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Influence of Nano particles in High Performance Concrete (HPC)

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Abstract: The mechanical properties of nano-SiO_2 and nano- Al_2O_3 concrete beams were experimentally studied. For this purpose, beams with conventional reinforcement (150 x 150 x 1000 mm) are tested. In the experimental program which is conducted on specimen of type two different types of nano particles i.e., and four different types of ratios are used viz. (0.5, 1, 1.5, 2). The experimental result showed that compressive and flexural strength measured at 28^{th} day of the concrete mixed with nano-siO_2 and nano- Al_2O_3 were higher than that of a plain concrete mix. The test results indicated that the incorporation of nano particles significantly enhanced the resistance to cracking behaviour of concrete. In the case of specimens without nano particles a sudden drop in the load was noticed beyond the peak load. On the other hand, nano particles concrete specimens exhibit more or less a flat descending portion of the curve beyond peak load. This indicates the improvement in the dimensional stability and structural integrity of the specimen even beyond the peak load when nano particles are added.
Key words: Nano-SiO_2 and Nano- Al_2O_3, Mechanical properties.

1. Introduction

Due to an ultrafine size, nano-particles show unique physical and chemical properties different from those of the conventional materials. Because of their unique properties, nano-particles have been gaining increasing attention and been applied in many fields. The development of high performance and self-compacting concrete made it possible to fill the concrete completely into a steel tubular column having number of diaphragms inside. Nano particles with High performance Concrete contains particles that are uniformly distributed and randomly oriented. Nano-SiO_2 and Nano- Al_2O_3 have an enormous potential in crack arresting and therefore nano concrete has many application in liquid storage structures and nuclear power plants where cracking must be avoided. When a structural element tends to crack under load, steel fibres bridge the cracks. Such bridging action provides the nano concrete specimen greater ultimate tensile strength and, more importantly, large toughness. The main functions of the nano particles in members subjected to compression are to resist the opening of cracks due to micro-cracking, increases the ability of the composite to withstand loads, and to allow large strains. Ye Qing et al [3] experimentally investigated the effects of Nano-SiO_2 on properties of hardened cement paste. Byung-Wan Jo et al [2] studied the influence of Nano-SiO_2 on characteristics of cement mortars. The results of these studies showed that Nano-SiO_2 can improve the mechanical properties of hardened cement paste and cement mortar. Hui Li [6] investigated the effects of Nano-SiO_2 and Nano-Fe_2O_3 on mechanical properties of cement mortars. Gengying Li [5] investigated the influence of Nano-SiO_2 on mechanical properties of high volume fly ash concretes. Through the literature survey of the authors there are few published studies on the influence of other Nano-particles on mechanical properties and durability of high performance concrete. Provision of nano particles checks the initiation of micro-cracks and also improves the strength and other characteristics of concrete. The addition of nano particles not only influence the ascending portion of stress-strain curves of HPC but also leads to noticeable increase in strain corresponding to peak stress and significant increase in ductility. The experimental programme consists of preparation of high performances concrete and plain concrete which include high performances and nano concrete with nano particles. Addition of nano-particle improved that was in agreement with the strength enhancement. Therefore, it is feasible to add nano-particles to make high performances concrete.

2. Material and Methods

2.1 Materials

Ordinary Portland cement of 53 grade confirming to IS 8112:1989[9]of locally available RAMCO cement which comprises good quality. The chemical configuration of cement was found using X-ray fluorescence analysis and has the following properties are given in table1. Aggregate were used as per IS: 383-1970. Although there are various nano phase materials are available nano-SiO_2 and nano-Al_2O_3 only were used in the study. The properties are given in table 2.

Table 1: Physical and chemical composition of ordinary Portland cement (OPC)

Description	Composition
Physical Properties	
Colour	Grey
Specific gravity	3.15
Specific surface area (cm^2/g)	3540
Chemical Composition	
CaO (%)	62.8
SiO_2 (%)	20.3
Al_2O_3 (%)	5.4
Fe_2O_3 (%)	3.9
MgO (%)	2.7
Na_2O (%)	0.14
K_2O (%)	62.8

For the present study design of mix has been done based on the ACI code. Since design guidelines for HPC are not included in Indian Standards, the mix was designed based on ACI 211 4R-93 recommendation. Mix ratio was obtained by trial and error and it is given in table 3.

