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Estimation of the Mechanical Response of Nano Materials in Cement Concrete – A Study

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Abstract— *Nanomaterials are a product of one of the truly revolutionary enabling technologies invented by mankind. Nanotechnology as it is appropriately called, can add up to the value of all products including cement concrete through these nanomaterials. In this paper optimized quantity of nanomaterials viz.Nano Silica (nS) and Carbon Nanotubes (CNT) are used to study the mechanical response of a standard M-40 Grade concrete. optimization of Nano-Silica (nS) and Carbon Nanotubes (CNT) for various proportions ranging from 0%, 0.5%, 0.75%, 1.0%, 1.25%, 1.5% of cement weight for nS and 0%, 0.02%, 0.05% and 0.1% of cement weight for CNT is carried out using ordinary Portland cement mortar mix in mortar cubes of 70.7 mm dimensions, taking cement: sand=1:3 and adding water as per the standard consistency formula P'=(P/4 +3) (1 part Cement+3parts Sand). Here P'=Quantity of water and P=Consistency of Cement used, as per Indian codal stipulations and mechanical testing of the cubes are done in laboratory scale under ordinary curing conditions at 28 days to obtain the specific optimized quantity. This optimized quantity of nS and CNTs as obtained, is then repeated for standard Grade M-40 concrete as per IS:10262 (2009) to study the mechanical response of it.*

Keywords— *Cement, Concrete, Nanomaterials, Optimization, Strength.*

I. Introduction

Elasticity is a way to characterize the mechanical response of the material body for applied stresses that stay within the stress-strain limit of the body. Modulus of elasticity of concrete is the ratio of stress to strain of the concrete under the application of loads. Considering the stress-strain curve of the first cycle, the modulus could be defined as the initial tangent modulus, secant modulus, tangent modulus or chord modulus as shown in figure 1. The above modulus of elasticity is sometimes termed as static (secant) modulus of elasticity in comparison with dynamic modulus of elasticity obtained by vibration test of concrete prisms or cylinders. The latter is approximately equal to the initial tangent modulus and hence greater than the static or secant modulus. Also, the elastic modulus is defined as the change in stress with an applied strain. Figure 1 is a graph of stress vs. strain for normal concrete. The slope of the curve is the elastic modulus of the material. The elastic modulus is the key material property for concrete in both approaches.

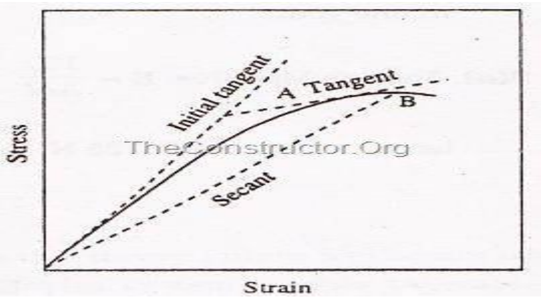

Fig. 1. Typical stress-strain curve for concrete

According to IS: 456 the modulus of *concrete* is 5000√ (fck), MPa, where fck is the characteristic compressive strength of *concrete***.** Our Paper aims to study the application of nanomaterials i.e. nS and CNT in enhancing the elastic response of concrete with nano additions when compared with normal standard control concrete. Previous literatures [2-22] suggest that nano materials have a beneficial effect especially on the behavior of cement concrete over other materials including fibers.

II. Material and Methods

The materials used were cement-OPC (43 Grade), Fine Aggregate (FA)-River sand conforming to Zone II of IS: 383 -1970, Potable water, Admixture (SuperPlastcizer) - PolyCarboxylate Ether and Nano Materials (viz. Nano Silica & Carbon Nanotubes).

The following Tables (1 & 2) below shows the specific properties of nano silica & carbon nanotubes used.

TABLE 1. The Specific properties of Nano Silica (SiO_2) used here

Sample	% Content(Lit.)	Specific Gravity(Lab.)	% Content(Lab.)	Specific Gravity(Lit.)
XLP	14-16%	1.12	21.4%	1.08-1.11
XTX	30-32%	1.16	40.74%	1.20-1.22
XFXLa	40-43%	1.24	41.935%	1.30-1.32

TABLE 2. The Specific properties of Multi-Walled Carbon Nanotubes (Industrial Grade) used here

Item	Description
Diameter	20-40nm
Length	25-45nm
Purity	80-85%(a/c Raman Spectrometer & SEM analysis)
Amorphous Carbon	5-8%
Residue(Calcination in Air)	5-6% by Wt.

