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EXPERIMENTAL STUDY ON HIGH STRENGTH CONCRETE USING COLLOIDAL NANO SILICA AND FLY ASH

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Abstract: This paper presents the results of an experimental investigation carried out on addition of CNS and fly ash on properties of high strength concrete (HSC). The Compressive strength, split tensile strength, flexural strength, density, and modulus of elasticity were studied. Cement is replaced by fly ash varying from 10% to 35 % by weight (0,10,15,20,25,30,35) at fixed water cement ratio in addition to this CNS was added ranging from 1% to 5% b.w.c. The result indicates that there is increase in density up to 3% addition of CNS and workability goes on decreasing with increase in % of CNS , it was also found that compared with control concrete , the compressive strength, split tensile strength and flexural strength increased up to 3% addition of CNS and 20 % addition of fly ash and there after decreases..

Notations –
b- Width of specimen in mm
D- Diameter of specimen in mm
d-Depth of specimen in mm
E-Modulus of elasticity (N/mm^2)
L-span in mm
P-Maximum load at failure
$Б_{b-}$ modulus of rupture (N/mm^2)
$Б_{bt-}$split tensile strength (N/mm^2)

Introduction

Fly ash, a waste, byproduct of power plants , has been widely used in cement and concrete due to its many advantages such as reduced carbon foot prints, increased flow ability, decreased heat of hydration, enhanced long term strength growth, reduced shrinkage, improved durability and reduced cost, at the same time it has disadvantage like early age strength gain is less. To overcome this many methods have been tried till date like mechanical grinding, chemical activation, mechanochemical treatment, and hydrothermal treatment.
(PengkumHou , et.al 2012)

More recently a more pozzolanic reactive material nano SiO_2 has been used to improve the mechanical properties of cementitious material and it shows an excellent enhancing effect on early age properties (Ye Q ,et.al 2007) . The improvement is attributed to three reasons 1) The acceleration effect of CNS on cement hydration, 2) Pozzolanic reaction of CNS, 3) Improved particle packing of matrix. for the pozzolan replacement cement based material system some researchers (Said A, et.al 2009) found that the physical and mechanical properties of fly ash/slag system can be greatly enhanced.

A common characteristic of CNS and fly ash is that they both are pozzolanic material, and both absorb, react with, or consume, CH that is generated from cement hydration. Normally to get considerable improvement of strength gain, since nanoSiO_2 and fly ash complete the absorbing CH and nanoSiO_2 is far more reactive than fly ash, it can deduced that there may be shortage of CH in nano SiO_2 added fly ash cementitious material system thus preventing fly ash hydration at later age, especially when fly ash content is high.

Nano technology is science; engineering and technology conducted at nano scale which about 1 to 100 nm. Nano technology applied to concrete includes the use of nano materials like nano silica (Sobolev and Gutierrez2005)Nano silica improves the microstructure and reduced the water permeability of concrete thus making it more dense and durable (Sham Sai,Perotiet et.al 2012) Nano silica can be used as an additive to eco concrete mixtures. In the case of eco concrete mixtures industrial waste such as fly ash, blast furnace slag etc. used in certain percentage as a replacement of cement. Use of nano silica in HSC improves the cohesiveness between the particles of concrete and reduces the segregation and bleeding.

The concept of nano technology was put forward theoretically in 1959,by Feynman, the Nobel Prize winning Physicist, said that nothing in the law of physics prevented us from arranging atoms the way we want. He even pointed to a development pathway: Machines that would make smaller machines suitable for making yet smaller machines and so on -----The classic “Top down “approach in 1974, Taniguchi introduced the term nanotechnology to describe precision manufacture of parts with finishes and tolerances in the range of 0.1nm to 100nm, in 1981, Drexler pointed out a new approach, construction of materials and devices from "bottom up "with ever atom in designed location.

In present study by using fly ash as cement replacement and CNS an attempt has been made to investigate the improvement in mechanical properties of high strength concrete and also to find the optimum % of CNS and fly ash required for high strength concrete

Materials

Cement

Ultra tech 53 grade ordinary Portland cement was used in the present study as which is most commonly used cement in India for various construction activities.

