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Impact of Silica Fume on High-Strength Concrete

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Abstract

For many decades, concrete has been the primary material used in construction because of its reliability under normal conditions. However, certain applications necessitate concrete with exceptionally high compressive strength and durability, particularly in aggressive environments. Consequently, achieving compressive strengths in the range of 60–140 MPa is critical for these demanding situations. Silica fume, a by-product of silicon and ferrosilicon smelting processes, has gained recognition as an effective cementitious material for enhancing concrete properties. This dissertation investigates the impact of substituting a portion of cement with silica fume in high-strength concrete, specifically employing an M80 concrete mix with a 14.58% replacement by weight of cement. The study involves a series of experiments to measure the compressive strength of the modified concrete at 7, 14, and 28 days. Findings reveal that the inclusion of silica fume results in a 15% increase in compressive strength. Therefore, incorporating silica fume not only improves the performance of high-strength concrete but also reduces the cement requirement, promoting sustainability in construction practices. These results suggest that silica fume should be widely adopted for its performance-enhancing and eco-friendly benefits.

Keywords: Compressive strength, high strength concrete, M80 grade, mix design, silica fume

INTRODUCTION

Among the numerous materials utilized in the construction industry, concrete stands out as one of the most widely used. This widespread use is largely due to the easy availability of its basic components: cement, fine and coarse aggregates, and water. For concrete to be considered of good quality, it must be workable when fresh, homogeneous, and resistant to segregation. Once it hardens, it should achieve the necessary strength, making an effective mix design crucial in construction [1–5].

Silica fume, also known as micro silica or condensed silica fume, is used as a synthetic pozzolanic admixture. It is produced during the manufacture of silicon or ferrosilicon alloys, where quartz is reduced with coal in an electric arc furnace. Chemically, silica fume consists of more than 90% silicon dioxide, along with trace amounts of carbon, sulfur, and oxides of aluminum, iron, calcium, magnesium, sodium, and potassium. Physically, silica fume particles have a diameter ranging from 0.1 to 0.2 microns, a surface area of approximately 30,000 $m^2\ kg^{-1}$, and a density that varies between 150 and 700 $kg\ m^{-3}$ [6–9].

LITERATURE REVIEW

The incorporation of silica fume in concrete has been widely researched due to its positive effects on the performance of high-strength concrete. Silica fume, a by-product of the silicon and ferrosilicon alloy production process, is recognized for its high silica content and pozzolanic properties, which enhance concrete strength and

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durability [10–17].

The strength and permeability of high-performance concrete. They concluded that silica fume significantly increases both compressive strength and impermeability, making it ideal for applications requiring high durability and strength [18–27].

The effects of partially replacing cement with silica fume in concrete. Their findings indicated that silica fume enhances compressive strength and reduces permeability, thus extending the concrete's lifespan and resistance to harsh environments [28–32].

The performance of high-strength concrete incorporating both nano silica and silica fume. Their research demonstrated that the combination significantly boosts mechanical properties, including compressive strength and modulus of elasticity.

On self-compacting concrete using silica fume. They highlighted that silica fume improves the flowability and filling capacity of self-compacting concrete while also enhancing its strength and durability [22–35].

High-strength concrete using fly ash and silica fume. Their research showed that the combination of these materials results in significant improvements in mechanical properties, such as increased compressive and tensile strengths, and enhanced durability [36–38].

The characterization of silica fume and its impact on concrete properties. They noted that silica fume acts as both a filler and a pozzolanic material, reducing porosity and enhancing the microstructure of concrete, leading to improved strength and durability [39–46].

The performance of silica fume in new and hardened concrete structures. They found that silica fume significantly improves compressive strength, tensile strength, and durability, making it an excellent additive for high-performance applications.

The influence of silica fume on concrete. Their findings suggest that silica fume increases concrete density and reduces permeability, resulting in enhanced mechanical properties and durability.

The effect of silica fume on high-strength concrete performance. Their research indicated that silica fume enhances compressive strength and reduces shrinkage and permeability, making concrete more durable and suitable for high-stress environments.

The changes in concrete properties with the use of silica fume. They found that silica fume improves mechanical properties, resistance to chemical attacks, and reduces the environmental footprint by partially replacing cement.

