodology

3.1 Material Selection and Mix Design

The materials used in this study include Ordinary Portland Cement (OPC), Flyash, and Microsilica. The aggregates used are coarse and fine aggregates conforming to standard specifications. The mix design is based on the guidelines provided by relevant standards, and the proportioning is aimed at achieving M70 grade concrete.

Table 1

Chemical compositions of Portland cement, fly ash and silica fume.

	Portland cement (%)	Flyash (%)	Silica fume (%)
Oxide			
SiO_2	20.8	39.8	95.3
Al_2O_3	5.0	21.5	0.6
Fe_2O_3	3.5	13.7	0.3
CaO	64.3	15.2	0.3
MgO	1.5	2.8	0.4
Na_2O	0.1	1.1	0.3
K_2O	0.6	2.0	0.8
P_2O_5	–	0.2	1.2
TiO_2	–	0.4	–
MnO_2	–	0.1	–
SO_3	2.6	2.4	0.2
CaO free	0.7	2.2	–
Loss on ignition (LOI)	1.4	0.1	–
Bogue compounds			
C_3S	54.8	–	–
C_2S	18.3	–	–
C_3A	7.3	–	–
C_4AF	10.7	–	–

3.2 Preparation of Specimens

Concrete mixes with varying proportions of Flyash and Microsilica (6%, 8%, and 10% by weight of cementitious material) are prepared. The mixing process involves careful batching, mixing, and placement to ensure uniformity and consistency. Specimens are cast in steel molds and subjected to standard curing conditions.

3.3 Mix Proportions

Concrete mixes were prepared with varying proportions of fly ash by weight of cement and micro silica (0%, 6%, 7% 8%, 9%,10% by weight of cement). The water-to-cement ratio was kept constant at 0.26.

MIX PROP./UNIT BATCH WEIGHTS / M 3	M70 Grade with 19% replacement of flyash & 0% replacement of microsilica	M70 Grade with 19% replacement of flyash & 6% replacement of microsilica	M70 Grade with 19% replacement of flyash & 7% replacement of microsilica	M70 Grade with 19% replacement of flyash & 8% replacement of microsilica	M70 Grade with 19% replacement of flyash & 9% replacement of microsilica	M70 Grade with 19% replacement of flyash & 10% replacement of microsilica
CEMENT , Kg	448	443	437	431	425	419
Flyash , Kg	142	112	112	112	112	112
CRUSHED SAND Kg	751	751	751	751	751	751
COARSE 1 (10MM) Kg	370	370	370	370	370	370
COARSE 2 (20MM), Kg	695	695	695	695	695	695
WATER in Kgs	155.0	155.0	155.0	155.0	155.0	155.0
ADMIX 1.0 %, in Kgs	5.900	5.900	5.900	5.900	5.900	5.900
Micro Silica	0.000	35.000	41.000	47.000	53.000	59.000
Theoretical B.D =	**2566.90**	**2566.90**	**2566.90**	**2566.90**	**2566.90**	**2566.90**

3.4 Specimen Preparation

- Compressive Strength: Cubes of size 150 mm × 150 mm × 150 mm.

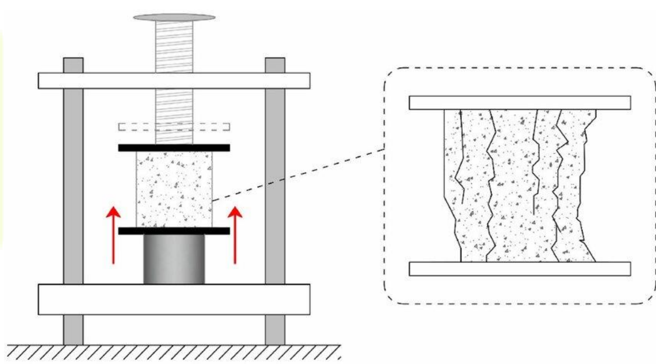
- Flexural Strength: Prisms of size 150 mm × 150 mm × 700 mm.

Specimens were cured in water at 27°C and tested at 7, 28 days.