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Average interlayer distance	0.34nm
Specific surface area	90-220 m^2/g
Bulk density	0.07-0.32gm/cc
Real density	1-8 gm/cc
Volume Resistivity	0.1-0.15 ohm.cm(measured at pressure in powder)

And the following Figures (1 and 2) below shows the XRD images of nano silica and carbon nanotubes used.

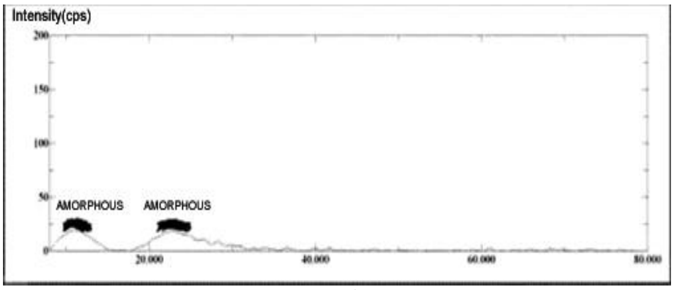

Fig. 2. XRD image of nano silica used.

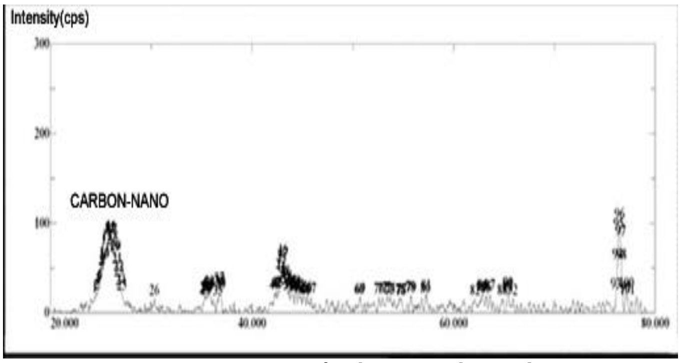

Fig. 3. XRD image of carbon nano tubes used.

2.1 Tests on Cement Mortar Composites:

Mortar Cubes of 70.7mmx70.7mmx70.7mm size were casted with 1 part of cement + 3 parts of sand with water added as per the normal consistency formula of Indian standards,IS:4031,i.e., according to the standard formula P'=(P/4 +3)(1 part Cement+3parts Sand).Here P'=Quantity of water & P=Consistency of Cement used.i.e. amount of water used to make 300gms cement paste to support a penetration of 5-7mm in a standard Vicat mould with a Vicat needle. Nano silica were added in various proportions ranging from 0%,0.5%,0.75%,1.0%,1.25%, &1.5%,Carbon Nanotubes in proportions ranging from 0%,0.02%,0.05%, & 1.0% as per literature review w.r.to cement wt. keeping the w/c ratio fixed at 0.4.The cubes were then ordinary cured under ordinary water at a constant temperature of (27$\pm$ 2)°C and tested for compressive strength and tested at 3 days,7 days,28 days ,90 days,180 days & 365 days as per IS:4031. Three (03) numbers of cubes were tested for each proportion/day.

2.2 Tests on M-40 Concrete:

Concrete cylinders(150mm Φ x300mm) size were casted with cement, FA, CA & water in proportions as per the mix design followed by Indian standards for M-40 Grade concrete for 100 mm slump keeping the w/c=0.4.The mix proportions were cement=400Kg/m^3, CA=1293.04 Kg/m^3 [CA1(90%)=1163.74 Kg/m^3; CA2(10%)=129.3 Kg/m^3], FA=687.54 Kg/m^3, water=157 Kg/m^3. Nano Silica & Carbon Nanotubes were added in optimized proportions as obtained in result (I). The cubes were then ordinary cured under water and tested for Modulus of Elasticity tests as per IS: 516 at 28 days. Also is casted in the same proportions as above and tested for as per IS: 516.

<u>*Test Data*</u>

a) Sp.Gravity of Cement = 3.08 (as lab experiment suggests).
b) Chemical Admixture = Superplastcizer (Polycarboxylate Ether).
c) Sp.Gravity of (i) CA (for 20mm =2.831 & for 12.5mm=2.845).Avg. Specific Gravity of CA = 0.9x2.845 + 0.1x2.831 = 2.8436 (ii)FA (River Sand confirming to Zone II, as per Table 4) =2.688
d) Water Absorption (i) CA =3.09, (ii) FA=Nil.
e) Free Surface Moisture (i) CA = 1.716 (ii) FA= 0.3

TABLE 3. Sieve analysis results of coarse aggregates.