Coarse and fine aggregate

Coarse aggregate (CA) of 10 mm size was obtained from Ahmednagar , Maharashtra as it has minimum water absorption and natural river sand was obtained from 'Pravara River ' was confirming to grading zone-II according to Table-4 of IS 383-1970 (BIS1970a)as shown in fig-1

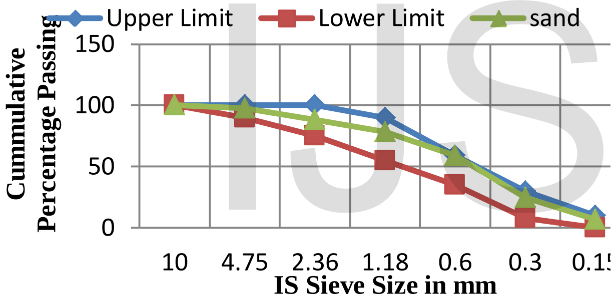

Fig-1 Grading of sand in Zone II

Fly ash

Fly ash of grade P-63 and P-100 was used as partial replacement of cement. The physical and chemical properties are mentioned in Table-I provided by Dirk India Pvt. Ltd Nasik Maharashtra

Colloidal Nano silica

Particle size of CNS is 5 to 8 nm which will be helpful to fill the pores spaces in the concrete and enhances the early age strength of the concrete due to which dense concrete will improve the Compressive, Split tensile, and flexural strength The CNS used for experimentation was supplied by Bee Chem. Pvt. Ltd Kanpur India with following properties as shown in Table –II

Table –II –Properties of CNS

Parameter	Nano Solids	Particle Size	Sp.gr.	Viscosity
Value	15-16%	5-8 nm	1.15	10-12 sec

Plasticizers

The super plasticizer **"Master Gleniumsky-8855"** along with retarder **"Master Pozzolith 44 R"** manufactured by BASF Chemicals Mumbai was used. **Water :**Drinking water was used for casting and curing of concrete

Physical Properties

The Physical properties of CA and sand was find out experimentally for finding out specific gravity of CA a weighing bucket was used and for sand Pycnometer was used (AIMILLtd, Mumbai, Maharashtra) according to IS 2386-1963(BIS1963). Water absorption was determined by conventional method. as shown in table-III

Table-III-Physical properties of CA and Sand

Property	10 mm CA	Fine Aggregate (FA)
Fineness Modulus	6.78	3.45
Specific gravity	2.60	2.77
Silt content	Nil	3%
Surface moisture	Nil	Nil
Water absorption	0.57	0.98

Laboratory Testing Program

Concrete mixes with various proportions of Fly ash in which P-100 grade of fly ash having constant 10% replacement and P-63 grade of fly ash was replaced in increment of 5% up to 25% i.e. total replacement of fly ash is done up to 35%along with this CNS was added ranging from 1% to 5% by weight of cementitious material. The water cement ratio selected for M60 grade of concrete was 0.22 after doing various trials at different water cement ratios from 0.28, 0.26.0.24.0.22, 0.20 and for each of these three cubes were casted and tested after 07 and 28 days out of which water cement ratio of 0.22 gives average compressive strength of 49.62 N/mm^2 and 69.21 N/mm^2 respectively. For the total experimental work 378 cubes, 126 cylinders and 126 beams were casted and tested after 7,28 and 56 days for compressive strength and after 28 days for Split tensile and flexural test The details of material used for various mix combinations is shown in table no IV

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Table I- Physical and Chemical properties of Fly Ash

Test No	Test	Unit	I.S Specification	Pozzocrete P-63	Pozzocrete P-100
1	Fineness by Blaine's Permeability	m2/Kg	320	400	610
2	25 micron residue	%	Not Specified	----	0.08
3	45 micron residue	%	34	10.0	Traces
4	Lime reactivity	N/mm2	4.5	5.5	7.0
5	Moisture Content	%	2.0	0.5	0.5
6	Autoclave Expansion	%	0.8 %	0.1 %	0.1 %
7	Compressive Strength at 28 days % of plain cement mortar	%	80	90	95
8	Loss on Ignition	%	5	2.5	2.5
9	SiO2+ Al2O3+Fe2O3	%	70 min. by mass	90	90.0
10	SiO2	%	35 min by mass	50	60.35
11	MgO	%	4 max. by mass	4.0	4.0
12	SO3	%	3 max. by mass	2.0	2.0
13	Na_2O	%	1.5 max. by mass	1.5	1.5
14	Total Chlorides	%	0.05max. by mass	0.05	0.05

