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Effect of nano-silica on mechanical properties and internal structure of pozzolanic concrete

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ABSTRACT

In this research work, advancement of nanotechnology is used in order to improve performance characteristics of pozzolonic concrete (concrete having 30% class F fly ash in replacement of cement) with use of nano-sized silica (SiO_2) particles, known as Nano-silica. This study may be considered as an important step towards better understanding the use of nano-silica in concrete as a remedy to overcome drawbacks of the use of pozzolans (drawback like late strength gain of hardened concrete). This research program aims at 1) further understanding the behaviour of cementitious materials when amended by nano-silicon various physio-mechanical properties (workability, compressive, tensile, flexural strength etc.) of pozzolonic concrete and 2) exploring the effect of this enhancement on the microstructure of cement matrix using SEM. The experimental program that was conducted included a laboratory investigation of concrete mixtures in which nano-silica was added to the compound cement and Class F fly ash. Three ratios of nano-silica (0%, 3% and 6% by wt. of the cementitious compound) were used in concrete mixtures to examine the extent and types of improvements that could be imparted to concrete. The conducted experimental program assessed these improvements in terms of mechanical properties and internal structure of the mixtures under investigation.

Keywords: *Concrete, Nano-silica, Mechanical properties.*

1. INTRODUCTION

The new technological capabilities made it possible to explore and control new levels of existence which were never known before. Although the nano-sized matter existed as early as the existence of earth, it was not until early 20th century when the nano-scale science started with the study of the molecular and atomic-sized objects. However, the development of methods to control the materials on the nano-scale level was not started until the last few decades. Current global trends are shifting towards a more sustainable construction industry, which has generated new research needs to control and improve concrete performance. The main approach applied to produce sustainable concrete is to reduce consumption of portland cement, while building more durable structures that have a longer service life, yet require minimal maintenance. The reduction of Portland cement use may be achieved either by decreasing its content in concrete mixtures or through replacing cement with recycled materials, thus reducing the carbon footprint of concrete. Furthermore, using other recycled materials (e.g. recycled concrete or aggregates) in mixtures is considered as one of the sustainable solutions for concrete another significantly important aspect of concrete sustainability is extending concrete structures' service time while reducing maintenance cost. This is mainly depending on enhancing concrete serviceability, long-term durability, and resistance to aggressive environmental attacks. This aspect becomes especially critical in case of structure expected to have a long service life in harsh conditions including, but not limited to, highway pavements and bridges, dams and marine structures. In these cases improving the durability of concrete may have a significant impact on the life cycle and maintenance plans for these structures. Concrete pavements and dams demonstrated over the last century that adequately designed and maintained concrete can serve for several decades.

2. GENERAL

In this chapter, the works of various authors on the use of nanomaterials in concrete has been discussed in brief. Nano-silica have been given a special focus for enhancement of various properties of concrete, especially when there is a partial replacement of pozzolanic material (fly ash) in concrete. A great number of researches have been performed to understand the nature of nanomaterials and their effect on the properties of concrete. A number of Research & Development work dealing with the use of nanomaterials like Nano silica, colloidal Nano-Silica (CNS), Al_2O_3, TiO_2, ZrO_2, Fe_2O_3, carbon nanotubes (CNT) in cement-based materials are discussed in the literature. The pozzolanic activity of the material is essential in forming the C-S-H gel and hence the CH crystals are prevented from growing and their number reduces. Thus the early age strength of hardened cement paste is increased. A comparative analysis of this work has been presented in the summary of this chapter which will highlight the significance of each work. Out of the numerous work done in the field only a few relevant works have been highlighted in the next section.

Steps Involved

Various steps can be briefed as follow:

i. MATERIAL TESTING

(It is done for checking materials quality for suitability of concrete of required strength.)