Overall, the literature consistently shows that silica fume significantly enhances the mechanical properties and durability of high-strength concrete. Its use as a partial replacement for cement contributes to the development of sustainable, high-performance concrete suitable for various demanding construction applications.

METHODOLOGY

The methodology for examining the effect of silica fume on high-strength concrete involves a systematic approach and detailed experimental procedures. The primary objective is to evaluate the effects of partially replacing cement with silica fume on the compressive strength and other properties of high-strength concrete. The following steps outline the detailed methodology:

Materials

Cement

Use Ordinary Portland Cement (OPC) of 53 grade.

Silica Fume

Utilize silica fume, an industrial by-product from the silicon and ferrosilicon alloy production process.

Aggregates

Employ both fine (sand) and coarse aggregates.

Water

Use clean, potable water for mixing.

Admixtures

Incorporate superplasticizers to improve workability.

Mix Design

Design a high-strength concrete mix (M80 grade) in accordance with IS 10262: 2019 guidelines. Determine the mix proportions for cement, silica fume, aggregates, water, and admixtures.
Calculate the required quantities for the mix design.

Preparation of Specimens

Control Mix

Prepare a control mix without silica fume to serve as a baseline.

Test Mix

Prepare test mixes with silica fume partially replacing cement at 14.58% by weight of cement.
Ensure thorough mixing to achieve a uniform blend.

Casting and Curing

Cast concrete specimens (cubes) of standard dimensions (150 mm × 150 mm × 150 mm) for each mix.

Compact the mix using a vibrating table to eliminate air voids and ensure proper density. Cure the specimens in water for durations of 7, 14, and 28 days to achieve proper hydration.

Testing

Compressive Strength Test: Conduct compressive strength tests on the cured specimens using a compression testing machine at 7, 14, and 28-day intervals. Record the compressive strength values and compare them with those of the control mix.

Data Analysis

Analyze the compressive strength results to evaluate the impact of silica fume on high-strength concrete.

Calculate the percentage increase in strength relative to the control mix.

Conduct statistical analysis to ensure the validity of the results.

DISCUSSION

Interpret the results to understand how silica fume affects the properties of high-strength concrete.

Discuss the practical implications of using silica fume in terms of strength, durability, and sustainability Figures 1 and 2 and Tables 1 and 2.

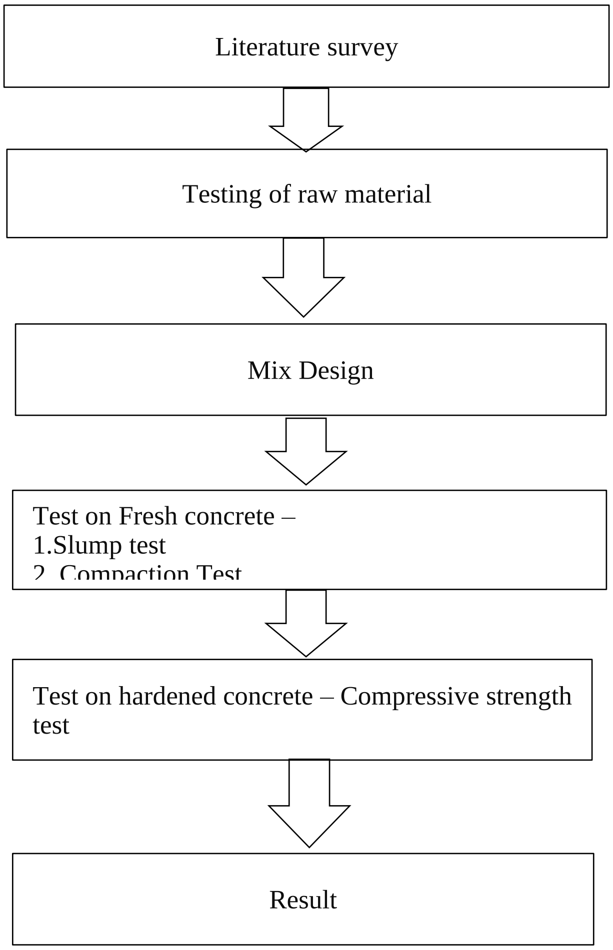

Figure 1. Methodology.

RAW MATERIALS

Cement

- Ordinary Portland cement (OPC) Of 53 grades
- satisfying the requirements IS:12269-1987 is used.