Preparation of Test Specimens

The 10 mm CA, Sand, different % of fly ash and cement were placed in a mixture and dry mixed. After this required % of CNS , super plasticizer of constant dose of 1.5 % and retarder of constant dose of o,5% by weight of total cementitious material was added along with water as calculated , this is mixed until homogeneous mixture was obtained, each batch is mixed approximately 05 minutes and mixture is then placed in metallic tray. The slump was immediately checked before the concrete is placed in different moulds.

Cubes

Cubes of size 150mmx 150 mm x 150 mm were prepared, before casting, cubes are cleaned with cloth and oil is applied to inner surface with brush, concrete was then placed in moulds in three layers and every layer was compacted with tamping rod of length 600 mm having 25 mm^2 cross sectional area after this these moulds were kept on vibrating table for 60 sec. to achieve proper compaction. The cubes were kept on leveled surface for 24 hrs. in the laboratory and then these cubes were removed from moulds and put in curing tank for curing.

Cylinders

Cylindrical moulds of size 150mm diameter and 300 mm height were used. Before casting oil is applied to inner surface of mould for easy removal of cylinder from the mould. Concrete was poured in the mould in three layers and compacted with tamping rod of same size and then compacted using vibrating table.

Beams

The beam mould of size 700mmx150mmx150mm were used for testing, Before casting oil is applied to inner surface of beam mould for easy removal of specimen from the mould. Concrete was poured in the mould in three layers and compacted with tamping rod of length 600 mm having 25 mm^2 and then compacted using vibrating table.

Curing

After casting of all cubes, beams and cylinders Curing was done in a curing tank, drinking water is used for the curing and it has been replaced after every 7 days, for cubes curing is done for 7,28and 56 days and for cylinders and beam moulds it is done for 28 days.

Test results and discussion

Effect of fly ash and CNS on Compressive strength

The compressive strength of various concrete mix as shown in table no IV of cube size 150mmx 150mmx150 mm was determined after 7,28,and 56 days. The maximum load at failure was noted and the average compressive strength was determined using the relation (BIS 1959)

$$\text{Compressive strength} = \frac{\text{Ultimate load}}{\text{Area of cross section}}$$

In this work cement is replaced by fly ash from 10-35% and along with this to improve the

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Table No. IV Concrete Mixtures with Different Proportions of CNS and Fly ash

