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A Comparative Assessment of Nano-SiO_2 & Nano-TiO_2 Insertion in Concrete

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ABSTRACT

One of the concrete that is becoming famous for its usage nowadays is nanoconcrete and our paper deals with the fact that nanomaterials (like nano-SiO_2 & nano-TiO_2) when added in optimized proportions to a standard M-40 Grade concrete improves its both fresh and hardened properties (both short term & long term).The results simply corroborated the fact that for nano concrete the workability increased by more than 90% w.r.to controlled M-40 Grade concrete. The compressive strength of nano concrete with nano-SiO_2 gave a strength gain of more than 24% at 28 days and more than 18% at 90 days while that of & nano-TiO_2 gave a strength gain of more than 9% at 28 days and more than 6% at 90 days all under ordinary curing conditions. However, under exposure to $MgSO_4$ & $MgCl_2$ the standard concrete specimens gave a greater crushing strength when compared with both the nanoconcretes, the reason of which is not clear.

Key words: Nanotechnology, Dwarf, Titanium Oxide, Silicon Oxide, Concrete

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INTRODUCTION

In the recent years nanotechnology is gaining day by day popularity in the field of civil engineering & construction technology. The objects produced using nanotechnology have unique characteristics such as super connectivity, high strength, low friction, high thermal insulation, specific beam frequency selectivity, quantum effects, extreme water repellence & self-assembling geometric patterns. In fact it was Nanotechnology that allowed creation of iPods, iPhones and all sort of these 'i' products which in a way completely changed the IT and electronics sectors. The continuous research in the area of concrete material & innovations has been made to cope with challenges of many construction aspects. One of the concrete that is becoming famous for its usage nowadays is nanoconcrete and it is due to its physical characteristics which makes it an obvious choice as an excellent medium of construction. Use of Nano concrete brings down weight, improves strength, allows for rationalization of design and being environment-friendly thus reducing carbon footprint is gaining attention from more academic institutes and housing construction agencies [1].

'Nano' is a Greek word and means 'Dwarf'. The new ISO working definition says that Nano technology (NT) is the application of scientific knowledge to the control and use of matter at the nanoscale (10^{-9}m), where size related phenomenon & processes may occur. There have been many successful nanotechnology based applications which could have been almost impossible without utility of nano sized particles. For example, anti-scratch paints, anti-bacterial paints, anti-fouling concrete, dirt repellant textiles, clothes that need no ironing, non-reflective glasses, wonder drugs etc. are only the tip of the ice-berg.

The Nanoparticles size which is below One billionth of a meter is produced as nano-additives are from traditional cement, silica (quartzite sand) or even fly ash. For larger scale, nano-Silica(nS)[the first nanomaterial to be used in construction] are produced from vaporization of silica or by feeding worms with rice husk or by precipitation method while techniques have been developed to produce Nanotubes in sizeable quantities, including arc discharge, laser ablation, high-pressure carbon monoxide disproportionate, and deposition. Nano-Titanium Oxide a Nano-additive as cement replacement in very insignificant dosages changes the hydration kinetics of entire cementitious system resulting in the improvement in the compressive strength of paste, mortar and concrete apart from its self-cleansing properties and is the most widely used Nano material today. Nano-Titanium Oxide is readily mined in its purest form from beach sand. Schomberg, a German Scientist, discovered in 1909 traces of monazite in the sand flakes on the imported coir from Sankaramangalam, Kerala, India.The beaches of

Sankaramangalam and nearby areas in Kollam are inextricably intertwined with a wealth of rare earth minerals that became the center of scientific attraction. Titanium Oxide is essentially harvested from sea. The Mineral Separation Unit(MS Unit) of Kerala Minerals & Metals Ltd.(India's first and only manufacturer of Rutile Grade Titanium Oxide by chloride process), a State Government public limited company is engaged in the separation of limenite, Rutile, Leucoxone, Monazite, Silliminite, etc. from beach sand by Gravitational, Magnetic & High Tension Electrostatic Techniques for separation of minerals from the sand.

EXPERIMENTAL PROGRAMME

The materials used were cement-OPC(43 Grade),Fine Aggregate(FA)-River sand conforming to Zone II of IS:383 - 1970, Coarse Aggregate(CA)- Pakur variety(20mm nominal size), Potable water, Admixture (Super Plastcizer) - PolyCarboxylate Ether and Nano Materials(viz. Nano Silica, Carbon Nanotubes & Nano Titanium Oxide). The following Tables (1 & 2) below shows the specific properties of nano silica & titanium di-oxide used here. And the following Fig.s (1 and 2) below shows the XRD images of nano silica & titanium di-oxide used.