IS Sieve Sizes (mm)	Analysis of Coarse Aggt.		% of Different Fractions			Remarks
	Fraction I (12.5mm passing)	Fraction II (20mm passing)	I 90%	II 10%	Combined 100% (I + II)	Conforming to Table 2 of IS:383 for graded aggregate of 20mm nominal size
20	99.44	50.322	0.9x99.44	0.1x50.322	94.5	95-100
10	56.70	1.062	0.9x56.7	0.1x1.062	51	25-55
4.75	--	--	--	--	--	0 to 10
2.36	--	--	--	--	--	--

TABLE 4. Sieve analysis results of fine aggregates.

IS. Sieve Sizes(mm)	Weight Retained (gms.)	%Weight Retained	Cum % Weight Retained	% Passing	Remarks (Conforming to Zone II of IS:383 for Fine Aggts.
4.75	--	--	--	100	90-100
2.36	67	6.77	6.77	93.23	75-100
1.18	101	1.20	16.97	83.03	55-90
600µ	277	27.98	44.95	55.05	35-59
300µ	367	37.07	82.02	17.98	0-30
150µ	161	16.26	98.28	1.72	0-10
75µ	17	1.72	100	--	
Pan	6	--	--	--	

Total Weight taken = 1000 gms.

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III. TEST RESULTS AND DISCUSSIONS

The Test Results shows that:-

1. The mortar compressive strength determined as per IS: 4031 shows a 32.55% increase in strength at 0.75% nS addition at 28 days, with the rate of strength gain increasing up to 59.8% at 90 days but then falling by 8.4% at 180 days at same optimization. For CNTs the gain in strength was 38.7% at 28 days but falling to 15.48% at 90 days & 10% at 180 days. However, it is seen that with the increased addition of nano materials like nano-silica (1% by cement wt.) and carbon nanotubes (0.1% by cement wt.) in OPC mortar the long term strength gain increases appreciably (as per Table 5).
2. IS: 456 states that the modulus of *concrete* is 5000√ (fck) = 5000√ (40) = 5000x6.32 = 31622.78MPa**.** Our test results is well satisfied by the formula and the Modulus of Elasticity results as per IS: 516 again showed a gain of about 419 %(for CNT added concrete) and 137 %(for nS added concrete).

TABLE 5. Strength (MPa) of nano-added OPC Mortar (% Increase w.r.t. ordinary cubes).

Sl No.	% Nano additions in Cement (OPC)	Avg. 7 day cube strength (% increase)	Avg. 28 day cube strength (% increase)	Avg. 90 day cube strength (% increase)	Avg. 180 day cube strength (% increase)	Avg. 365 day cube strength (% increase)
1.	OPC (0% nS/CNT)	21.08	31.89	31.20	30.01	30.01
2.	OPC(0.5% nS)	23.85(13.14%)	35.51(11.35%)	41.3(32.7%)	27.47(-9.2%)	26.76(-4.29%)
3.	OPC(0.75% nS) (optimized)	23.85(13.14%)	42.27(32.55%)	49.85(59.8%)	32.52(8.4%)	31.5(4.96%)
4.	OPC(1.0% nS)	25.07(18.93%)	37.36(17.15%)	42.98(37.7%)	33.68(12.2%)	32.41(8.0%)
5.	OPC(1.25% nS)	23.17(9.91%)	30.85(3.26%)	39.45(26.4%)	35.24(17.4%)	31.3(4.29%)
6.	OPC(1.5% nS)	23.81(12.95%)	37.79(18.5%)	33.42(7.12%)	31.23(4.07%)	29.12(-2.96%)
7.	OPC(0.02% CNT)(optimized)	17.69(-10.4%)	43.75(38.7%)	35.59(15.48%)	30.89(10%)	28.53(-4.93%)
8.	OPC(0.05% CNT)	27.19(-16.1%)	34.88(37.2%)	31.85(14.07%)	38.55(3.0%)	41.69(38.92%)
9.	OPC(0.1% CNT)	21.69(28.9%)	24.83(9.37%)	31.5(2.08%)	30.16(23.55%)	50.78(69.21%)

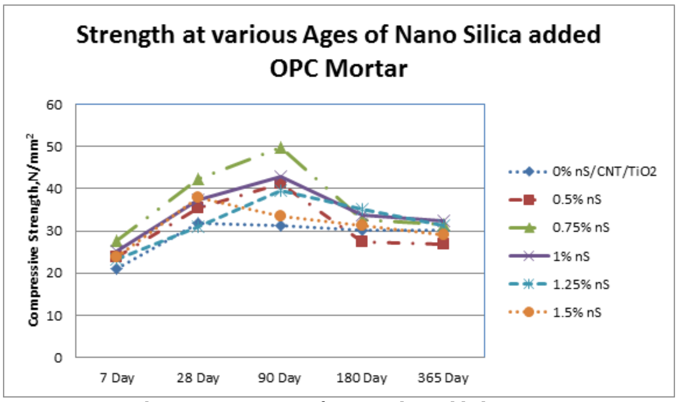

Fig. 4. Strength at various stages of Nano Silica added cement composites used.

