Effect of nanosilica on drying shrinkage and creep properties of cement concrete

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Abstract

The microstructure and time dependent properties of nanosilica (nS) added high performance concrete (nS-HPC) were investigated, and a comparison of these properties with those of microsilica (mS) added high performance (mS-HPC) concrete and a reference concrete (RefCon) are presented. 3% colloidal nS and 7.5% powder mS were used to make nS-HPC and mS-HPC, respectively. The scanning electron microscopic image of the 90 days' nS-HPC revealed that the quantity of $Ca(OH)_2$ present was almost negligible and the concrete attained a finer and compact microstructure with finer C-S-H as compared to that of other two concretes. The creep and drying shrinkage of the nS-HPC were found to be higher than those of RefCon and mS-HPC. However, the observed drying shrinkage of all the concrete mixes was found to be conforming with the estimates made from Indian Road Congress (IRC):112-2011 model, while on the other hand, the creep coefficients of mS-HPC and nS-HPC was found to be higher than the corresponding estimated creep coefficients, and the same were found to be higher by 13.3% and 18.2%, respectively, at 100 days. The increase in drying shrinkage and creep of both the high-performance concretes (HPC) than that of RefCon may be attributed to higher amounts of gel water present in the finer C-S-H produced due to pozzolanic action. The results from the study indicates suitability of nS-HPC for construction of bridge structures. Copyright © 2017 VBRI Press.

Keywords: Nanosilica, microsilica, microstructure, drying shrinkage, creep.

Introduction

Concrete, one of the most widely used building material, is a product of portland cement hydration and hardening. As soon as water is added to the cement-aggregate mixture, the hydration reaction initiates and continues for a long duration, resulting in a strong concrete with high durability. Advancements in concrete research transformed the concrete mix from a simple combination of cement, aggregate and water, to complex combinations including admixtures and additives. In this connection, Supplementary Cementitious Materials (SCM's) have attracted worldwide attention due to their ability to partly replace Portland cement, whose production is becoming unsustainable due to its high embodied energy and CO_2 emission. SCM's such as fly ash, silica fume or mS and blast furnace slag have already been accepted as alternative materials or additives in concrete due to their high pozzolanic activity and filler ability, resulting in sustainable and durable building material. Of late, addition of nanomaterials in concrete has attracted researchers' attention due to their ability to alter/enhance concrete properties at smaller replacements **[1]**. nS is one such material which has been found to have high pozzolanic activity, resulting in a concrete with reduced $Ca(OH)_2$, higher quantities of finer C-S-H and compact microstructure **[2-6]**. Also, the nS added concrete was reported to possess high strength and durability **[7-9]**. IRC:112-2011 **[10]** categorizes those concretes containing one or more SCM's, as HPC.

The time dependent properties such as shrinkage and creep play an important role on the behavior of structural concrete elements subjected to environmental exposure and load effects, and can lead to development of cracks and deformation if the same are not accounted properly in the design. These properties of concrete are generally associated with a change in volume, and are influenced by the fineness and quality of C-S-H, gel water, refinement of hydration products etc. However, the effect of nS on these properties has not been reported, although such a study is important when nS based concrete is considered for applications in roads and bridges.

Therefore, an attempt has been made in this study with an objective to investigate the influence of nS addition on time dependent properties of concrete. The test results of this study were compared with the limiting values of shrinkage and creep suggested by IRC:112-2011 **[10]** to ensure its conformity for use in road bridge applications.

Scanning Electron Microscopic (SEM) images were analyzed to corroborate the test results with the microstructure of the concrete. The properties of nS-HPC were also compared with those of mS-HPC and RefCon, to understand the effect of nS in concrete.

Experimental

Materials

Ordinary Portland cement of 43 grade conforming to Indian Standards (IS): 8112-2013 **[11]** was used. The specific gravity, consistency, initial and final setting times of the cement were determined as per IS: 4031 Part IV and V-1988 **[12-13]** and the same were found to be 3.15, 32.3%, 140 minutes and 205 minutes, respectively. The cement strength was evaluated as per IS: 4031 Part VI-1988 **[14]** and the observed compressive strength was 28, 36 and 45 MPa at 3, 7 and 28 days, respectively. Densified powder type amorphous mS of 920 D grade (Elkem-Sweden make) with a silica content of 86.7% was used. The silica content of mS conformed to the specification of IS: 15388-2003 **[15]**. The specific gravity of mS was 2.2. Colloidal nS of Cembinder 8 grade (AkzoNobel-Germany make) having 50% solid content and 92.4% silica content was used. The specific gravity of nS was 1.38.