Table -1 The Specific properties of Nano Silica (SiO_2) used

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 Nano Titanium Oxide (TiO_2) used

Nano Titanium Oxide %	97
Rutile content %	98
pH	7
Average particle size (TEM)	30-40 nm
Treatment	Nil
Moisture %	1.75-2
Bulk Density	0.31gm/cc
Water Solubility	In-soluble

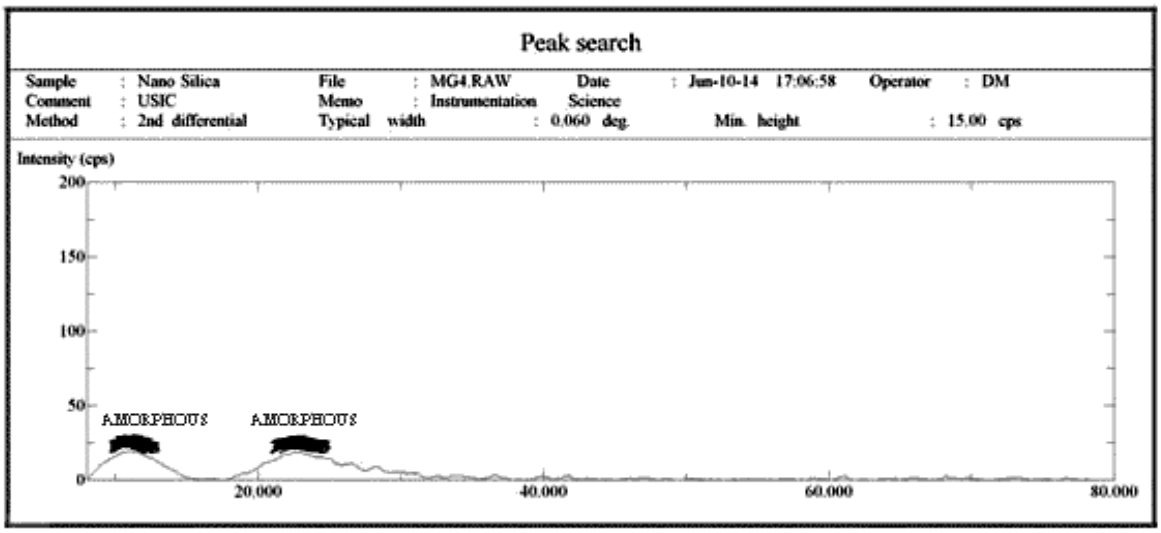

Fig. 1: XRD image of Nano Silica used

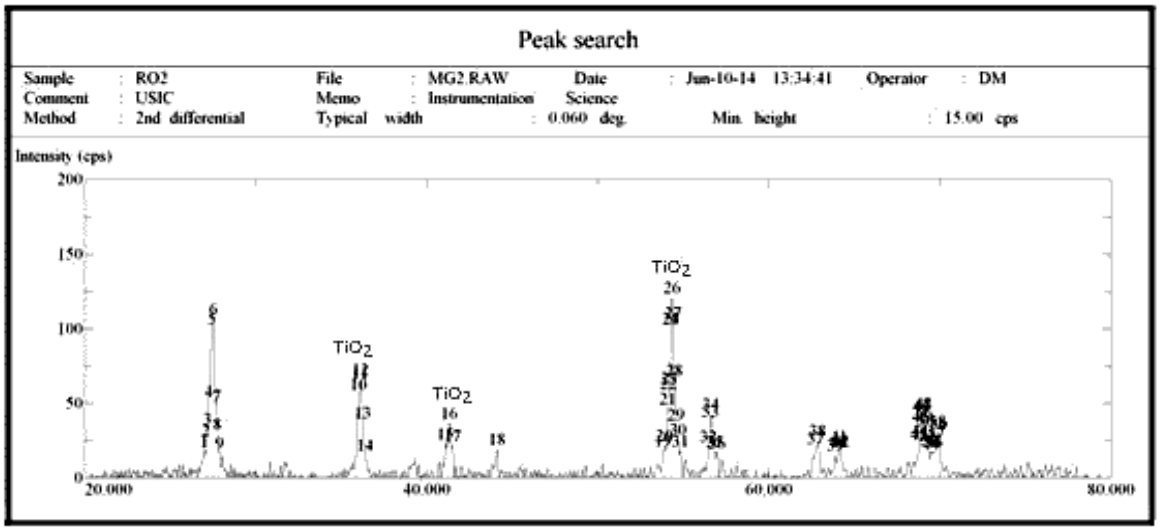

Fig. 2 XRD image of Nano Titanium Di-Oxide used

Tests on Concrete

Concrete cubes of 150mmx150mmx150mm 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. The cubes were then ordinary cured for 28 days and tested in a compression testing machine at 7 days, 28 days & 90 days at different exposure conditions viz. air, $MgSO_4$ & $MgCl_2$.