Fine Aggregates

- Crushed sand was used as a fine aggregate

Coarse Aggregates

- Mechanically crushed stone of 20 mm maximum size, satisfying to IS: 383-1978 was used.

Silica Fume

Silica fume has ultrafine spherical particles, around 0.15 µm in diameter, significantly smaller than cement particles. Its bulk density varies from 130 to 600 specific surface area ranges from 15,000 to 30,000 $m^2\ kg^{-1}$, measured using the BET or nitrogen adsorption method.

Table 1. Physical properties of materials.

Materials	Specific Gravity	Fineness modulus (%)	Bulk Density (kg m^{-1})
Cement	3.14	2	1500
Fine aggregate	2.65	3.15	1400
Coarse aggregate	2.63	5.88	1440
Silica fume	2.35	0.41	635

MIX DESIGN

1. Cement: 480 kg
2. Fine aggregates, sand: 673 kg
3. Coarse Aggregates C.A.–20 mm: 654 kg
   Coarse Aggregates C.A–10 mm: 436 kg
4. Free water: 141 kg
5. W cm^{-1} ratio: 0.256
6. Silica fume:70 kg
7. Admixture:1.2%

Mix proportion = Cement: Sand: Aggregate
= 550:673:1090= 1:1.22:1.981

RESULT AND DISCUSSION

As shown in the graph (7 Days, 14 Days, 28 Days), Tests are to be made at 7,14,28 days. Three specimens are made for testing at each selected age. As per the standard practice, concrete gains 65% strength in 7 days, 95 % in 14 days, and 99% in 28 days (Figure 2).

Table 2. Tests are to be made at 7, 14, 28 days.

Age of Concrete	Compressive strength (N mm^{-2})
7 Days	76.77
14 Days	88.53
28 Days	96.08

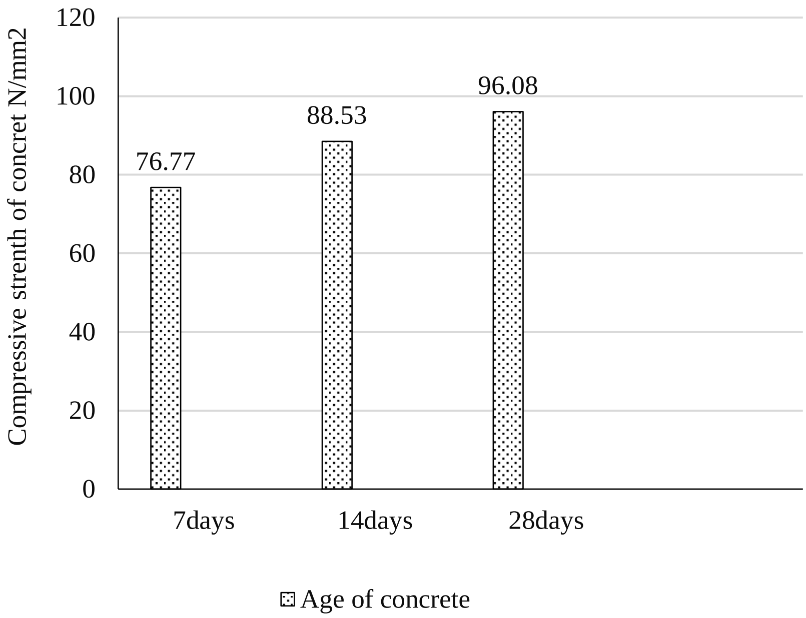

Figure 2. Variation in compressive strength of age of concrete.

CONCLUSION

Based on the tests conducted and the subsequent analysis of the results, the following conclusions have been drawn:

The findings from this study indicate that silica fume possesses significant potential for use in concrete as a substitute for cement.

As the proportion of silica fume increases, the workability of the concrete decreases.