Following material properties were identified:

- Size of grains: - for fine aggregates (sand), coarse aggregates (gravels) and cement using sieve analysis.
- Percentage water absorption: - for fine and coarse aggregates.
- Colour and texture: - for cement and aggregates.
- Specific gravity: - for aggregates and cement.
- Setting time: - for cement fly ash mixes.

ii. CALCULATION AND CASTING

Two calculations were done: -

- Mix design calculations for concrete mixes confirming to IS 10262:2009 [48] and IS 456:2000 [49].
- Calculations for material's quantity for making molds for various experiments on the principal weight batching.

After calculations 7, 14 and 28 days' batches were cast in different shapes (cubes, cylinders, beams etc.) as per need for various experiments.

iii. CURING

Casted concrete elements were put in curing tank for submerged curing after 24 hours of it being cast. 7,14 and 28 days curing were done for:

- Compression strength test: - 7, 14 and 28 days cured batches.
- Tensile and flexural strength test: - 14 and 28 days cured batches.
- SEM test: - 7 and 28 days cured batches.

iv. TESTING

Tests were done for identity:

a) Fresh concrete properties: - Tests like

- Slump cone/ compaction factor test,
- Pressure method and
- Vicat apparatus test.

were performed on freshly made or plastic concrete/ cement paste.

b) Mechanical properties: -Tests like

- Compressive strength test,
- Tensile strength test and
- Flexural strength test.

were performed on hardened concrete.

c) Microstructural properties: - SEM test, this is a test for visible inspection of the concrete surface at the micro scale.

3. CONCLUSION

The review of a number of literature shows the importance of this field of research. The findings show that a number of nanomaterials like SiO_2, TiO_2, Al_2O_3, colloidal nano-silica, metakaolin, and others can be incorporated to improve the properties of concrete. The results show the improved characteristics of the blended concrete in terms of compressive, tensile and flexural strength. Apart from that the permeability of the specimen can also be decreased by adding a small percentage of the nanomaterial. The SEM analysis shows an improved microstructure with a reduced number of pores. The current study is concerned with the incorporation of Nano SiO_2 in concrete which is made of using class F fly ash as partial replacement of cement (30% replacement).

Slump Value

To maintain a consistent level of workability for all mixtures, several trial batches were performed to adjust the dosages of HRWRA. The target slump for all mixtures was between 75 and 125 mm which led to different admixtures dosage as shown in Table 4.7. Immediately after mixing, slump test was performed on each of the three concrete mixtures investigated in this study according to IS 7320:1974 [52]. The slump values for the different mixtures are shown in Table 5.1.

Table 1: Summary of the Slump values of the tested mixtures

Mixture	Slump value (mm)
P0	98
P3	76
P6	89

Setting Time

In order study the impact of nano-silica on the setting time of concrete and mortars, Vicat needle testing was performed according to toIS 5513:1996 [54]. Pastes were prepared by mixing 400 grams of cementitious materials with 100 grams of water (w/c=0.40) and (0%, 3% and 6% by wt. of cementitious material) are mixed as specified in the IS standard. Unlike concrete mixtures, no water reducing admixtures were used for any of the pastes as most types of admixtures may affect setting times. The cementitious materials used were selected to represent the same proportions of the concrete mixtures tested during this study (see Table 4.7). The paste was moulded in the standard moulds and kept in a moisture closet with a temperature of 27 ± 2°C and relative humidity not less than 90%. The penetration of the standard Vicat needle (1 mm in diameter) was recorded every 15 minutes and the molds were kept in the moisture closet between readings. The initial setting time is defined as the time when the needle penetration is equal to 25 mm. This value was determined via interpolation between the two closest readings to 25 mm. On the other hand, final setting time was determined as the time when no penetration could be visually observed. Table 5.2 shows the tested pastes along with the measured initial and final setting times.