Crushed granite natural coarse aggregate of 20 and 10 mm sizes, and crushed stone fine aggregate available in Delhi region were used. The salient features of these aggregates were determined as per IS 2386-1963 **[16-18]** and the results are presented in **Table 1**. The aggregates were generally found to be suitable for the preparation of normal weight concrete. Potable water conforming to the requirements of IS: 456-2000 **[19]** was used for mixing and curing of concrete. A polycarboxylic ether polymer based superplasticizer (MasterGlenium SKY 8777, BASF-India make) was employed in the study.

Table 1. Salient properties of aggregates used.

	RefCon	mS-HPC	nS-HPC
Cement (kg/m³)	420	388.5	407.4
mS (kg/m³)	-	31.5	-
nS (kg/m³)	-	-	25.2
Water (kg/m³)	168	168	155.4
Coarse aggregate (kg/m³)	1233	1225	1229
Fine aggregate (kg/m³)	649	645	647

Mix proportioning and specimen preparation

A 40 MPa grade concrete suitable for applications in a ‘very severe’ exposure condition was designed based on IS: 10262-2009 **[20]**. The optimum cement replacement of mS and nS were obtained from their respective maximum strength efficiency factor levels **[21]**. Accordingly, the cement was replaced with 7.5% mS in mS-HPC, and 3% nS in nS-HPC. The mix proportions of concrete mixes are presented in **Table 2**. A uniform proportion of superplasticizer at 1.5% by weight of cementitious materials was used for all the mixes. The variation in the specific gravity of mS and nS with respect to cement, and the water content of colloidal nS were taken in to account during the mix design. The concrete was mixed in a tilting type rotational mixer of capacity 100kg. Test specimen were made from each mix for the experimental study. Concrete cube specimens of size 150 mm size were cast to determine the compressive strength and microstructure of the concretes, while 500×100×100 mm size prism specimens were cast for study of time dependent properties. Vibrating wire strain gauges (ACE Instrument-model 1240 VW) were placed inside the prism specimen at the time of casting, to monitor the strain developed inside the specimen due to drying shrinkage and creep. The range of the strain gauge was + 1000 με (at compression) and -500 με (at tension), and its sensitivity was 0.5 με. The concrete specimens were cured at 27 ± 2^0C by immersing in water for 28 days.

Table 2. Proportions of concrete mixes.

	RefCon	mS-HPC	nS-HPC
Cement (kg/m³)	420	388.5	407.4
mS (kg/m³)	-	31.5	-
nS (kg/m³)	-	-	25.2
Water (kg/m³)	168	168	155.4
Coarse aggregate (kg/m³)	1233	1225	1229
Fine aggregate (kg/m³)	649	645	647

Test procedure

The drying shrinkage and creep of the concrete test specimens were determined for 100 days, as per ASTM C512 **[22]** using concrete prism specimens immediately after 28 days’ water curing. The room temperature during testing was maintained at 22±2^0C. The unloaded specimens, for drying shrinkage, were kept vertically (standing position) and undisturbed during the test period, while the creep specimens were mounted on a loading frame through which a load equal to 40% of their 28 days’ compressive strength was applied. The creep specimens were maintained at a constant stress during testing and the corresponding load was 18.8 MPa for RefCon, 20.9 MPa for mS-HPC and 23.8 MPa for nS-HPC. The load on the frame was applied using a hydraulic jack of adequate capacity, and was maintained consistently by manual monitoring at frequent intervals. The strain developed inside the specimen due to drying shrinkage and creep was measured through the vibrating wire strain gauges, using a strain readout unit (Geokon model: GK403). The test results of drying shrinkage and creep of the concrete specimens were compared against the theoretical estimates, of concrete with a characteristic compressive strength of 40 MPa, obtained from models given in IRC:112-2011 **[10]** for the same. The relative humidity was taken as 50% for the estimation. The results of drying shrinkage and creep were also corroborated with the microstructure analysis of the hardened concrete at 90 days. The microstructural study was carried out on 1 cm concrete sample, using a high magnification SEM equipment (ZEISS: EVO-LS 15). The surface of the concrete sample was coated with gold before imaging, so as to achieve conductivity of the electron beam on to the concrete surface.

