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The Influence of Nano Silica and Micro Silica on the Compressive Strength of Hybrid Fiber-Reinforced Concrete

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Fiber-reinforced concrete (FRC) has gained significant attention due to its high mechanical properties compared to conventional concrete. However, further improvements in strength and performance are desirable for various structural applications. This study investigates the influence of incorporating nano-silica and micro-silica on the compressive strength of hybrid fibre-reinforced (HyFRC) composites. NS and MS were incorporated as supplementary cementitious materials in varying proportions, along with a combination of fibres as hybrid reinforcement. The experimental program involved the design, preparation, and testing of multiple HyFRC mixtures with different NS and MS contents. The strength tests were conducted to evaluate the strength development and assess the synergistic effects of NS, MS, and fibre reinforcement. The results shows a significant increase in compressive strength in incorporation of NS and MS in HyFRC composites. Optimal dosages of NS and MS were identified, beyond which further additions did not yield substantial strength improvements. The hybrid fibre reinforcement effectively bridged micro-cracks and improved the post-cracking behavior, contributing to the overall strength enhancement. This work provides added significance into the synergistic influence of NS, MS, and hybrid fibre reinforcement on the compressive strength of HyFRC composites. The findings offer guidelines for tailoring the mixture design and optimizing the performance of HyFRC for various structural applications, ultimately contributing to sustainable and durable construction practices.

Keywords: Cement, Fiber-reinforced concrete, Micro-silica, Nano-silica, Sustainability.

1. Introduction

Sustainability is the main key in present construction scenario, sustainable materials plays a vital role due to its excellent compressive strength, durability, and versatility. Also,its low tensile strength and brittleness have led to the development of various reinforcement techniques, including the incorporation of Fibres and supplementary cementitious materials (SCMs). One such approach is the use of hybrid fiber-reinforced concrete (HyFRC), which combines the benefits of different fiber types to improve the mechanical properties and overall performance.

In recent years, incorporation of nano and micro silica has gained significant attention to further increasing the compressive strength of HyFRC. Nano and micro silica, which are highly reactive materials with calcium hydroxide (CH) produced by cement hydration, forming C-S-H gel, thereby enhancing the strength of the concrete matrix [1], [2].

Several studies have investigated the influence of silica on the strength of HyFRC. For instance, Jalal et al. [3] showed a significant increase with nano silica to hybrid fiber-reinforced self-compacting concrete. They attributed this improvement to the reaction between nano silica and CH, also with effect of silica particles, which facilitates the C-S-H gel.

Similarly, Parveen et al. [4] noticed a notable improvemet in the strength of HyFRC containing MS and fibres.They suggested that the incorporation of micro silica not only contributed to the pozzolanic reaction but also improved the ITZ between the paste and aggregates, resulting in a denser and more compact microstructure. Furthermore, the combined reaction of silica on the compressive strength of HyFRC has been explored by various researchers [5], [6]. The synergistic action of these two SCMs can lead to efficient reaction, further densifying the concrete matrix and improving its strength properties.

2. Materials and Methods

- Test Materials

The concrete mixtures were prepared using the following materials:

a) Cement: Ordinary Portland Cement (OPC) of 53 grade, manufactured by Dalmia Cements, with a specific gravity of 3.15, was used as the cementitious material.

b) Nano Silica: A nano silica product supplied by ASTRRA Chemicals, Chennai, with a specific surface area of 202 m^2/g, specific gravity of 1.20, and a white color was incorporated.

c) Micro Silica: A micro silica product, also supplied by ASTRRA Chemicals, Chennai, with a specific surface area of 20 m^2/g, specific gravity of 2.22, and a white color was used.

d) Aggregates: The fine aggregate consisted of locally available M-sand conforming to IS 383:2016, with a combined specific gravity of 2.67. The coarse aggregate was crushed granite with a maximum particle size of 20 mm, conforming to IS 2386:2016, and having a specific gravity of 2.72.

e) Water: Potable water conforming to IS 456:2000 was used for mixing the concrete, with a water-to-binder ratio of 0.48 maintained for all mixes.

f) Superplasticizer: A sulphonated naphthalene-based superplasticizer conforming to ASTM C494, supplied by Forsoc Chemicals, Chennai, was used. The dosage was determined through trials to achieve the desired workability and strength requirements.

g) Fibers: Hooked-end steel fibers with volume fractions of 1%, 1.5%, and 2% were used.

Additionally, polypropylene fibers with volume fractions of 0.1%, 0.2%, and 0.3% were incorporated.

The materials were carefully selected and sourced to ensure compliance with relevant standards and specifications, enabling the preparation of high-quality concrete mixtures for the research study.For this research study, Ordinary Portland Cement (OPC), coarse aggregate with 20 mm maximum size, river sand and M-sand combine as fine aggregate, potable water, superplasticizer, micro silica, nano silica and hooked end steel fibre were used.

- Test Specimens

The designations assigned to all the concrete specimen mixes investigated in this study are listed in Table 1.

Table 1 Designations of Control Specimens

Specimen	Description
CC	Control
NMSPF0	Specimen with 10 %MS and 1 % NS (as partial replacement of cement)
NMSPF1	Specimen with 10 %MS, 1 % NS and 1% Steel Fibre and 0.1% polypropylene Fibres
NMSPF2	Specimen with 10 %MS, 1 % NS and 1.5% Steel Fibre and 0.2% polypropylene Fibres
NMSPF3	Specimen with 10 %MS, 1 % NS and 2% Steel Fibre and 0.3% polypropylene Fibres

- Compressive Strength Test on Cubes

The Cube specimens of (150 x 150 x 150)mm were cast using the concrete mixtures containing different combinations of nano silica, micro silica, and hybrid Fibres. After initial curing for 24 hours, and were demolded followed by curing in water for the desired curing period (typically 28 days). Further the curing period, were tested for compressive strength by applying a gradually increasing load until failure in a compression testing machine. The load was recorded, and calculated. Three replicate specimens were tested for each concrete mixture, and the average compressive strength was reported to find the influence of nano silica, micro silica, and hybrid Fibres on the compressive strength of the concrete.

