Experimental study on mechanical properties of high strength concrete using Nano-Silica

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Abstract - *Engineers are constantly exploring the limits to improve the performance of concrete with the help of innovative chemical admixtures and supplementary cementations materials. The use of large quantity of cement products increases co-emissions and consequence the greenhouse effect. The use of nano materials in concrete is a new revolutionary movement in construction industry. Nano materials like nano-silica, nano titanium oxide, carbon nano tubes, nano alumina etc. which are presently used in concrete to modify its strength properties. This study summarises the effect or influence of nano-silica on mechanical properties such as compressive strength, split tensile strength, flexural strength impact test and modulus of elasticity of M_{50} grades of concrete with the use of optimised nano-silica as partial replacement of cement. The compared results of both with and without the nano-silica are studied. Hence, It was found from the experimental study that concrete composites with superior properties can be produced using nano-silica.*

***Key Words*: Nano-Silica (NS), Conventional Concrete (CC), Compressive strength, Flexural strength, Split Tensile, Impact Resistance, PINB (Percentage of increase in number of post-first-crack blows to failure)**

1. INTRODUCTION

Nano technology is one of the most promising field in material science and engineering towards the evolution of peculiar technological materials. It finds its application in various fields of science and technology. Concrete is a highly heterogeneous material produced by mixture of finely powdered cement, aggregates of various sizes and water with inherent physical, chemical and mechanical properties. At present, the researchers emphasises on nanotechnology to produce a new generation of concrete materials that could achieve the sustainable concrete structures. Evolution of materials is the must for improved performance for special engineering applications and modifying the bulk state of materials in terms of composition or microstructure or nanostructure.it has been the established route for synthesizing new materials. The newer materials can also be obtained by intelligent and intermixing of existing materials at element level. It's also a new revolutionary approach developed to handle traditional problems tilting towards the development of sustainable materials in the construction industry. The optimal use of nano-silica will create a new concrete mixture that will result in long lasting concrete structures in the future. Nano technology will set new standards for the construction industry.

2. OBJECTIVE

The primary objective of the project is to study the influence of nano-silica on the mechanical properties of high strength concrete. Besides, we do emphasis to control or improve materials properties at nano-size level and to compare the conventional concrete with nano-silica concrete from the deciphered information reveal from the experimental study.

3. MATERIALS USED

3.1 Cement

OPC 53 grade was used. The physical properties determined in the laboratory. The cement satisfies the requirements of IS: 12269-1987 specifications.

Table -1: Properties of Cement

Properties of Cement		
Sl no.	Characteristics	Value
1	Specific gravity	3.15
2	Normal Consistency	31 %
3	Setting Time	
	(i) Initial Setting Time	45 min
	(ii) Final Setting Time	510 min

3.2 Fine Aggregate (F.A)

The fine aggregate was used in the experimentation were conform to IS: 383-1970 specifications.

Table -2: Properties of fine aggregate

Properties of fine aggregate		
Sl no.	Characteristics	Descriptions
1	Specific gravity	2.66
2	Fineness modulus	2.81
3	Water absorption	0.07

3.3 Coarse Aggregate (C.A.)

The coarse aggregate use in the experiment is 10 mm size aggregate and tested as per IS: 383-1970 specifications. Physical properties of coarse aggregates as determined in a laboratory

Table -3: Properties of coarse Aggregate

Properties of coarse Aggregate		
Sl no.	Characteristics	Descriptions
1	Max nominal size	10 mm
2	Specific gravity	2.66
3	Fineness modulus	6.77

3.4 Superplasticizer

Polycarboxylic Ether is used as super plasticizer. It's an admixture of a new generation based on modified polycarboxylic ether.

Table -4: Properties of superplasticizer

Properties of superplasticizer		
Sl no.	Characteristics	Descriptions
1	Specific gravity	1.09
2	pH	4-7
3	Chloride content	nil

3.5 Additional Material

Nano-Silica is used as additional material.

Table -5: Properties of Nano-Silica

Properties of Nano-Silica		
Sl no.	Characteristics	Descriptions
1	Physical State	Powder
2	Specific gravity	1.30-1.32
3	pH	9-10
4	Particle size	5-40 nm

4. EXPERIMENTAL WORKS AND DISCUSSION

Experimental program was designed to compare the mechanical properties i.e. compressive strength, split tensile strength, flexural strength, impact abrasion test and modulus of elasticity of high strength concrete with M_{50} grade of concrete and with partial replacement levels of ordinary Portland cement (53 grade) with nano-silica with various percentages (1%, 2%, 3%, 4%, 5%, 6%, 7% & 8%). The optimised value is determined. Comparative mechanical strength properties of M_{50} grade concretes were studied with conventional and optimum nano-silica (4%) concrete.