3.5 Tests conducted

Compressive strength (fcu)

The compression strength test was performed to find out compressive strength of normal concrete, polymer modified concrete and polymer modified steel fibre reinforced concrete using cube specimens, confirming to IS:51641. The test was carried out using compression testing machine of capacity 2000 kN.



The compressive strength of specimen was calculated in accordance with IS: 516.The compressive strength of the specimen is calculated by dividing the maximum load applied to the specimen during the test by the cross-sectional area, i.e. by using the formula,

$$f_{cu} = \frac{P_c}{A}$$

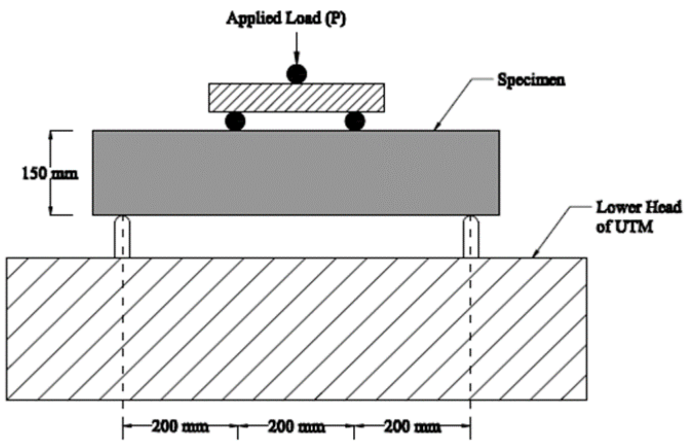
where fcu = Compressive strength of concrete in MPa

Pc = Maximum applied load in kN

A = Cross sectional area in mm2

Flexural strength (fcr)

To find out flexural strength of concrete, prism specimens of size 150 × 150 × 700 mm were used and tested according to IS:51641 and/or ASTM C1609/ C1609M42. The arrangement for loading of flexure test specimen is shown in Fig. 1.



The flexural strength of the specimen shall be expressed as the modulus of rupture (fb) and calculated by using following expression

$$f_b = \frac{Pl}{bd^2}$$

when 'a' is greater than 200 mm, or

$$f_b = \frac{3Pa}{bd^2}$$

when 'a' is less than 200 mm but greater than 170 mm.

where

P = Maximum applied load to the specimen in kN

a = the distance from the line of fracture to the nearer support, measured on the center line of the tensile side of the specimen in mm (Note: if 'a' is less than 170mm then the results of the test shall be discarded).

b = measured width of the specimen in mm.

d = measured depth of the specimen at the point of failure in mm.

l = length of the span on which the specimen is supported in mm.

In this test, deflections have been recorded with reference to neutral axis of the prism to get the correct load deflection behavior and to compute the correct flexural toughness using load-deflection graphs and the modulus of elasticity from load-deflection equation.

4. Analysis

The experimental results are analyzed to compare the performance of high-strength concrete incorporating Flyash and Microsilica with that of plain concrete. The data is used to determine the optimal proportions of Flyash and Microsilica for achieving desired mechanical properties.

5. Results and Discussion

5.1 Compressive Strength

The compressive strength results indicate that the incorporation of Flyash and Microsilica significantly enhances the strength of concrete. The highest strength is observed at 10% replacement levels of both materials.

5.2 Flexural Strength and Toughness

Flexural strength and toughness measurements show improvements in load-bearing capacity and ductility with the addition of Flyash and Microsilica. The load versus deflection curves demonstrates increased energy absorption and resistance to cracking.

6. Suitability and Application

Based on the experimental results, high-strength concrete with Flyash and Microsilica is suitable for various structural applications, offering improved performance and sustainability.

5. Conclusion

This study demonstrates that the combined use of Flyash and Microsilica in high-strength concrete enhances mechanical properties and addresses environmental concerns. The optimized mix design provides a sustainable solution for modern construction, with significant improvements in compressive strength, flexural strength, and durability

The synergistic use of fly ash and micro silica significantly enhances the performance of M70 grade high strength concrete. These materials not only improve the mechanical properties but also increase the durability and sustainability of the concrete. This study recommends the optimal proportions of fly ash and micro silica for achieving superior performance in high strength concrete applications. Future research should focus on long-term durability studies and the economic implications of using these supplementary cementitious materials.