Maximum compressive strength was observed when silica fume is replaced is about 14.58% are 65% in 7 days, 95% in 14 days, and 99% in 28 days

REFERENCES

1. Blash AM, Yami GSM, Yami MAE. Effect of Silica Fume (SF) on the strength and permeability of high-performance concrete. Int J Eng Sci Invention. 2020; 9 (12): 36–42p.
2. Kumar R, Dhaka J. Review paper on partial replacement of cement with silica fume and its effects on concrete properties. Int J Technol Res Eng. 2016; 4 (1): 83–85.
3. Reddy TVV, Rajasekhar K, Janardhana S. Study and performance of high strength concrete using with nano silica and silica fume. Int J Civil Eng Technol. 2015; 6 (11): 184–196p.
4. Kalantri SJ, Bhuskade SR. Review on self-compacting concrete using Silica Fume. J Emer Technol Innov Res. 2019; 6 (3): 328–330p.
5. Srivastava R, Kumar Y, Kumar R, Kumar S, Gupta S, Kumar V, Mahajan V. Investigation of high-strength concrete using fly ash and Silica Fume. Int J Technol. 2020; 10: 40–46.
6. Ahad A, Kapoor K. A review for characterization of Silica Fume and its effects on concrete properties. Int J Latest Res Eng Comput. 2017; 5 (3): 13–15p.
7. Kumar A, Gupta RK, Raza A, Rai P. Review the study of Silica Fume performance on new and hardened concrete structures. Int Res J Eng Technol. 2021; 8 (7): 3572–3581p.
8. Ghutke VS, Bhandari PS. Influence of Silica Fume on concrete. Int Conf Adv Eng Technol. 2014; 3: 44–47p.
9. Gražulytė J, Vaitkus A, Šernas O, Čygas D. Effect of Silica Fume on high-strength concrete performance. Proceedings of the 5th World Congress on Civil, Structural, and Environmental Engineering (CSEE'20). Lisbon, Portugal. 2020, October 18–20. Paper No. ICSECT 16.
10. Dhanjode G, Ghormade A, Chinchkhede D, Tirpude D, Suryawanshi S, Thawkar S. Literature review on change in property of concrete by using Silica Fume. Int Res J Mod Eng Technol Sci. 2023; 5 (4): 3727–3730p.
11. Patel YJ, Shah KD. The effect of Silica Fume on mechanical properties of high-strength concrete. Int J Eng Res Appl. 2013; 3 (3): 79–82.
12. Siddique R. Influence of Silica Fume on concrete strength and durability parameters. Int J Adv Struct Eng. 2011; 3 (4): 431–440.
13. Ramezanianpour AA, Mahdikhani M, Ahmadibeni G. The effect of rice husk ash on mechanical properties and durability of sustainable concretes. Int J Civil Eng. 2009; 7 (2): 83–91.
14. Bentz DP, Garboczi EJ. Modelling the influence of Silica Fume on the diffusivity of cement-based materials II. Multi-scale modelling of concrete diffusivity. Cem Concr Res. 1991; 21 (2–3): 289–306.
15. Bhanja S, Sengupta B. Influence of Silica Fume on the tensile strength of concrete. Cem Concr Res. 2005; 35 (4): 743–747.
16. Bai J, Wild S, Sabir BB. Chloride ingress and strength loss in concrete with different PC-PFA-MK binder compositions exposed to synthetic seawater. Cem Concr Res. 2003; 33 (3): 353–362.
17. Patel YJ, Shah KD. The effect of Silica Fume on mechanical properties of high-strength concrete. Int J Eng Res Appl. 2013; 3 (3): 79–82.
18. Siddique R. Influence of Silica Fume on concrete strength and durability parameters. Int J Adv Struct Eng. 2011; 3 (4): 431–440.
19. Ramezanianpour AA, Mahdikhani M, Ahmadibeni G. The effect of rice husk ash on mechanical properties and durability of sustainable concretes. Int J Civil Eng. 2009; 7 (2): 83–91.
20. Bentz DP, Garboczi EJ. Modelling the influence of Silica Fume on the diffusivity of cement-based materials II. Multi-scale modelling of concrete diffusivity. Cem Concr Res. 1991; 21 (2–3): 289–306.
21. Bhanja S, Sengupta B. Influence of Silica Fume on the tensile strength of concrete. Cem Concr Res. 2005; 35 (4): 743–747p.
22. Bai J, Wild S, Sabir BB. Chloride ingress and strength loss in concrete with different PC-PFA-MK binder compositions exposed to synthetic seawater. Cem Concr Res. 2003; 33 (3): 353–362p.
23. Malhotra VM. Role of Silica Fume in concrete: a review. Adv Cem Based Mater. 1993; 1 (4):