4.1 Mix Proportions

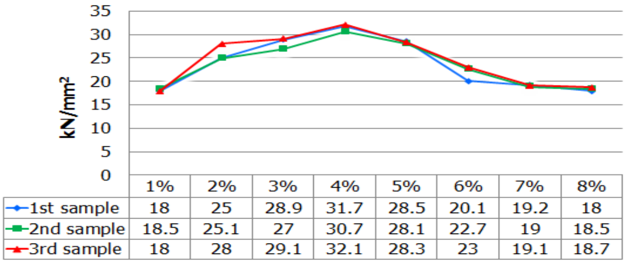
Concrete mix is design to a compressive strength of M_{50} grades with water cement ratio of 0.35 as per IS code 10262-2009.

Table -6: Mix Design

Mix Design			
Water	Cement	F.A.	C.A.
0.35	1	2.1	2.1

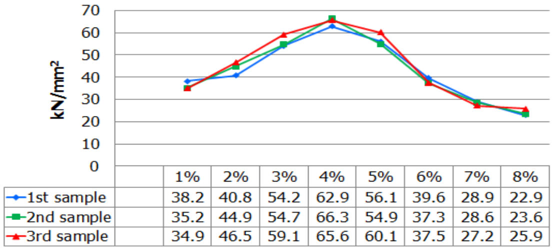
4.2 Compressive Strength

To find the optimum percentage of nano-silica to be added, series of compressive test are conducted for various percentage of nano silica (1%, 2%, 3%, 4%, 5%, 6%, 7% & 8 %). Cube specimens were cast for M_{50} grade of concrete were tested for 3, 7 & 14 days on compression testing machine as per I.S. 516-1959. Compressive strength of the specimen at 7, 14 & 28 days, with replacement of nano-silica was increased gradually upto a certain percentage of NS and then decreased. The optimised value was obtained as 4%. The optimisation for 3, 7 and 28 days of compressive strength with various percentage of nano-silica are presented in Chart -1, 2 & 3 respectively. There is an increase of 47.2%, 47.9% and 29.62 % in the 3, 7 and 28 days compressive strength respectively of the same M_{50} grade concrete. Also, the compressive strength of the nano-silica concrete is 1.5, 1.5 & 1.3 times greater than conventional concrete for 3, 7 and 28 days respectively. The specimen before and after testing is presented in Fig -1.



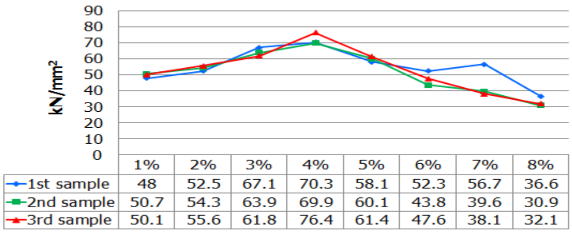
	1%	2%	3%	4%	5%	6%	7%	8%
1st sample	18	25	28.9	31.7	28.5	20.1	19.2	18
2nd sample	18.5	25.1	27	30.7	28.1	22.7	19	18.5
3rd sample	18	28	29.1	32.1	28.3	23	19.1	18.7

Chart -1: Optimisation of 3 days compressive strength with various percentage of Nano-Silica



	1%	2%	3%	4%	5%	6%	7%	8%
1st sample	38.2	40.8	54.2	62.9	56.1	39.6	28.9	22.9
2nd sample	35.2	44.9	54.7	66.3	54.9	37.3	28.6	23.6
3rd sample	34.9	46.5	59.1	65.6	60.1	37.5	27.2	25.9

Chart -2: Optimisation of 7 days compressive strength with various percentage of Nano-Silica



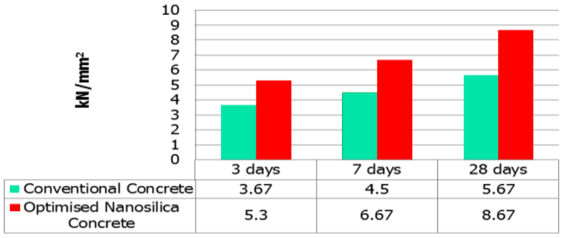
	1%	2%	3%	4%	5%	6%	7%	8%
1st sample	48	52.5	67.1	70.3	58.1	52.3	56.7	36.6
2nd sample	50.7	54.3	63.9	69.9	60.1	43.8	39.6	30.9
3rd sample	50.1	55.6	61.8	76.4	61.4	47.6	38.1	32.1

Chart -3: Optimisation of 28 days compressive strength with various percentage of Nano-Silica

Fig -1: Compressive strength test before and after testing

4.3 Flexural Strength

Flexural strength test is done as per IS: 516-19595. Specimens are tested in universal testing as presented in Fig -2. The comparison of average (avg) flexural strength of the specimen with nano-silica and conventional concrete with 3, 7 & 14 days are presented in Chart -4. There is an increase of 44.41 %, 48.22 % and 52.91 % in flexural strength for 3, 7 & 28 days respectively.