Table 2: Physical and chemical properties of nano-silica.

Particulars	Values
Particle size	10-20 nm
Density	2.2-2.6 g/ml at 25 °C
Bulk density	0.011 g/ml
Form	Powder
Surface area	140-180 m^2/g
BP	2230 °C
MP	mp >1600 °C
Molecular Weight	60.08 g

Table 3 Mix Proportion for HPC of M70 Grade and compaction factor 0.9

Particulars	kg/m^3
Cement	389
Fly ash	118
Fine aggregate	622
Coarse aggregate	1078
Water	172 l/m^3
Super plasticizer	2.3 %

Admixtures (Super-plasticizer): CONPLAST SP430 (G) complies with IS: 9103:1999[11] and BS: 5075 (Part 3) and ASTM-C-494[12] type 'F' having a specific gravity of 1.2 was used as a high range water reducing agent.

2.2 Methods

2.2.1 Flexural Test

The experimental programme consists of preparation of nano concrete with high performances concrete which include nano particles. Beam of size (150 x 150 x 1000mm) were prepared with reinforcement of 12mm bars at the tension side. The two point load was applied at 200 mm from the end support so that the minor span (flexure span) of 200mm and major span of 900 mm could be obtained. The beams were subjected to monotonic loading for different types of nano particles. The load was applied in stages. For every 0.5 KN of loading, the following readings have been noted for small specimen alone. Load at that stage and deflection at the mid span of the specimen.

Specimen of size 150x150x1000 mm was tested in a Universal Testing Machine of capacity 300T (2943 KN). In order to note down the applied load precisely, a load cell of 25T (245KN) capacity, with a least count of 0.01T (0.098KN) was used. The rate of loading was kept as 140kg/cm2/min. Two linear variables differential transducer (LVDT) were used for measuring the longitudinal strain at the top and bottom of the beam to find out the moment-curvature relationship. The longitudinal deformation at the top and bottom were measured using LVDT with a range of ±5mm and a resolution of 0.001mm. The LVDT were placed at a distance of 20 mm from the extreme compression and tension of beam. The vertical deflection at the mid span was measured using a dial gauge having a travel of 50mm and a last count of 0.01 mm. The beams were supported on two rollers having 30mm diameter and one of which was fixed and the other was capable of rotation. The effective span was kept as 900mm. The specimens were tested under two point loading. Values are noted for deflection at mid span, LVDT reading at 20mm and crack width at the soffit and propagation of crack.

3. Test Result and Discussions

3.1 Load-Deflection Behaviour

The load versus mid span deflection response of the beam specimens under monotonic loading is discussed here. The recorded values of load and deflection have been used to obtain the P-plots. The load-deflection responses of beams under monotonic loading are shown in the figure 1 and 2.

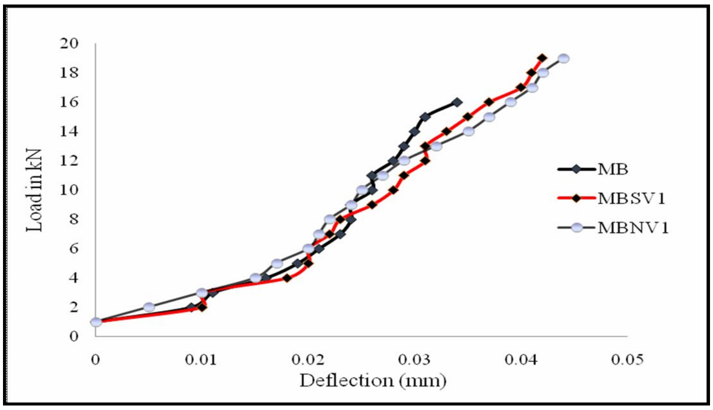

Fig 1 Comparison load versus deflection of beam with weight fraction of admixtures by cement