Table 2: Setting time test result

MIX WITH (70%Cement+30%Flyash)	INITIAL SETTING TIME(Min)	FINAL SETTING TIME(Min)
0% Nano-silica mix	30	396
3% Nano-silica mix	26	307
6% Nano-silica mix	24	285

Generally, the results of Vicat needle testing indicate that using nano-silica has an impact on shortening of both of the initial and final setting times. The effect of nano-silica is readily observed in case of mixtures incorporating fly ash. Class F fly ash may generally extend the setting time of cement paste due to the slow hydration process. However, adding 6% of nano-silica to the fly ash concrete reduced the initial and final setting time by around 25%, while this reduction was around 20% in case of adding 3% of nano-silica.

The impact of nano-silica on the fresh properties of concrete was generally significant especially on the workability level in terms of slump values and setting times. This effect was expected due to the very small particle size of nano-silica having significantly larger surface area compared to other concrete components. The large surface area increases the adsorbed water on the surface which impacts the fresh properties of concrete. Generally, any fine particles added to concrete, mortar or paste mixtures can impact the workability and sitting time in a similar way. The next sections and chapters of this study discuss the evidence of the effect of nano-silica on hardened concrete performance.

The previously presented results indicate that the fresh properties of concrete incorporating nano-silica may be a controlling factor for mixture design and proportioning for some application. This is attributed to the significant impact of nano-silicon workability and setting time of concrete.

Mechanical Properties

Compressive Strength

The compressive strength at different curing ages up to one month was evaluated for the three investigated mixtures. In addition, the splitting tensile strength and modulus of rupture were determined at 14 days and 28 days. Cubes of size 15*15*15 cm or Cylinders of 15 cm diameter and 20cm height, prepared, moulded and compacted according to toIS 6461(Part 7):1973 [55], were used for evaluation of the compressive and the splitting tensile strengths respectively. Moulds were unmoulded after 24 hours of mixing then cured in a curing room until the time of testing. The compressive strength was measured at ages of 7, 14 and 28 days, with the average of 3 cubes at least for each age. The splitting tensile test was performed at the ages of 14 and 28 days. For evaluation of modulus of rupture, concrete beams 150×150×700mm were prepared for the three mixtures. At 28 days, the beams were tested in flexure up to failure.

For the compressive strength testing, (according to toIS 4031(Part 6):1988 [56]) was used for the evaluation of the early strengths up to 7 days for all the mixtures. For compressive strength testing at 28 days, moulds were prepared for the tested cylinders according to toIS 4031(Part 6):1988 [56]. The average compressive strength of the three mixtures at different curing ages is shown in Figure 5.3 for curing age at 7, 14 and 28 days, in Figure 5.1 results are graphically represented.

Table 3: The compressive strength of cubes of different mixes

CONCRETE MIX	COMPRESSIVE STRENGTH (N/mm^2)		
	7 DAYS	14 DAYS	28 DAYS
P0	21.33	28.12	32.32
P3	27.05	35.17	38.65
P6	30.06	38.35	43.57