Test Data

- Cement = OPC 43 Grade
- Sp.Gravity of Cement = 3.08(as Lab. Experiment suggests)
- Chemical Admixture = NA(for 1st mix)/Superplastcizer (Polycarboxylate Ether)(for 2nd mix)
- Sp.Gravity of →
  (i)Coarse Aggregate (for 20mm =2.831 & for 12.5mm=2.845)
- Now,Avg. Specific Gravity of Coarse Aggregates = 0.9x2.845 + 0.1x2.831 = 2.8436
- (ii)Fine Aggregate(River Sand confirming to Zone II)=2.688
- Water Absorption →
  (i)Coarse Aggregate =3.09
  (ii) Fine Aggregate=Nil.
- Free Surface Moisture→
  (i)Coarse Aggregate = 1.716
  (ii) Fine Aggregate = 0.3
- Sieve analysis: As performed in the Laboratory.

Coarse Aggregate

IS.Sieve Sizes(mm)	Analysis of Coarse Aggr.		% 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 Agg. of 20mm nominal size)
20	99.44	50.322	0.9x99.44	0.1x50.322	94.5	95-100
10	56.7	1.062	0.9x56.7	0.1x1.062	51	25-55
4.75	--	--	--	--	--	0 to 10
2.36	--	--	--	--	--	--

Fine Aggregate

IS. Sieve Sizes (mm)	Weight Retained (gms.)	%Weight Retained	Cum % Weight Retained	% Passing	Remarks (Conforming to ZoneII of IS: 383 for Fine Aggregates.
4.75	--	--	--	100	90-100
2.36	67	6.77	6.77	93.23	75-100
1.18	101	10.20	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	--	--	--	

Mix Calculations (for Controlled Concrete Mix)

- Vol. of concrete = 1m^3
- Vol. of cement = 400/(3.08x1000) = 0.129m^3
- Vol. of water = 157/1000 = 0.157 m^3
- Vol. of All-in-Aggregate = 1-(0.129+0.157+0.00347) = 0.7105
- Vol. of CA/TA (From Table 3 of IS:10262(2009)) = 0.62 (for w/c =0.5)

[For CA/TA =∓0.01 the adjustment of w/c = ± 0.005]

So, for w/c = 0.41, Vol. of CA/TA = 0.64 & Vol. of FA/TA = 0.36

- Mass of CA=0.7105x2.84x0.64x1000=1293.04kg/m^3
- Mass of CA1(12.5mm) = 0.90x1293.04=1163.74kg/m^3
- Mass of CA2(20mm) = 0.1x1293.04 = 129.304kg/m^3
- Mass of FA = 0.7105x2.688x0.36x1000 = 687.54 kg/m^3

Mix Calculations (for Nano Concrete with Nano-SiO_2 Mix)

- Vol. of concrete = $1m^3$
- Vol. of cement = 400/(3.08x1000) = $0.129m^3$
- Vol. of water = 157/1000 = 0.157 m^3
- Vol. of All-in-Aggregate = 1-(0.129+0.157+0.00347) = 0.7105
- Vol. of CA/TA (From Table 3 of IS: 10262(2009)) = 0.62 (for w/c =0.5)
- [For CA/TA = ∓ 0.01 the adjustment of w/c = ± 0.005]
- So, for w/c = 0.41, Vol. of CA/TA = 0.64 & Vol. of FA/TA = 0.36
- Mass of CA=0.7105x2.84x0.64x1000=1293.04kg/m^3
- Mass of CA1 (12.5mm) = 0.90x1293.04=1163.74kg/m^3
- Mass of CA2 (20mm) = 0.1x1293.04 = 129.304kg/m^3
- Mass of FA = 0.7105x2.688x0.36x1000 = 687.54 kg/m^3
- Net Water added = 157 – (0.7) x (1/100) x400 = 154.20kg/m^3
- Mass of Nano-Silica added = 0.75x0.129x3.08x1000=298gms≡858.93gms of XTX soln