3. Results and Discussions

Test was conducted confirming to IS 516: 1959. The compressive strength outcomes are illustrated in Table 2.

Table 2. Compressive Strength Test Result

S.No	Specimen	Average Compressive Strength
1.	CC	42.5 Mpa
2.	NMSPF0	44.21 Mpa
3.	NMSPF1	47.56 Mpa
4	NMSPF2	49.44 Mpa
5	NMSPF3	46.29 Mpa

The control concrete mix (CC) exhibited an average compressive strength of 42.5 MPa, which serves as the baseline for comparison. The incorporation of nano silica, micro silica, and hybrid Fibres in the NMSPF mixes led to noticeable improvements in compressive strength.NMSPF0, which contained a combination of nano silica, micro silica, and hybrid Fibres, showed a 4.03% increase in average compressive strength compared to CC, achieving 44.21 MPa. This enhancement are attributed to the reaction of nano and micro silica, which contributes to the formation C-S-H gel, thereby densifying the concrete matrix and improving its strength. The Average compressive strength is shown in Figure.1

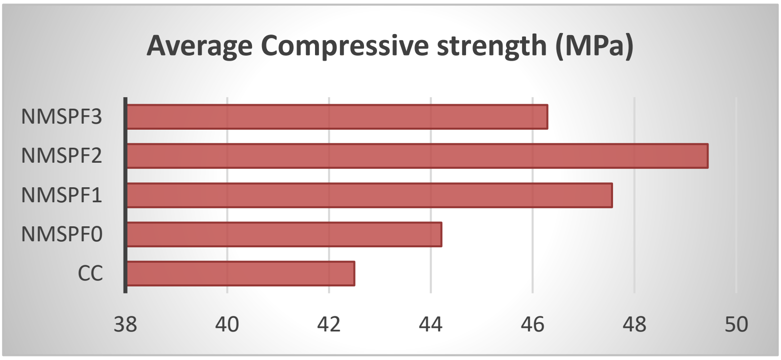

Fig. 1. Compressive strength

Further improvements in compressive strength were observed in the NMSPF1, NMSPF2, and NMSPF3 mixes. NMSPF1 exhibited an average compressive strength of 47.56 MPa, representing an 11.89% increase compared to CC. NMSPF2 demonstrated the average percentage of strength as 49.44 MPa, that is 16.36% higher when compared to CC. NMSPF3 achieved an average compressive strength of 46.29 MPa, an 8.89% increase compared to CC. The superior performance of NMSPF2 can be attributed to an optimum combination and proportion of nano silica, micro silica, and hybrid Fibres in this mix design. The synergistic effect of these materials contributes to a more efficient pozzolanic reaction, resulting in a denser and more compact concrete microstructure, thereby enhancing the strength. The percentage in strength is shown in Figure.2.

It is significant that while NMSPF3 exhibited a lower compressive strength than NMSPF1 and NMSPF2, it still outperformed the control mix (CC), indicating the positive influence of incorporating nano silica, micro silica, and hybrid Fibres in concrete mixtures.

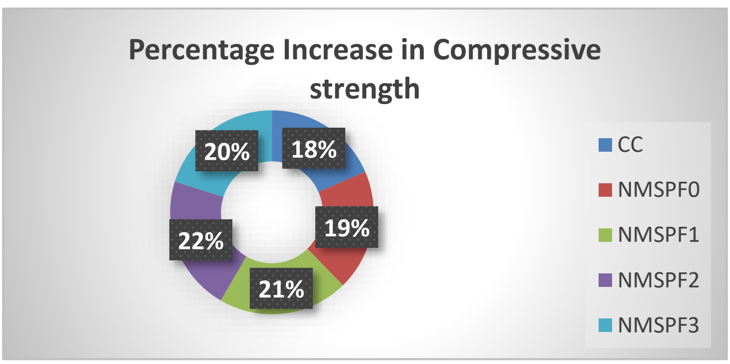

Fig. 2. Percentage increase in Compressive strength

4. Conclusions

This work investigated the influence of incorporating nano silica, micro silica, and hybrid Fibres on the strength of concrete. The experimental results shows significant improvements in the compressive strength of concrete mixes containing these materials when compared to CC.

The concrete mix designated as NMSPF2, containing an optimum combination and proportion of nano silica, micro silica, and hybrid Fibres, exhibited the highest average compressive strength of 49.44 MPa. This represents a remarkable 16.36% in compressive strength to CC, which had an average compressive strength of 42.5 MPa.

The other concrete mixes also demonstrated considerable improvements in compressive strength. NMSPF1 achieved an average compressive strength of 47.56 MPa, corresponding to an 11.89% increase compared to the control mix. NMSPF0 exhibited a 4.03% increase in compressive strength, with an average value of 44.21 MPa. Even NMSPF3, which had a lower compressive strength than NMSPF1 and NMSPF2, still outperformed the control mix by 8.89%, with an average compressive strength of 46.29 MPa.

In conclusion, the incorporation of nano silica, micro silica, and hybrid Fibres in concrete mixtures has demonstrated significant potential for lifting up the compressive strength of concrete. With the optimal mix design (NMSPF2), a remarkable 16.36% increase in compressive strength was achieved to the control mix. These advanced concrete materials could pave the way for more durable, sustainable, and high-performance construction solutions, provided further research and optimization efforts are undertaken.

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