Concrete Mix No.	Concrete Mix Proportion	Quantities in (Kg/m^3)							
		Cement	Fly Ash		CNS (Lit)	Water	C.A. 10mm	Sand	S.PL (1.5%)
			P-63	P-100					
1A	100% cement	681.82	--	--	0	150	934.74	717.85	10.22
2A	85%C+5%P-63+10%P-100	579.55	34.09	68.18	0	150	934.74	717.85	10.22
3A	80%C+10%P-63+10%P-100	545.45	68.18	68.18	0	150	934.74	717.85	10.22
4A	75%C+15%P-63+10%P-100	511.37	102.27	68.18	0	150	934.74	717.85	10.22
5A	70%C+20%P-63+10%P-100	477.27	136.36	68.18	0	150	934.74	717.85	10.22
6A	65%C+25%P-63+10%P-100	443.18	170.45	68.18	0	150	934.74	717.85	10.22
1B	90%C+1%CNS+10%P-100	613.64	0	68.18	6.81	150	934.74	717.85	10.22
2B	90%C+2%CNS+10%P-100	613.64	0	68.18	13.64	150	934.74	717.85	10.22
3B	90%C+3%CNS+10%P-100	613.64	0	68.18	20.45	150	934.74	717.85	10.22
4B	90%C+4%CNS+10%P-100	613.64	0	68.18	27.27	150	934.74	717.85	10.22
5B	90%C+5%CNS+10%P-100	613.64	0	68.18	34.09	150	934.74	717.85	10.22
1C	85%C+1%CNS+5%P63+10%P-100	579.55	34.09	68.18	6.81	150	934.74	717.85	10.22
2C	85%C+2%CNS+5%P63+10%P-100	579.55	34.09	68.18	13.64	150	934.74	717.85	10.22
3C	85%C+3%CNS+5%P63+10%P-100	579.55	34.09	68.18	20.45	150	934.74	717.85	10.22
4C	85%C+4%CNS+5%P63+10%P-100	579.55	34.09	68.18	27.27	150	934.74	717.85	10.22
5C	85%C+5%CNS+5%P63+10%P-100	579.55	34.09	68.18	34.09	150	934.74	717.85	10.22
1D	80%C+1%CNS+10%P63+10%P-100	545.45	68.18	68.18	6.81	150	934.74	717.85	10.22
2D	80%C+2%CNS+10%P63+10%P-100	545.45	68.18	68.18	13.64	150	934.74	717.85	10.22
3D	80%C+3%CNS+10%P63+10%P-100	545.45	68.18	68.18	20.45	150	934.74	717.85	10.22
4D	80%C+4%CNS+10%P63+10%P-100	545.45	68.18	68.18	27.27	150	934.74	717.85	10.22
5D	80%C+5%CNS+10%P63+10%P-100	545.45	68.18	68.18	34.09	150	934.74	717.85	10.22
1E	75%C+1%CNS+15%P63+10%P-100	511.37	102.27	68.18	6.81	150	934.74	717.85	10.22
2E	75%C+2%CNS+15%P63+10%P-100	511.37	102.27	68.18	13.64	150	934.74	717.85	10.22
3E	75%C+3%CNS+15%P63+10%P-100	511.37	102.27	68.18	20.45	150	934.74	717.85	10.22
4E	75%C+4%CNS+15%P63+10%P-100	511.37	102.27	68.18	27.27	150	934.74	717.85	10.22
5E	75%C+5%CNS+15%P63+10%P-100	511.37	102.27	68.18	34.09	150	934.74	717.85	10.22
1F	70%C+1%CNS+20%P63+10%P-100	477.27	136.36	68.18	6.81	150	934.74	717.85	10.22
2F	70%C+2%CNS+20%P63+10%P-100	477.27	136.36	68.18	13.64	150	934.74	717.85	10.22
3F	70%C+3%CNS+20%P63+10%P-100	477.27	136.36	68.18	20.45	150	934.74	717.85	10.22
4F	70%C+4%CNS+20%P63+10%P-100	477.27	136.36	68.18	27.27	150	934.74	717.85	10.22
5F	70%C+5%CNS+20%P63+10%P-100	477.27	136.36	68.18	34.09	150	934.74	717.85	10.22
1G	65%C+1%CNS+25%P63+10%P-100	443.18	170.45	68.18	6.81	150	934.74	717.85	10.22
2G	65%C+2%CNS+25%P63+10%P-100	443.18	170.45	68.18	13.64	150	934.74	717.85	10.22
3G	65%C+3%CNS+25%P63+10%P-100	443.18	170.45	68.18	20.45	150	934.74	717.85	10.22
4G	65%C+4%CNS+25%P63+10%P-100	443.18	170.45	68.18	27.27	150	934.74	717.85	10.22
5G	65%C+5%CNS+25%P63+10%P-100	443.18	170.45	68.18	34.09	150	934.74	717.85	10.22

microstructure of the concrete CNS was added varying from 1% to 5% and the optimum percentage of fly ash was found to 20 % and CNS as 3%. For controlled concrete the compressive strength at 7, 28, and 56 days was 53.60, 67.25, 70.17 N/mm^2 where as at 20% replacement of fly ash along with 3% CNS it has increased by 12.29%, 12.72% and 13.46% respectively at 7, 28 and 56 days of curing. It is

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observed that from1% to 3% addition of CNS the compressive strength goes on increasing and there after it decreases. So it is due to accelerating effect of CNS on the formation of C-S-H gel and beyond 3% it is less reactive with cement and fly ash combination and also physically it was observed that the mix is become more and more stiff as % of CNS is increases. According to Shih JY, Chang TP(2006) after adding CNS along with fly ash early gain of strength is good at 7 days mainly because of packing effect, it is actually act as filler material. Which fills into interstitial spaces and pores inside the matrix of hardened concrete .increasing its density as well as strength. At later ages of curing the strength improvement is due to reduction in $Ca(OH)_2$ along with production of secondary C-S-H gel, to the matrix densification and pore size refinement. Fig 2, 3, 4 shows the variation in compressive strength of M60 grade of concrete at 7,28,and 56 days of curing