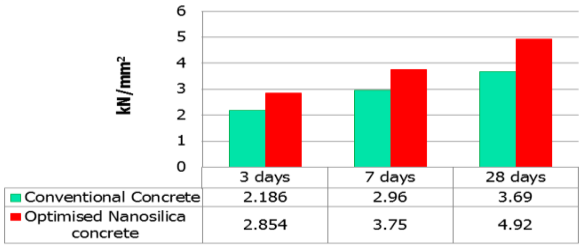
	3 days	7 days	28 days
Conventional Concrete	3.67	4.5	5.67
Optimised Nanosilica Concrete	5.3	6.67	8.67

Chart -4: Comparison of average flexural strength with CC & NS

Fig -2: Flexural test

4.4 Split Tensile Strength

Testing for split tensile strength of concrete is done as per IS 5816-1999. The test is conducted on compression testing as presented in Fig -3. The comparison of average split tensile strength with Nano-Silica and conventional concrete for 3, 7 & 28 days are presented in Chart -5. The Split Tensile Strength is increase by 30.56%, 26.70% & 33.33% for 3, 7 & 28 days respectively.



	3 days	7 days	28 days
Conventional Concrete	2.186	2.96	3.69
Optimised Nanosilica concrete	2.854	3.75	4.92

Chart -5: Comparison of average split tensile strength with CC & NS

Fig -3: The split tensile test proceedings before and after test testing

4.5 Impact Resistance Test

This test is widely used to demonstrate the relative impact resistance of concrete. PINB (Percentage of increase in number of post-first-crack blows to failure) values that indicate the ability to absorb kinetic energy suggest that adding nano-silica delays failure strength. Increased in impact resistance are given below:

(i) 3days : NS is 2 times greater than CC

(ii) 7days : NS is 2.72 times greater than CC

(iii) 28days : NS is 3.5 times greater than CC

The comparison of CC and NS avg PINB value and avg no. of blows are presented in Chart -6 & Chart -7 respectively. The specimen before crack, initial crack & failure were presented in Fig-4.

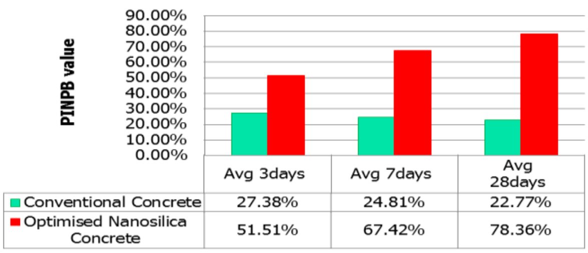


Chart -6: Comparison of average PINB value with CC & NS

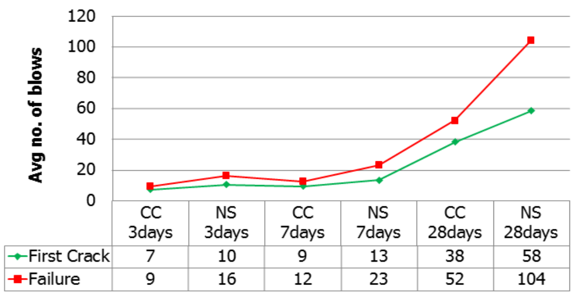


Chart -7: Average no. of blows for first crack and failure

Fig -4: Impact test proceedings of the specimen before testing, initial crack and failure

4.6 Modulus of Elasticity

The test was conducted as per IS: 516-1959. The comparison of modulus of elasticity of M_{50} grade of concrete containing 4% nano-silica (optimised) content for 28 days testing is presented in Chart -7. The modulus of elasticity of concrete containing nano-silica increases by 47.993 % compared to the conventional concrete for 28 days testing. The modulus of elasticity of optimised nano-silica concrete is 1.5 times greater than the conventional concrete for 28 days testing.

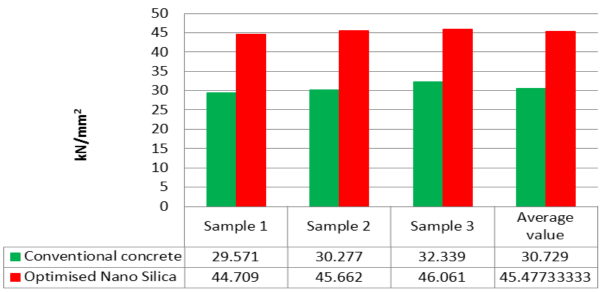


Chart -7: Comparison of 28 days modulus of elasticity with Nano-Silica & Conventional Concrete.

3. CONCLUSIONS

There is an overall increase in mechanical properties of the concrete with the introduction of nano-silica appreciably.