Results and discussion

Drying shrinkage

A comparison of the observed drying shrinkage of all the concrete specimens, and the corresponding estimated drying shrinkage (from IRC:112-2011 **[10]** model) is presented in **Fig. 1**. It was observed that the drying shrinkage of the RefCon was lower than that of mS-HPC and nS-HPC. The drying shrinkage values were almost similar in mS-HPC and nS-HPC till 20 days after which the value of nS-HPC increased than that of mS-HPC, indicating the development of higher quantities of finer C-S-H in nS-HPC. However, the measured drying shrinkage strain was lower than the estimated values from IRC:112-2011 **[10]** model for all concretes. Also, no visible cracks were found on these samples due to drying shrinkage.

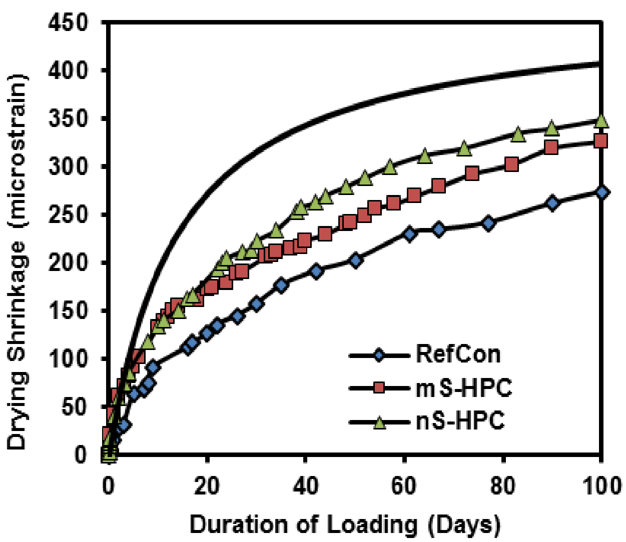

Fig. 1. Variation of drying shrinkage with time.

The above inference was corroborated by an examination of the SEM images **(Fig. 2-4)** of the hardened concrete which indicated that the addition of SCM's resulted in production of increased quantities of C-S-H as a result of pozzolanic action. The identification of $Ca(OH)_2$ in nS-HPC was highly difficult to distinguish due to the formation of denser and crowded microstructure. On the other hand, large plies of $Ca(OH)_2$ sheets were observed in RefCon. However, in the case of mS-HPC the $Ca(OH)_2$ was observed to be partially consumed, forming a ring pattern along the sheets, which could be due to continuing pozzolanic action even at 90 days. The size of the C-S-H gel reduced from coarser lumps in RefCon to a smaller size in mS-HPC, and extremely fine C-S-H in nS-HPC. The observations from the microstructural analysis of the concrete were found to be in agreement with those reported in literature [**23-24**].