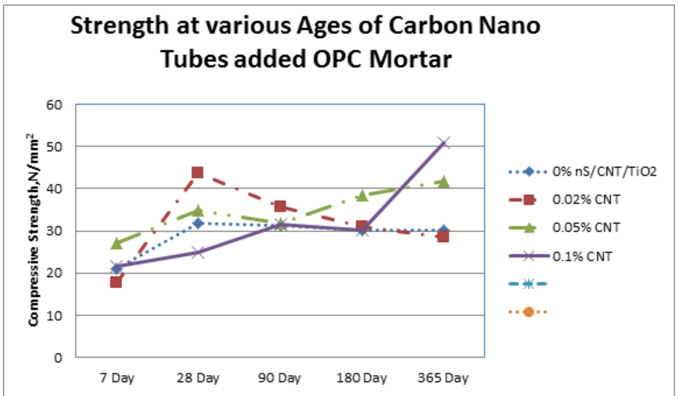

Fig. 5. Strength at various stages of Carbon Nanotubes added cement composites used.

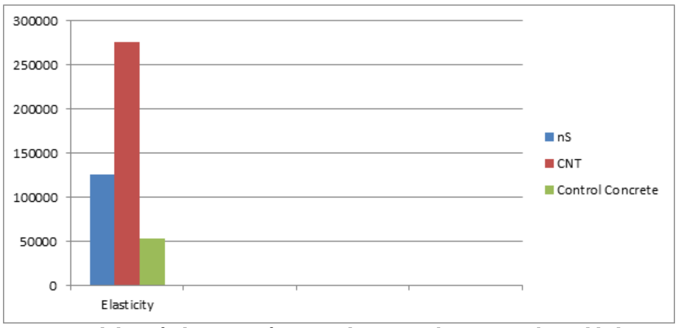

Fig. 6. Modulus of Elasticity of Nano Silica & Carbon Nanotubes added M-40 Concrete

IV. CONCLUSIONS

1. The results showed that the optimizations for nanomaterials in OPC mortar are nS=0.75%, CNT=0.02% and TiO_2=1.0% for cement mortar up to 28 days as per Table 4. In the long-term strength, some contradictions were noticed where more addition of nanomaterials yielded good results.
2. Modulus of Elasticity results showed an abnormal gain of about 419 %(for CNT added concrete) and 137 %(for nS added concrete) for which the reasons are not clear
3. Further research on micro structural studies is necessary for characterization of nanomaterials in cement and concrete.

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TABLE 6. Modulus of Elasticity (in N/mm^2) of Control Concrete & Nano-Silica added concrete at 28 days at w/c Ratio of 0.4.