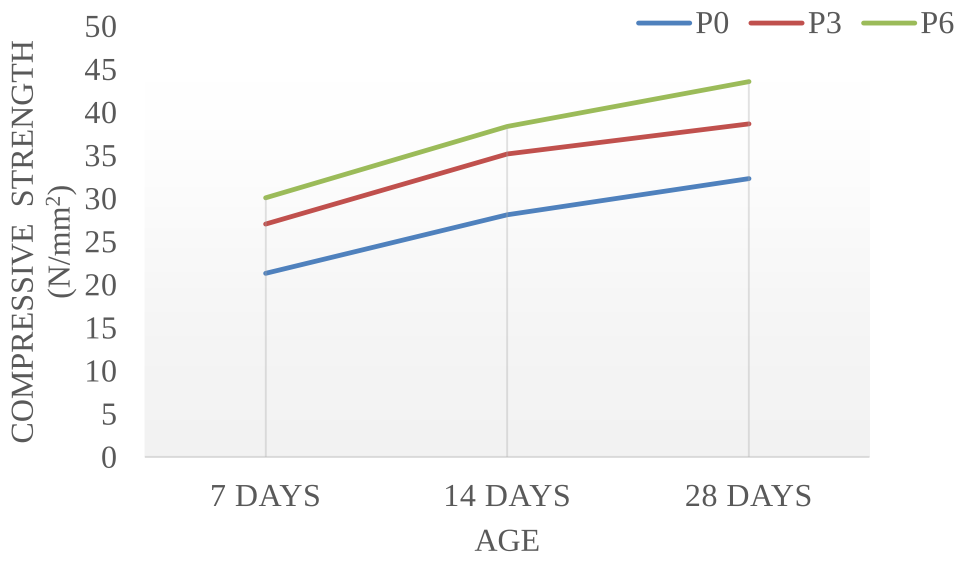

Figure 1: Compressive strength versus curing time

Tensile Strength

The splitting tensile test was performed at 14 and 28 days on concrete cylinders according to toIS 5816:1999 [57]. The average splitting tensile strength for each of the tested mixtures is presented in Figure 5.2. For compressive strength and tensile strength testing, at least three cylinders were tested for each mixture at the different testing ages.

Table 4: The tensile strength of cylinders of different mixes

CONCRETE MIX	TENSILE STRENGTH (N/mm^2)	
	14 DAYS	28 DAYS
P0	3.15	3.81
P3	4.53	5.67
P6	4.78	5.44

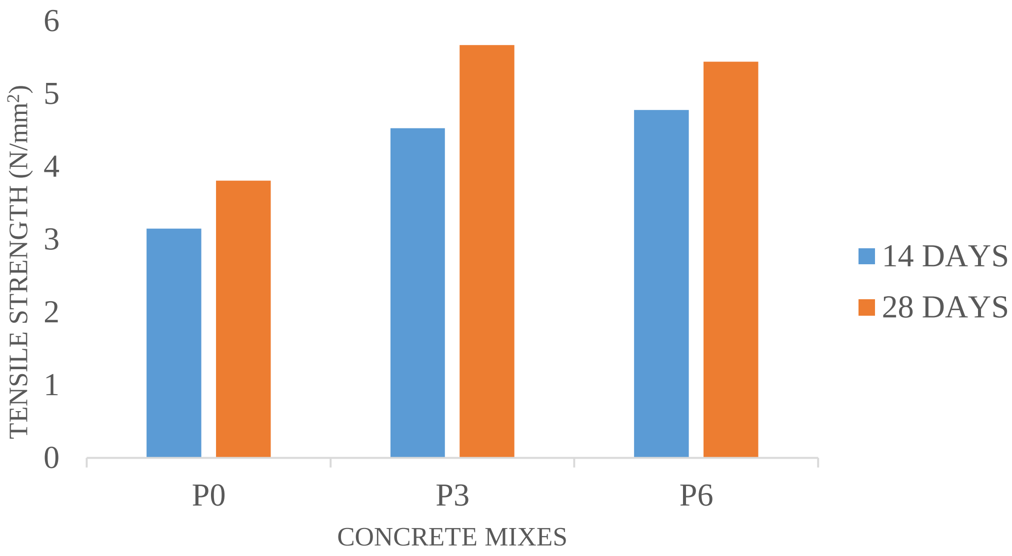

Figure 2: Splitting tensile strength vs time

Flexural Strength

For evaluating the modulus of rupture of the tested concrete mixtures, two beams were tested for each mixture according toIS 9399:1979 [58]. The beams were simply supported with two loads applied at one-third of the span from each of the two supports. The total span of the tested beams was 600mm with 50mm overhanging from each side. The modulus of rupture was then calculated for each specimen at failure based on the exact dimensions of the cross section measured at the surface of failure. Figure 5.3 shows the average measured modulus of rupture for the tested mixtures.

Table 5: Flexural Strength of beam for different mixes

CONCRETE MIX	FLEXURAL STRENGTH (N/mm^2)	
	14 DAYS	28 DAYS
P0	3.72	3.89
P3	4.19	4.36
P6	4.35	4.81

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