It may be noted that for all the curves, in pre-cracking stage, the deflection increases linearly with the loading. This is expected since the strain in the steel and concrete are relatively small and both the materials are in the elastic portion of their respective response. In the post cracking stage, there is a change in slope in the load-deflection plot due to cracking, which induces the effective moment of inertia. After cracking deflections again increase slightly non-linearly with load up to point just after yielding of all tensile steel. In the post yielding stage, due to yielding of the tensile steel, the entire load-deflection plot exhibits some changes in slope. At a sectional level, the depth of the neutral axis reduces significantly, thereby increasing both curvature and deflection immediately after yielding. Each beam exhibited different post-yield load-deflection response. In the case of specimens without nano particles a sudden drop in the load was noticed beyond the peak load. On the other hand, nano concrete specimens exhibit more or less a flat descending portion of the curve beyond peak load. This indicates the improvement in the dimensional stability and structural integrity of the specimen even beyond the peak load when particles are added. The contribution of nano Sio_2 is most important for the flexural strength. This is due to the nano particles bridging of the crack, allowing flexure significant tensile stresses to be transmitted in the stretched region. In addition, the increase in the maximum moment (at the peak load) for the reinforced materials also produced higher compressive stresses and consequently a better exploitation of the material. The nano material beams showed approximately the same stiffness as the conventional beams up to the first crack load. This greater post-cracking stiffness can be seen in the load deflection diagram. Under reinforced beams are adequately ductile in themselves and the addition of nano Sio_2 is beneficial in improving deformational characteristics of the beams. The improvements in these characteristics are reflected in terms of reduced strains in steel, reduced curvatures, and reduced deflections. Reduced steel strains are indicative of reduced crack width, and such modifications are much desired in slender structures conventionally reinforced with high-performance deformed bars. Typical plots showing load versus central deflection.

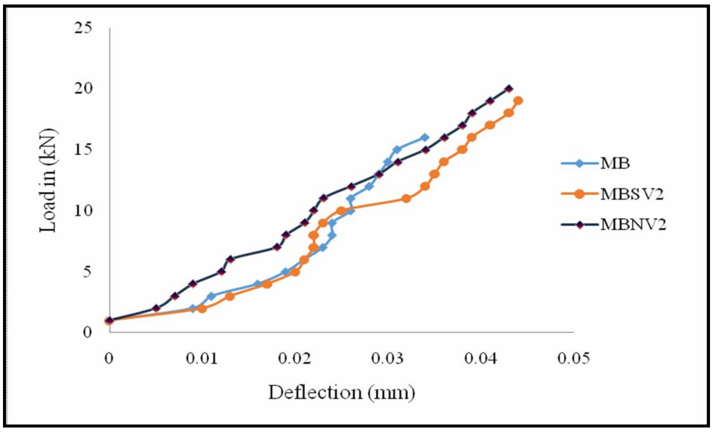

Fig 2 Comparison load versus deflection of beam with weight fraction of admixtures by cement

3.2 Flexural strength of Beam

The results obtained from the static flexural tests on the beam are tabulated in Tables 4 & 5. The values shown in the table are the average of results obtained from the tests on two identical beams under same type of loading. The first crack load shown was determined from the respective load-mid span deflection curve of the test beam. The load was taken as the one corresponding to that point on the curve at which the curve started departing from its initial straight portion. As the nano particles content increases, the first crack load and ultimate load increase. The first cracking load in the case of all high performance concrete beams was found to be more when compared to beam without nano materials. From the figure 3 Failure Moment, it is found nano particles in tension zone are increase and maintaining structural integrity of the beam. Cylindrical strength is a shown figure 4. It is important parameter considered in the design of structures subjected to large deformation.