Mix Calculations (for Nano Concrete with Nano- TiO_2 Mix)

- Vol. of concrete = $1m^3$
- Vol. of cement = 400/(3.08x1000) = $0.129m^3$
- Vol. of water = 157/1000 = 0.157 m^3
- Vol. of chemical admixture(@ 1% by wt. of cement) = (1/100)x(400)/(1.15x1000)=0.00347kg/m^3
- Vol. of All-in-Aggregate = 1-(0.129+0.157+0.00347) = 0.7105
- Vol. of CA/TA (From Table 3 of IS:10262(2009)) = 0.62 (for w/c =0.5)
- [For CA/TA = ∓ 0.01 the adjustment of w/c = ± 0.005]
- So, for w/c = 0.41, Vol. of CA/TA = 0.64 & Vol. of FA/TA = 0.36
- Mass of CA=0.7105x2.84x0.64x1000=1293.04kg/m^3
- Mass of CA1 (12.5mm) = 0.90x1293.04=1163.74kg/m^3
- Mass of CA2 (20mm) = 0.1x1293.04 = 129.304kg/m^3
- Mass of FA = 0.7105x2.688x0.36x1000 = 687.54 kg/m^3
- Net Water added = 157 – (0.7)x(1/100)x400 = 154.20kg/m^3
- Mass of TiO_2 added= (1.0/100)x0.129x3.08x1000=397.32gm

As admixture added @ 1.0% by wt. of cement.

RESULTS AND DISCUSSIONS

The following Table shows the strength development at various ages in cement concrete.

Table -3 Fresh Rheological Properties of Concreteat w/c Ratio of 0.4

S. No.	Type of Concrete	w/c Ratio	Slump Range	Avg. Slump	% increase in Slump
1.	Control Concrete	0.4	28-38 mm	31.69 mm	--
2.	Nano-Concrete(0.5%PCE +0.75% nS addition)	0.4	56-65 mm	60.3 mm	90.28%
3.	Nano-Concrete(1%PCE+1%TiO_2)	0.4	100-150mm	125mm	315%

Table -4 Compressive Strength (N/mm^2) of M-40 Grade Nano Concretes (% increase w.r.to M-40 Grade Control Concrete)

S. No.	% Nano additions in M-40 Grade concrete	7 day strength (% increase)	28 day strength (% increase)	90 day strength (% increase)
1.	Control Concrete (M-40)	33.47	40.12	40.62
2.	Nano Concrete(0.5% PCE+0.75% nS)	33.69(0.66%)	49.77(24.05%)	48.12(18.46%)
3.	Nano Concrete(1% PCE+1.0%TiO_2)	28.57(-14.64%)	43.96(9.57%)	43.34(6.69%)

Table -5 Compressive Strength (in N/mm^2) of 100mm cubes at 28 days at different Exposure Conditions at w/c Ratio of 0.4

Type of Concrete	Exposure Conditions	Individual Compressive Strength in N/mm^2 at 90 days	% increase in Strength
Control Concrete	In $MgCl_2$	48.51	---
	In $MgSO_4$	47.04	---
Nano-Concrete (0.75% nS addition)	In $MgCl_2$	34.19	-29.51%
	In $MgSO_4$	33.29	-29.23%
Nano Concrete (1% PCE+1.0%TiO_2)	In $MgCl_2$	36.89	-23.95%
	In $MgSO_4$	35.68	-24.15%

- For nano concrete the workability increased by more than 90% w.r.to controlled M- 40Grade concrete.
- For compressive strength of concrete as per IS:516 a modest gain of 24.1%& 8.74% are obtained for nano –SiO_2 & TiO_2 respectively at 28 days and of 18.46%& 6.69% are obtained for the same optimized doses at 90 days respectively.
- For compressive strength of concrete for different exposure conditions in $MgCl_2$ & $MgSO_4$ more than 20% loss in strength was observed for both the nano concretes with nano –SiO_2 & TiO_2 respectively with respect to controlled M-40 Grade concrete.

CONCLUSIONS

- The results showed that for the optimizations of Nano Silica, nS=0.75% & Nano-Titanium Oxide,TiO_2=1.0% by weight of cement, the gain in strength in nano concrete up to 28 days was modest for nano-silica addition. For long term strength the trend is not clear.
- The optimum percentages based on the above when tried for nano concretes ceased to be effective under .adverse exposure conditions of $MgCl_2$ & $MgSO_4$ with respect to controlled concrete, due to reasons not very clear.

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