References :

1. Chai Jaturapitakkul et al 2004 "Use of ground coarse fly ash as a replacement of condensed silica fume in producing high-strength concrete" Science Direct Engineering Structures 34 (2004) 549 – 555
2. Thanongsak Nochaiya et al 2010 "Utilization of fly ash with silica fume and properties of Portland cement–fly ash–silica fume concrete" Science Direct Engineering Structures 89 (2010) 768–774
3. F.U.A. Shaikh et al 2014 "A study on the effect of nano silica on compressive strength of high volume fly ash mortars and concretes" Science Direct Engineering Structures 60 (2014) 433–442
4. Deng-Deng Zheng et al 2016 "Effect of the combination of fly ash and silica fume on water resistance of Magnesium–Potassium Phosphate Cement" Science Direct Engineering Structures 106 (2016) 415–421
5. L. Ponraj Sankar et al 2019 "Investigation on binder and concrete with fine grinded fly ash and silica fume as pozzolanic combined replacement" Science Direct Engineering Structures 2019
6. Mehran Khan et al 2019 "Improvement in concrete behavior with fly ash, silica-fume and coconut fibers" Science Direct Engineering Structures 203 (2019) 174–187
7. Daniel Hatungimana et al 2019 "Compressive strength, water absorption, water sorptivity and surface radon exhalation rate of silica fume and fly ash based mortar" Science Direct Engineering Structures 23 (2019) 369–376
8. V.V. Sai Chand et al 2020 "Investigation on chloride penetration in concrete mixes of different cement replacement percentages with fly ash and silica fume" Science Direct Engineering Structures 2020
9. Sathi Kranthi Vijaya et al 2020 "Behaviour of M60 grade concrete by partial replacement of cement with fly ash, rice husk ash and silica fume" Science Direct Engineering Structures 2020
10. Liaqat Ali Qureshi et al 2020 "Combined effects of supplementary cementitious materials (silica fume, GGBS, fly ash and rice husk ash) and steel fiber on the hardened properties of recycled aggregate concrete" Science Direct Engineering Structures 263 (2020) 120636
11. Suseela Alla et al 2020 "An experimental investigation for replacements of river sand and cement with Robosand, fly-ash and silica fume in concrete to evaluate the influence in durability properties" Science Direct Engineering Structures 2020
12. Shaswat Kumar Das et al 2020 "Fresh, strength and microstructure properties of geopolymer concrete incorporating lime and silica fume as replacement of fly ash" Science Direct Engineering Structures 32 (2020) 101780
13. M.D. Ikramullah Khan et al 2020 "The impact of fly ash and structural fiber on the mechanical properties of concrete" Science Direct Engineering Structures 2020
14. Sachin Patil et al 2021 "Durability and micro-structure studies on fly ash and silica fume based composite fiber reinforced high-performance concrete" Science Direct Engineering Structures 2021
15. Rakesh Choudhary et al 2021 "Permeation, corrosion, and drying shrinkage assessment of self-compacting high strength concrete comprising waste marble slurry and fly ash, with silica fume" Science Direct Engineering Structures 33 (2021) 971–985
16. Thanongsak Nochaiya et al (2022) "Acidic corrosion-abrasion resistance of concrete containing fly ash and silica fume for use as concrete floors in pig farm" Science Direct Engineering Structures 28 (2006) 690-703.
17. Qiang Fu et al 2022 "Erosion behavior of ions in lining concrete incorporating fly ash and silica fume under the combined action of load and flowing groundwater containing composite salt" Science Direct Engineering Structures 17 (2022) e01659
18. Dheeresh Kumar Nayak et al 2022 "Fly ash for sustainable construction: A review of fly ash concrete and its beneficial use case studies" Science Direct Engineering Structures 6 (2022) 100143

19. Dashdondog Oyunbileg et al 2023 “Evaluation of thermal and freeze-thaw resistances of the concretes with the silica fume addition at different water-cement ratio” Science Direct Engineering Structures 19 (2023) e02633
20. Ganesh Prabhu Ganapathy et al 2023 “Effects of fly ash and silica fume on alkalinity, strength and planting characteristics of vegetation porous concrete” Science Direct Engineering Structures 2023;24:5347 e5360