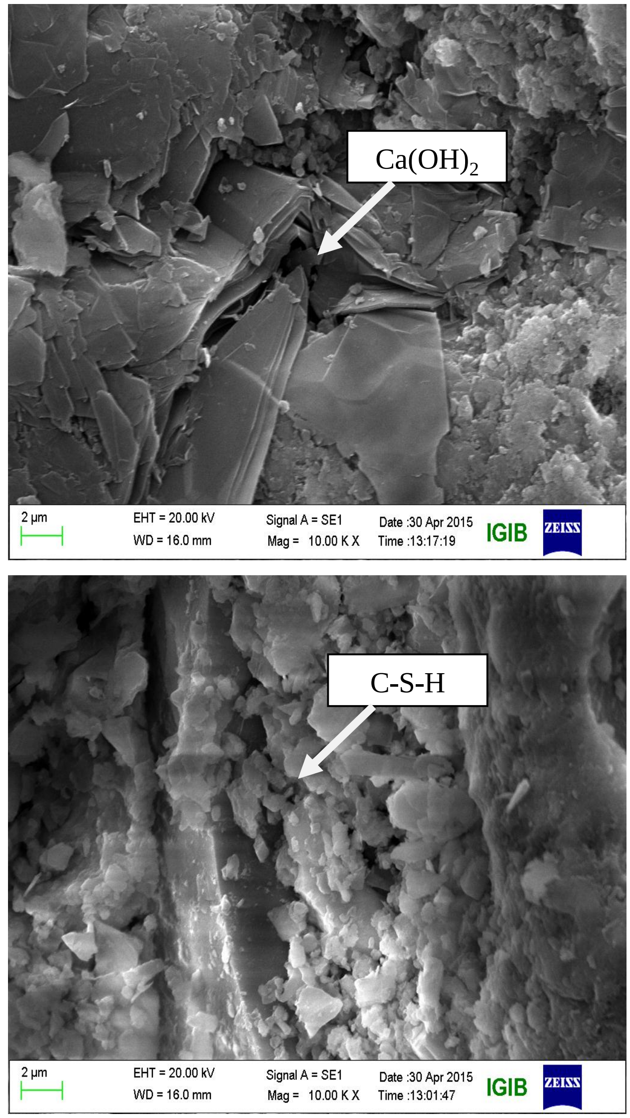

Fig. 2. SEM images of RefCon.

As the occurrence of drying shrinkage of concrete is due to expulsion of gel water, the higher drying shrinkage of nS/mS HPC's as compared to that of RefCon can be attributed to the presence of higher amounts of finer C-S-H holding higher amounts of gel water, which is released during drying shrinkage.

Creep

The measured variation in the creep strain with time is presented in **Fig. 5 (a)**, from which it can be observed that, similar to the drying shrinkage, the creep of nS-HPC was higher than that of mS-HPC and RefCon. In general, creep is considered as a deformation phenomenon due to the readjustment and expulsion of gel water in the concrete under sustained load. As was observed from **Fig. 2-4**, higher amounts of finer C-S-H due to high pozzolanic activity of the mS and nS would result in corresponding higher amounts of gel water, the expulsion of which during loading resulted in higher creep value of mS-HPC and nS-HPC.

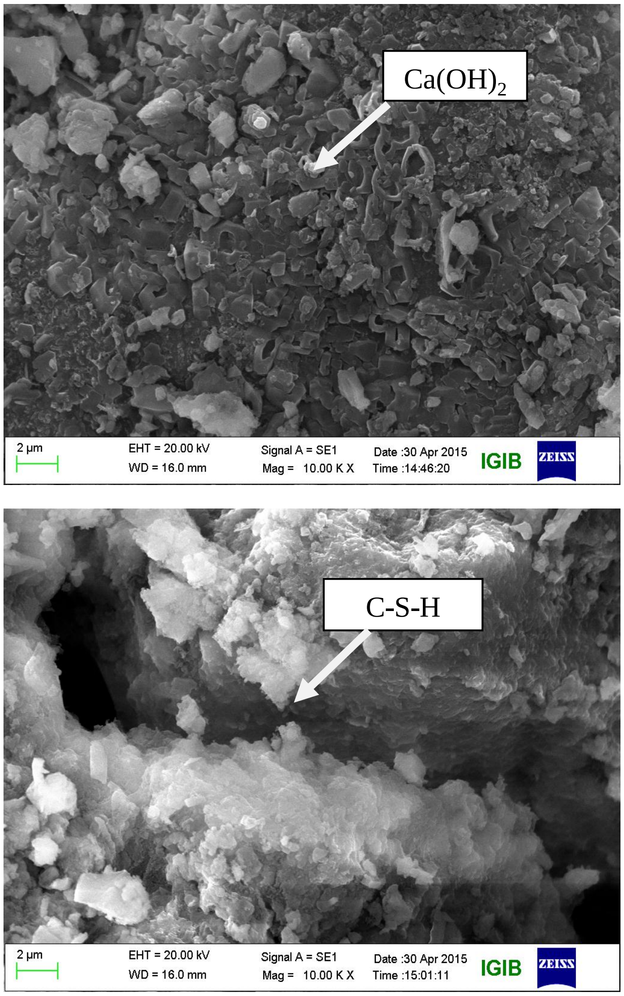

Fig. 3. SEM images of mS-HPC.

