Effect of mineral admixtures on early age properties of high performance concrete

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Abstract. In effect, the early age characteristics of concrete practically determines the performance of concrete during service. While several factors influence the fresh nature of concrete, water-binder (w/b) ratio and admixtures are particularly the most important. In this study, the effect of Nano-silica (NS) and fly ash on early strength characteristics of an M50 grade of high performance concrete was investigated. The contents of fly ash and Nano silica were used in varying proportions, from 28% to 32% and 1.0% to 2%, respectively, by weight of cement in the mix. Natural river sand was partially replaced by manufactured sand (M-sand) at 0%, 50% and 100% levels. Concrete mixture was achieved at 0.39 water/binder ratio. The workability and setting time of fresh concrete, by slump and penetration resistance tests, respectively, were determined as per ASTM C-403. The strength development at the early age was investigated and compared with that of the control concrete, based on tests on cube and cylinder specimens. Based on the obtained results, the early age strength of HPC containing NS was improved than the results obtained using the IS: 456-2000 code recommended models.

Keywords: Nano-silica, early age properties, M-sand, HPC

1. Introduction
High performance concrete (HPC) is a concrete with unique properties such as, high workability, durability and strength characteristics. Most of the properties of HPC are achievable through the use of admixtures, and mixing of constituent materials at low water-binder ratio. In recent years, supplementary cementitious materials (SCM), having pozzolanic nature, are used as replacement of Portland cement as potential cementitious binder [1-4]. Generally, HPC is expected to develop strength continually for a longer time than the conventional concrete. Also, the fresh properties HPC are also expected to vary, depending on ingredient and supplementary cementitious materials used for the mix. Several SCMs have been investigated experimentally in HPC. Fly ash (FA) is an example of SCM that is widely used in HPC. A research finding has revealed that FA addition slows the rate of strength development than in normal concrete [5], mainly because the setting time is reduced with increasing FA content [6].

Energy consumption and sustainability issues are main concern in the construction sector. For instance, in India, sand sourced from the river bed leads to the economical imbalance, particularly in the agriculture sector along with the strict local body legislation [7]. As a result, manufactured sand (MS) is considered as an alternative to natural sand, for fine aggregate portion of concrete, but its blending has to be investigated [8]. Manufactured sand has high water absorption capacity, when used as aggregate in concrete, this consequently reduces the workability and setting time of concrete [9,10]. Recent development in concrete technology has led to the use of nano materials as additive in concrete. The common nano materials, which are applicable to concrete are nano-silica (NS) and nano-fibers. It has been reported that using NS in mortar and concrete improves the strength properties [11-13]. The higher strengths obtained in concrete containing NS are attributed to the reduction of concrete pores [12], accelerated hydration [11], improved interfacial transition zone (ITZ) [13], and larger particle specific surface area [14]. Thus, NS can be suitable for making durable concrete [15]. The addition of NS was also found to reduce the setting time of concrete containing...
slag [16]. Also, there is reduction in both the initial and final setting time of pastes having NS [17]. Yet, the variation in the setting time of paste decreased with increasing NS content [18]. Kawashima et al. [19] reported that the presence of NS particle in fly-ash blended concrete improved the early age strength of concrete [19].

While several studies have explored the use of nano silica and manufactured sand in concrete, the current study focuses on the influence of NS on the early age properties of high performance containing manufactured sand. Properties of the HPC, such as homogeneity, setting time and strength development are studied. The study also developed a relationship between setting time and 28 days strength of M-sand based HPC.

2. Materials and methods

The materials used in this study were Grade 53 Ordinary Portland cement conforming to IS: 12269-1987, Class F fly ash, which fulfils the requirements of ASTM C 618. Nano silica with an average particle size of 12nm was used. The properties of all these materials are presented in Table 1. Polycarboxylic based superplasticizer (SP) with a specific gravity of 1.07 was utilized, in order to achieve the desired workability. Local river sand, having fineness modulus and specific gravity of 2.67 and 2.71, respectively, and M-sand having fineness modulus and specific gravity 2.62 and 2.68, respectively, were used as fine aggregate. The coarse aggregate is comprised of crushed granite with a maximum size of 20mm. The fineness modulus and the specific gravity of the coarse aggregate were 2.78 and 7.19, respectively. Both fine aggregate and coarse aggregate complied with the requirements of IS: 383-1970. The results of grain size distribution (zone – II) of river sand and M-sand are shown in Fig. 1.