Type of Concrete		**Control Concrete**[Density=2502.47kg/m^3]				**Nano-Concrete**(0.75% nS addition)							
						Sample1[Density=2519.65kg/m^3]				Sample2[Density=2455.28kg/m^3]			
Load (Ton)	Stresss (N/mm^2)	Deflection(mm)				Deflection(mm)				Deflection(mm)			
		Longitudinal		Lateral		Longitudinal		Lateral		Longitudinal		Lateral	
		Reading (R) (net)	Value (Rx0.01) (mm)	Reading (R) (net)	Value (Rx0.002) (mm)	Reading (R) (net)	Value (Rx0.01) (mm)	Reading (R) (net)	Value (Rx0.002) (mm)	Reading (R) (net)	Value (Rx0.01) (mm)	Reading (R) (net)	Value (Rx0.002) (mm)
0	0	0	0	0	0	0	0		0	0	0	0	0
5	2.83	0	0	0	0	0	0		0	0	0	0	0
10	5.66	0	0	0	0	0	0		0	0	0	0	0
15	8.49	0.005	0.00005	0	0	0.0049	0.000049	0	0	0.0033	0.000033	0.003	0.000006
20	11.32	0.008	0.00008	0.0085	0.000017	0.0062	0.000062	0.007	0.000014	0.0033	0.000033	0.003	0.000006
25	14.15	0.018	0.00018	0.019	0.000038	0.0083	0.000083	0.008	0.000016	0.0066	0.000066	0.0065	0.000013
30	16.98	0.033	0.00033	0.035	0.000070	0.011	0.00011	0.011	0.000022	0.001	0.0001	0.01	0.000020
35	19.81	0.043	0.00043	0.0455	0.000091	0.015	0.00015	0.015	0.000030	0.0023	0.00023	0.023	0.000046
38	21.508 (Failure)	0.183	0.00183	0.194	0.000388								
40	22.64					0.0205	0.000205	0.021	0.000041	0.14	0.0014	0.14	0.00028
45	25.47					0.026	0.00026	0.026	0.000052	0.24	0.0024	0.24	0.00048
48	26.6 (Failure)									0.36	0.0036	0.36	0.00072
50	28.3					0.059	0.00059	0.09	0.00018				
55	31.3 (Failure)					0.01	0.001	0.1	0.0002				
Modulus of Elasticity (N/mm^2)		E= $\frac{S_2 - S_1}{e_2 - e_1}$ Where, S_2 = 0.4x(21.508)→ with e_2 to be determined from Stress-Strain Curve. & S_1= to be determined from the Stress-Strain Curve at an strain[e_1] value of 0.5 x 10^{-6} for all the cases. E= $\frac{8.6032-5.68}{0.00855-0.5/1000000}$ = 53,197.45MPa				E= $\frac{S_2 - S_1}{e_2 - e_1}$ Where, S_2= 0.4x(31.3)→with e_2 to be determined from Stress-Strain Curve. & S_1= to be determined from the Stress-Strain Curve at an strain[e_1] value of 0.5 x 10^{-6} for all the cases. E= $\frac{12.452-5.688}{0.0000704-0.5/1000000}$ = 96,136.46MPa				E= $\frac{S_2 - S_1}{e_2 - e_1}$ Where, S_2= 0.4x(26.6)→ with e_2 to be determined from Stress-Strain Curve. & S_1= to be determined from the Stress-Strain Curve at an strain[e_1] value of 0.5 x 10^{-6} for all the cases. E= $\frac{10.868-5.703}{0.000033-0.5/1000000}$ = 1,56,752.65MPa* *Subject to Experimental Variations			
						Average Elasticity$_{\text{Nano-Concrete}}$ = 1,26,444.56MPa							
% incr. in Elasticity		--				+137.69							

TABLE 7. Modulus of Elasticity (in N/mm^2) of CNT added Concrete added concrete at 28 days at w/c Ratio of 0.4.

Load (Ton)	**Stress (N/mm^2)**	**Deflection(mm)**			
		Longitudinal		**Lateral**	
		Reading(R) (net)	**Value(Rx0.01) (mm)**	**Reading(R) (net)**	**Value(Rx0.002) (mm)**
0	0	0	0	0	0
5	2.83	0	0	0	0
10	5.66	0	0	0	0
15	8.49	0.001	0.00001	0.002	0.000004
20	11.32	0.002	0.00002	0.008	0.000016
25	14.15	0.003	0.00003	0.011	0.000022
30	16.98	0.004	0.00004	0.014	0.000028
35	19.81	0.005	0.00005	0.023	0.000046
40	22.64	0.006	0.00006	0.032	0.000064
45	25.47	0.007	0.00007	0.040	0.00008
50	28.31	0.008	0.00008	0.050	0.0001
55	31.14	0.009	0.00009	0.052	0.000104
60	33.97	0.011	0.00011	0.061	0.000122
65	36.80	0.012	0.00012	0.070	0.000140
70	39.63	0.013	0.00013	0.073	0.000146
75	42.46	0.015	0.00015	0.09	0.00018
80	45.29	0.016	0.00016	0.01	0.0002
85	48.12	0.018	0.00018	0.012	0.00024
90	50.96	0.019	0.00019	0.0132	0.00026
95	53.78(Failure)	0.020	0.00020	0.016	0.00032
100					

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Modulus of Elasticity (N/mm^2)	$E = \frac{S_2 - S_1}{e_2 - e_1}$ Where, $S_2 = 0.4x(53.78) \rightarrow$ with e_2 to be determined from Stress-Strain Curve. & S_1= to be determined from the Stress-Strain Curve at an strain[e_1] value of 0.5 x 10^{-6} for all the cases. $E = \frac{21.51 - 5.68}{0.000058 - 0.5/1000000} = 2,76,589.8MPa$ *Subject to Experimental Variations
% incr. in Elasticity	+419.93%

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