The influence of varying percentages of nano-silica M_{50} grade of concrete is studied.The optimised percentage found to be 4%.Increase in percentage beyond the optimised value, decreases the compressive strength.

The maximum increase in compressive strength, flexural strength, split tensile strength & PINB are 47.90 %, 52.91 %, 33.33 % & 85.26 % respectively.

There is an increase of 47.993 % in modulus of elasticity of concrete.

With the addition of nano-silica, the failure crack pattern changed from a single large crack into a group of narrow cracks, revealing the beneficial effects of Nano-Silica concrete subjected to loading.

The increase in the strength of optimised nano-silica concrete can be attributed to the availability of additional binder in the presence of nano-silica. Nano-Silica has high amorphous silicon dioxide content and is a very reactive pozzalanic material. As the Portland cement in concrete begins to react chemically, it releases calcium hydroxide. The nano-silica reacts with the calcium hydroxide to form additional binder material. The availability of additional binder enhances the paste-aggregate bond which results in the concrete with nano-silica that has improved strength properties

The experimental studies reveals that improved strength characteristics of concrete can be obtained with the use of nano-silica.

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REFERENCES

[1] Sanchez F. and Sobolev K., "Nano Technology in concrete-a review", Constr. Build Mater, Vol.24, pp.2060-71 (2010).

[2] Bjornstrom J., Martinelli A., Matic A., Borjesson L. and I.Panas, "Accelerating effects of colloidal nano-silica for beneficial calcium–silicate–hydrate formation in cement", Chemical Physics Letters, Vol.392 (1), pp.242-248 (2004).

[3] Ji T., "Preliminary study on the water permeability and microstructure of concrete incorporating nano-SiO_2", Cem.and Con. Res., Vol.35 (10), pp.1943–1947 (2005).

[4] Ye Qing, Zenan Z., Deyu K. and Ch. Rongshen, "Influence of nano-SiO_2 addition on properties of hardened cement paste as compared with silica fume", Constr. Build Mater., Vol.21, pp.539–545 (2007).

[5] Gaitero J.J., Campillo I. and Guerrero A., "Reduction of the calcium leaching rate of cement paste by addition of silica-nano particles", Cem.and Con. Res., Vol.38, pp.1112–1118 (2008).

[6] Mohamed Heikal, S. Abd el Aleem, W.M. Morsi, "Characteristics of blended cements containing nano-silica", HBRC Jl., Vol.9 (3), pp.243-255(2013).

[7] Lin K.L., Chang W.C., Lin D.F., Luo H.L and Tsai M.C, "Effects of nano-SiO_2 and different ash particle sizes on sludge ash–cement mortar", Jl. of Environ. Manage., Vol.88, pp.708–714 (2008).

[8] Li G., "Properties of high-volume fly ash concrete incorporating nano-SiO_2", Cem.and Con. Res., Vol.34, pp1043–1049 (2004).

[9] Lin D.F., Lin K.L., Chang W.C., Luo H.L and Cai M.Q, "Improvements of nano SiO_2 on sludge/fly ash mortar", Waste Management, Vol.28(6),pp.1081-1087 (2008).

[10] Nazari A. and Riahia S., "Splitting tensile strength of concrete using ground granulated blast furnace slag and SiO nanoparticles as binder", Energy and Buildings, Vol.43(4),pp.864-872 (2011).

[11] Byung Wan Jo, Chang Hyun Kim, and Jae Hoon Lim, "Investigations on the Development of Powder Concrete with Nano-SiO Particles", KSCE Journal, Vol.11 (1), pp.37-42(2007).

[12] Jo Byung-Wan, Kim Chang-Hyun, and Lim Jae-Hoon, "Characteristics of cement mortar with nano-SiO_2 particles", ACI Mat. Jl., Vol.104 (4), pp.404-407 (2007).

[13] Min-Hong Zhang, Jahidul Islam and SulaphaPeethemparan, "Use of nano silica to increase early strength and reduce setting time of concretes with high volumes of slag", Cem and Con. Compo., Vol.34, pp.650-662 (2012).

[14] Min-Hong Zhang, Jahidul Islam, "Use of nano silica to reduce setting time and increase early strength of concretes with high volumes of fly ash or slag", Constr. Build Mater., Vol.29, pp.573–580 (2012).

[15] Mastafa Jalal, Esmaeel Mansouri, MohammadAharifipour, Ali Reza Pouladkhan, "Mechanical, rheological, durability and micro structural properties of high performance self compacting concrete containing SiO_2 micro and nanoparticles", Materials and Design, Vol.34, pp.389-400 (2012).

[16] Berra M., Carassiti F., Mangialardi T., Paolini A.E., Sebastini M., "Effect of nanosilica addition on workability and compressive strength of Portland cement pastes",Constr. Build Mater., Vol.35,pp.666-675 (2012).

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