Table 4: Contribution of nano particles in flexural tensile stress

Beam designation	**Volume fraction of nano particles V_f (%)**	**Failure Load (KN)**	**Failure moment (KN-m)**	**Contribution in flexural stress due to fibres (N/mm^2)**	**Deflection at ultimate load (mm)**	**Cylinder strength (N/mm^2)**
PL	0	9.8	0.891	----	0.51	51.25
NA1	0.5	10.3	0.893	0.354	0.62	50.75
NA2	1	10.5	0.9	0.386	0.66	53.08
NA3	1.5	10.7	0.93	0.399	0.69	53.67
NA4	2	10.8	0.95	0.41	0.72	54.02
NS1	0.5	10.7	0.92	0.385	0.67	52.08
NS2	1	10.9	0.94	0.399	0.7	54.98
NS3	1.5	11.12	0.97	0.41	0.73	56.62
NS4	2	11.53	0.99	0.45	0.76	58.04

Table 5: Result of Beam test

Beam designation	Volume fraction of fibres V_f (%)	Calculated load (KN)	Maximum test load	Deflection at maximum load (mm)	Cylinder strength (N/mm^2)
PL	0	71.03	72.02	7.2	51.25
NA1	0.5	72.08	72.65	7.5	50.75
NA2	1	72.89	73.87	7.9	53.08
NA3	1.5	73.75	74.23	8.01	53.67
NA4	2	74.23	75.02	8.1	54.02
NS1	0.5	72.34	73.0	7.5	52.08
NS2	1	74.72	75.98	7.90	54.98
NS3	1.5	75.54	76.62	8.52	56.62
NS4	2	78.62	79.72	9.09	58.04