174–186p.
24. Chao-Lung H, Anh-Tuan BL, Chun-Tsun C. Effect of rice husk ash on the strength and durability characteristics of concrete. Constr Build Mater. 2011; 25 (9): 3768–3772p.
25. Muthukumar M, Mohan D, Arumugam R, Sivakumar M. Properties of high-performance concrete with Silica Fume as a supplementary cementitious material. IOP Conf Ser Mater Sci Eng. 2017; 263 (3): 032030p.
26. Buratti N, Mazzotti C, Savoia M. Self-compacting concrete with fly ash and silica fume: experimental results and technical applications. Constr Build Mater. 2011; 23 (9): 2890–2901p.
27. Yazici H, Arel HS, Baradan B, Tabak V. Effect of fly ash and silica fume on compressive strength, sorptivity and carbonation of SCC. Mater Struct. 2010; 43 (8): 1195–1204p.
28. Uysal M, Yilmaz K. Effect of mineral admixtures on properties of self-compacting concrete. Cem Concr Compos. 2011; 33 (7): 771–776p.
29. ACI Committee 234. Guide for the Use of Silica Fume in Concrete. Farmington Hills, MI: American Concrete Institute; 2006. Report No.: ACI 234R-06.
30. Li G. Properties of high-volume fly ash concrete incorporating nano-SiO_2. Cem Concr Res. 2004; 34 (6): 1043–1049p.
31. Chindaprasirt P, Rukzon S, Sirivivatnanon V. Resistance to chloride penetration of blended portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash. Constr Build Mater. 2008; 22 (5): 932–938p.
32. Patel YJ, Shah KD. The effect of Silica Fume on mechanical properties of high-strength concrete. Int J Eng Res Appl. 2013; 3(3): 79–82.
33. Siddique R. Influence of Silica Fume on concrete strength and durability parameters. Int J Adv Struct Eng. 2011; 3 (4): 431–440.
34. Ramezanianpour AA, Mahdikhani M, Ahmadibeni G. The effect of rice husk ash on mechanical properties and durability of sustainable concretes. Int J Civil Eng. 2009; 7 (2): 83–91p.
35. Bentz DP, Garboczi EJ. Modelling the influence of Silica Fume on the diffusivity of Cement-based Materials II. Multi-scale modelling of concrete diffusivity. Cem Concr Res. 1991; 21 (2–3): 289–306p.
36. Bhanja S, Sengupta B. Influence of Silica Fume on the tensile strength of concrete. Cem Concr Res. 2005; 35 (4): 743–747.
37. Bai J, Wild S, Sabir BB. Chloride ingress and strength loss in concrete with different PC-PFA-MK binder compositions exposed to synthetic seawater. Cem Concr Res. 2003; 33 (3): 353–362p.
38. Malhotra VM. Role of Silica Fume in concrete: a review. Adv Cem Based Mater. 1993; 1 (4): 174–186p.
39. Chao-Lung H, Anh-Tuan BL, Chun-Tsun C. Effect of rice husk ash on the strength and durability characteristics of concrete. Constr Build Mater. 2011; 25 (9): 3768–3772p.
40. Muthukumar M, Mohan D, Arumugam R, Sivakumar M. Properties of high-performance concrete with silica fume as a supplementary cementitious material. IOP Conf Ser Mater Sci Eng. 2017; 263 (3): 032030p.
41. Buratti N, Mazzotti C, Savoia M. Self-compacting concrete with fly ash and silica fume: experimental results and technical applications. Constr Build Mater. 2011; 23 (9): 2890–2901p.
42. Yazici H, Arel HS, Baradan B, Tabak V. Effect of fly ash and silica fume on compressive strength, sorptivity and carbonation of SCC. Mater Struct. 2010; 43 (8): 1195–1204p.
43. Uysal M, Yilmaz K. Effect of mineral admixtures on properties of self-compacting concrete. Cem Concr Compos. 2011; 33 (7): 771–776p.
44. ACI Committee 234. Guide for the Use of Silica Fume in Concrete. Farmington Hills, MI: American Concrete Institute; 2006. Report No.: ACI 234R-06.
45. Li G. Properties of high-volume fly ash concrete incorporating nano-SiO_2. Cem Concr Res. 2004; 34 (6): 1043–1049p.
46. Chindaprasirt P, Rukzon S, Sirivivatnanon V. Resistance to chloride penetration of blended portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash. Constr Build Mater. 2008; 22 (5): 932–938p.