Table 1. Physical and Chemical characteristics of cementitious materials

| Properties | Portland Cement (%) | Fly-ash (% | Nano-silica (%) |
|------------|----------------------|------------|-----------------|
| CaO        | 61.6                 | 1.78       | -               |
| SiO₂       | 22.4                 | 51.85      | >98.5           |
| Al₂O₃      | 5.2                  | 25.31      | -               |
| Fe₂O₃      | 3.8                  | 11.5       | -               |
| MgO        | 1.7                  | 1.5        | -               |
| Loss (LoI) | 2.3                  | 2.4        | -               |

| Physical Properties | Portland Cement | Fly-ash | Nano-silica |
|---------------------|-----------------|---------|-------------|
| Specific surface area | 295 m²/kg | 217 m²/kg | 201 m²/g |
| Specific gravity     | 3.15           | 2.92     | 2.28*       |
| Average particle size | 27.8 µm  | 27.2 µm  | 12nm |
| Comp. strength (28 days) | 58.5 MPa | -        | -           |

* Information provided by the supplier

The trial mix proportion of M50 grade HFC investigated follows the procedure suggested by Laskar [20]. The river sand was partially replaced by manufactured sand (M-sand) at 0%, 50% and 100% levels. The FA content was added in proportions 28% to 32%, and NS was added at 1.0% and 2% in the mix proportions. The sand content was replaced by M-sand at the level of 0%, 50% and 100%, and coarse aggregate content was slightly adjusted so as to keep the workability constant. Table 2 shows the final mix proportion obtained after trial tests. The setting time of fresh concrete was found by the penetration resistance test using Penetrometer as per procedures of ASTM C-403/C-403M-08[21] and IS: 8142-1976[22], respectively. The penetration resistance curve was prepared against elapsed time. From the penetration resistance curve, the time required to reach the resistance equal to 3.5 MPa is read on the X-axis which gives the initial setting time and the penetration resistance of 27.6 MPa gives the final setting time of concrete. Also, slump of concrete mixes was determined. For each type of concrete, three concrete cubic specimens of 150 x 150 x 150 mm size and three cylindrical specimens of 150 mm diameter and 300 mm long were tested for finding compressive strength and splitting tensile strength, respectively, after curing regimes of 1, 3, 7 and 28 days.
Figure 1: Gradation curve for river sand and M-sand

Table 2. Mix Proportions for HPC

| Mix designation | Cement (kg/m³) | FA | NS | Sand | M-Sand | CA | w/b ratio | SP (l/m³) |
|-----------------|---------------|----|----|------|--------|----|-----------|-----------|
| AMS0            | 500           | 140| 0  | 790  | 0      | 900| 0.39      | 1.42      |
| AMS50           | 500           | 150| 0  | 390  | 390    | 910| 0.39      | 2.10      |
| AMS100          | 500           | 160| 0  | 780  | 900    | 0  | 0.39      | 2.51      |
| BMS0            | 500           | 140| 5.0| 790  | 0      | 900| 0.39      | 1.48      |
| BMS50           | 500           | 160| 5.0| 390  | 390    | 910| 0.39      | 2.12      |
| BMS100          | 500           | 160| 5.0| 780  | 900    | 0  | 0.39      | 2.55      |
| CMS0            | 500           | 140| 7.5| 790  | 0      | 900| 0.39      | 1.52      |
| CMS50           | 500           | 160| 7.5| 390  | 390    | 910| 0.39      | 2.20      |
| CMS100          | 500           | 160| 7.5| 780  | 900    | 0  | 0.39      | 2.69      |
| DMS0            | 500           | 140| 10.0| 790 | 0    | 900| 0.39      | 1.60      |
| DMS50           | 500           | 160| 10.0| 390 | 390  | 910| 0.39      | 2.31      |
| DMS100          | 500           | 160| 10.0| 780 | 900  | 0  | 0.39      | 2.97      |

3. Results and Discussion

3.1 Workability and setting time

The slump result is presented in Table 3. The dosage of the superplastizer in all the concrete mixtures was adjusted between 1.42 to 2.97 l/m³ to produce the slump range of 150 - 200 mm. The addition of M-Sand and NS caused marginal reduction in slump value. This could be due to the variation in the particle sizes and textural characteristics of M-sand, and high specific surface area of NS particles. The dosage of the superplastizer increased with M-sand dosage, due to slightly higher water absorption properties of M-sand, than in the river sand.

Table 3. Mix proportions for HPC

| Mix designation | Slump value (mm) |
|-----------------|------------------|
| AMS0            | 180              |
| AMS50           | 173              |
| AMS100          | 168              |
| BMS0            | 168              |
| BMS50           | 165              |
### Mix designation and Slump value (mm)

| Mix designation | Slump value (mm) |
|-----------------|-----------------|
| BMS100          | 160             |
| CMS0            | 165             |
| CMS50           | 162             |
| CMS100          | 160             |
| DMS0            | 160             |
| DMS50           | 162             |
| DMS100          | 158             |

The penetration resistance curves for determining the initial and final setting time of selected samples HPC, namely AMS0, BMS0, CMS0 and DMS0, is shown in Fig.2. The initial and final setting time of AMS0 was found as 462 and 572 min, respectively. Fig. 3 presents the effect of NS on initial and final setting time of the mixtures. There was an increase in both the initial setting time (Fig. 3a) and final setting time (Fig. 3b) as the M-sand was increased. Thus, replacing river sand by M-sand at 50% and 100% increased the initial setting time by 6.7% and 11%, respectively. Similarly, adding M-sand at 50% and 100% increased the final setting time by 6.5% and 14%, respectively.