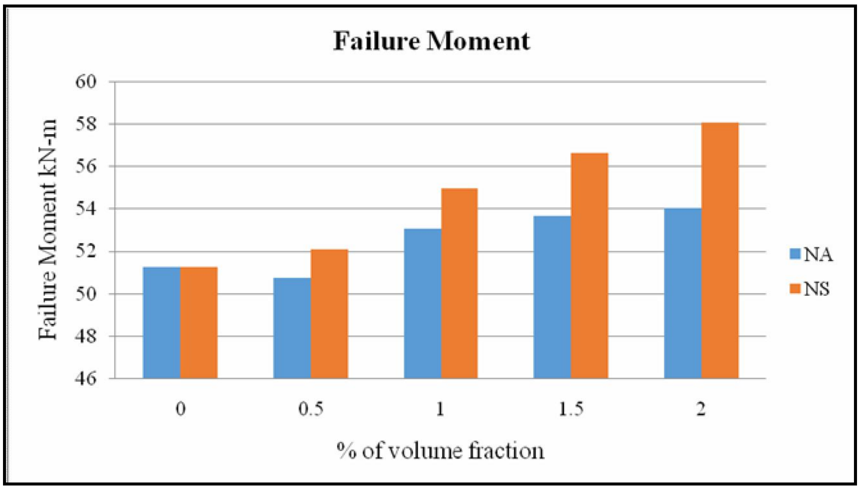

Fig 4 Failure Moment of Nano particles

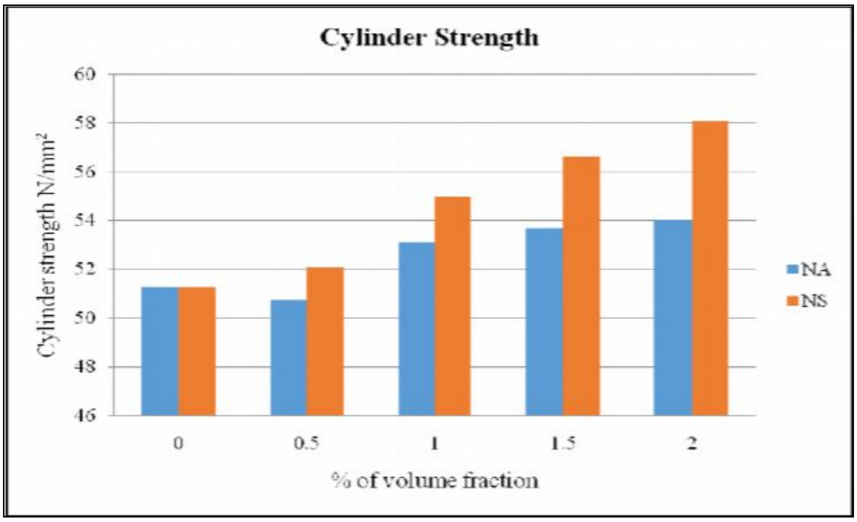

Fig 5 Cylinder Strength of Nano particles

3.3 Moment Curvature Relationship

An attempt was made to draw the Moment's curvature for all specimens. The strains at 20mm below extreme compression nano particles and at 20mm above extreme tensile have been measured using LVDTs. These values of strains were used to calculate for every loading stage. The values of M and φ thus obtained were used to plot the M- φ curves. The moment curvature plots for all specimens were drawn. They are shown in figures below. The moment Curvature curves can be explained with respect to the idealised moment curvature curve were shown in figure 6. The first part OA of the curve is the zone of loading in initial stage up to cracking, characterized by a steep slope and hence a high value of flexural rigidity (EI_g). The second part of AB represent the zone of loading after cracking in which the flexural cracks are predominant with the formation of shear cracks. This part is characterized by a lesser (mild) slope. This is due to the reduction in the effective area of cross section caused by the formation of tension cracks resulting in the lesser value of flexural rigidity (EI_{cc}). This third part BC is the zone of loading just prior to the ultimate load is the limit of useful strain in the nano concrete. The moment curvature plots obtained from the experimental results are shown in figure3.

The improvement in the behaviour of specimens as the nano Sio_2 content increases may be due to the following reasons. When nano Sio_2 are added to concrete they intercept the cracks, and will not allow them to propagate in the same direction. Hence the cracks intercepted by the Sio_2 have to take a meandering path, which requires more energy for further propagation resulting in higher load carrying capacity.

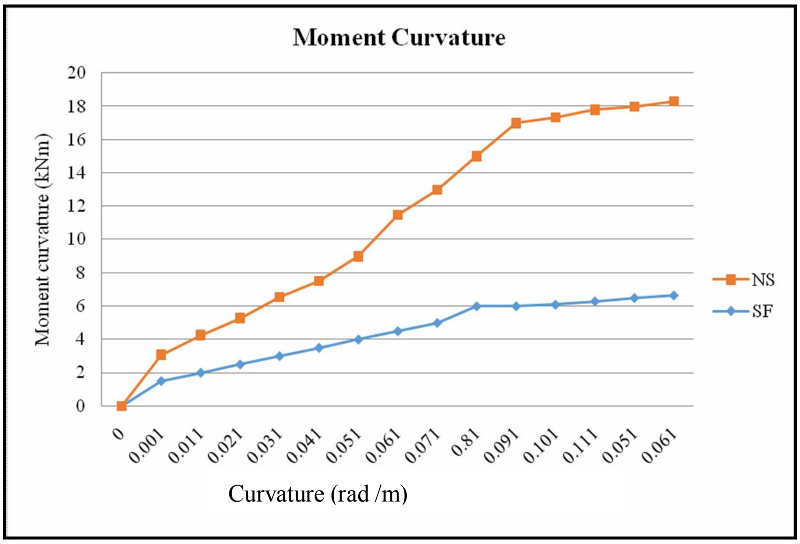

Fig 6 Comparison of moment versus curvature of beam under loading

4. Conclusions

An experimental investigation was carried out to study the effect of nano particles on the behaviour of high performance concrete flexural members. A total 49 specimens were cast and tested for present investigation. The specimens were tested under monotonic loading. Based on the experimental and analytical studies conducted, the following conclusion arrived.

1. The inclusion of nano SiO_2 concrete beam conventionally reinforced with high performance deformed bars bring about desirable modification in the deformational characteristics of such beams under pure bending.
2. Strain in reinforcing nano particles, curvatures, and deflections are reduced at any given load by including nano SiO_2 in conventionally reinforced concrete beams.
3. For the range of service loads, such modifications are more significant and desirable since they result in cracks smaller widths decreased deflections, and increased flexural rigidity.
4. The addition of nano SiO_2 increases the first crack load and ultimate load on average of 3.5% and 30.25% respectively.
5. The method proposed in the investigation, to predict the first crack load and width of crack of nano SiO_2 reinforced concrete flexural members are satisfactorily.

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