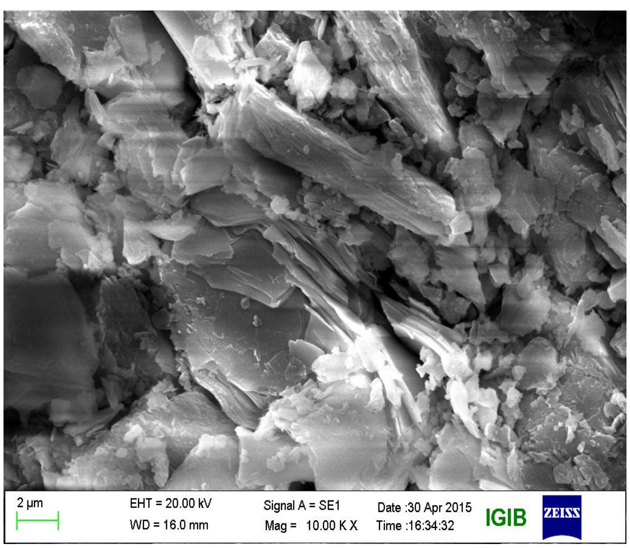

Fig. 4. SEM images of nS-HPC.

The elastic strain of the concrete as measured immediately after loading was obtained as 250 µε and 253 µε for mS-HPC and nS-HPC, respectively. The creep coefficient values are presented in **Fig. 5 (b)**, which indicate that the creep coefficients of both mS-HPC and nS-HPC were almost in the similar range. It was also observed that the creep coefficients of mS-HPC and nS-HPC at different ages were higher than those predicted by the IRC:112-2011 **[10]** model, and the same were found to be higher by 13.3% and 18.2%, respectively, at 100 days.

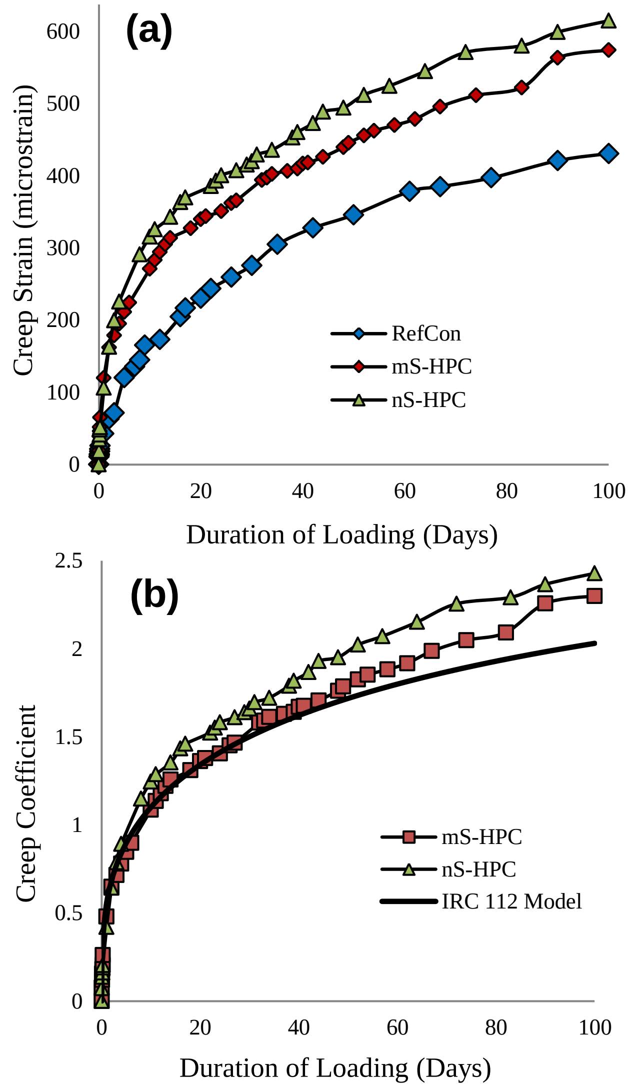

Fig. 5. Variation of creep with time

Conclusion

The time dependent properties namely, drying shrinkage and creep, of nS-HPC were found to be higher than those of RefCon and mS-HPC, due to microstructure refinement of concrete at nano-level. However, the overall drying shrinkage values of nS-HPC were found to be lower than the values estimated from the IRC:112-2011 model, while on the other hand a slight increase in the creep coefficient from the permissible limits suggested by IRC was observed in case of both the HPC's. As already stated the nS-HPC also imparts higher strength and durability as that of mS-HPC, but at a lower dosage **[7-9, 21].** Hence it is concluded that the nS-HPC can be efficiently used for the construction of bridge structures.

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