The substitution of NS content by 0.5% and 1% reduced the setting time. This may have been caused by high surface area of NS particles. Also, NS was reported to reduce paste liquidity and decrease setting time [20]. The setting time of HPC samples with 50% M-sand and 1% NS was that of control concrete. Fig.3, also show that adding more than 1% of NS increased the setting time. And a further increase of NS, increased the surface area of the cementitious content, which also led to shortage of hydration water.

#### Figure 2
Penetration resistance curve of HPC specimens with M-Sand

### 3.2 Strength Properties

Compressive strength of HPC, obtained after curing regimes 1, 3, 7 and 28 days, is shown in Fig.4. The replacement of sand by M-sand yielded marginally lower compressive strength compared to that of the control mix in both early and later curing periods. In Fig.4, it was observed that HPC incorporating M-sand exhibited good strength up to 50% by weight with natural river sand, but strength reduced when 100% M-sand was used. Test results indicate that the NS addition significantly improved the compressive strength of HPC specimens at all the early curing regimes. It was deduced from the results that, the percentage increase of compressive strength of control HPC specimen was 17.34 and 39.29% at the age of 1 day by adding 0.5 and 1.0% NS, respectively. A 1% NS substitution enhanced the compressive strength of concrete when 50% river sand was replaced by M-sand. Fig.4 show that the percentage increase of compressive strength of HPC with 50% M-sand is 2.01 and 23.62% at the age of 1 day by adding 0.5 and 1.0% NS, respectively.
Figure 3 Setting time variation of NS blended HPC (a) Initial setting time (b) final setting time

Figure 4 Compressive Strength of NS blended HPC

The results obtained from 3 days and 7 days compressive strength revealed higher values compressive strength when 1\% NS was used. The increased early strength with the incorporation of nano size silica could be due to high specific surface area of NS, and with this, hydration and pozzolanic reactivity are altered. This assertion agrees with the results obtained by Qing et al. [14]. However, the substitution of 2.0\% NS had shown reduction in compressive strength of M-sand based HPC in all the curing periods. The similar kinds of results were noticed in 28 days strength also. From the results, it has
been observed that the combination of 50% river sand and 50% M-sand with 1.0% NS had shown the best results in compressive strength in both early age and also later age.

The effect of M-sand and NS on the splitting tensile strength of HPC at 3, 7, and 28 days is shown in Fig. 5. The splitting tensile strength with 100% M-sand was not considered due to the poor performance of the same mix in compression test. From Fig.5, the marginal improvements in splitting tensile strength were noticed when 50% M-sand has been added instead of river sand due to surface texture of M-sand. By inspection, there was 14.0 and 16.8% increase in splitting tensile strength of control HPC specimen at the age of 3 days by adding 0.5 and 1.0% NS, respectively. Similar kinds of increase in result were observed in 7 days strength of control and 50% M-sand based HPC. With the incorporation of 1% NS in 50% M-sand HPC, 10.5% increase in splitting tensile strength was observed. There was subsequently reduction in splitting tensile strength of M-sand based HPC at 2.0% substitution of NS over all the curing periods. Similar trend of results were obtained at 28 day test.

![Image of splitting tensile strength](image_url)

**Figure 5.** Splitting tensile strength of NS blended HFC

### 3.3 Strength models development

The model equations for strength properties of HPC with NS and M-sand at 3 days and 7 days, obtained by regression analysis, is shown in Fig. 6. Based on the data obtained, the relationship at 3 days was $f_t = 0.6205(f_{ck})^{0.5704}$, and at 7 days was $f_t = 0.6679(f_{ck})^{0.5295}$. As shown, the early age strength of HPC with NS was improved than the IS: 456-2000 code recommended models.
4. Conclusion

This study focuses on the effect of mineral admixtures on early age properties of high performance concrete. The conclusions drawn from the study are as follows:

i) In order to maintain the workability in the range of 150 mm in M-sand and NS blended HPC, the dosage of the superplastizer was increased to cater for slightly higher water absorption properties of M-sand than the river sand.

ii) The initial and final setting time increased with increasing M-sand. Up to 1% substitution of NS reduced both the initial and final setting time of concrete to the level of the control concrete level.

iii) The HPC incorporating M-sand up to 50% by weight of natural river sand developed higher strength. The percentage increase in compressive strength of HPC with 50% M-sand is 2.01 and 23.62% at the age of 1 day by adding 0.5 and 1.0% NS, respectively.

iv) The relationship between compressive strength and splitting tensile strength of HPC with NS and M-sand at 3days and 7 days are found to be $f_t = 0.6205f_{ck}^{0.5704}$ and $f_t = 0.6679f_{ck}^{0.5295}$ respectively. The results show that the early age strength of HPC with NS was improved than the IS: 456-2000 code recommended models.

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