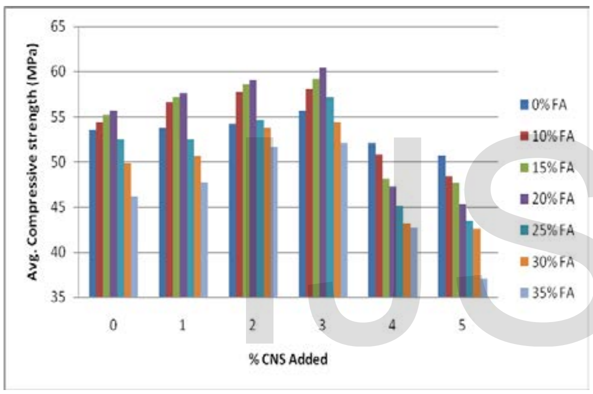


Fig-2-% CNS Vs Compressive Strength at 7 Days

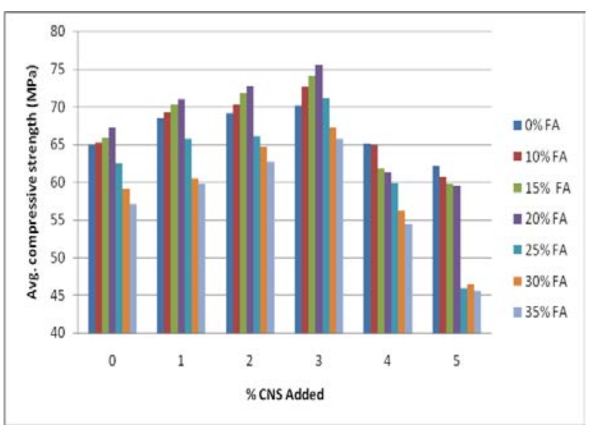


Fig-3 -% CNS Vs Compressive Strength at 28 Days

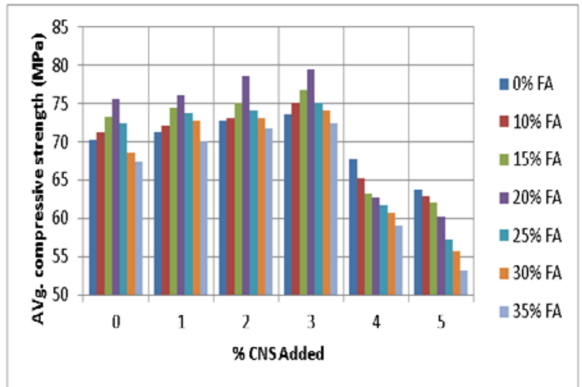


Fig-4 -% CNS Vs Compressive Strength at 56 Days

Effect of fly ash and CNS on Split tensile strength

For this test cylindrical specimen of size 150 mm diameter and 300 mm height were casted and tested under compression testing machine of capacity 3000KN. The specimens are kept at centre with wooden plank at top and bottom and load was applied at the rate of 1.3KN/sec and the ultimate load was noted. The variation is shown in fig-5 .The split tensile strength was calculated according to IS5816-1970(BIS 1970b) and IS 516-1959(BIS, 1959) by using formula

$$Б_{bt=} 2P/Пdl$$

In above equation $Б_{bt}$ is split tensile strength in N/mm^2, P is maximum load at failure, L is span and D is the diameter of the specimen. The split tensile strength is 6.08 N/mm^2 of the CC and it goes on increasing as 6.86, 7.86, 7.96 $N/mm^2$for 1%, 2%, and 3% addition of CNS and there after it was 5.65, 4.29, N/mm^2 at 4% and 5% addition of CNS. The % increase was found 12.82%, 29.27%, and 30.92% and there after it decreases by 7.072%and 29.44% with respect to CC. Fig 5 shows variation in split tensile strength with increase in fly ash percent and CNS percentage.

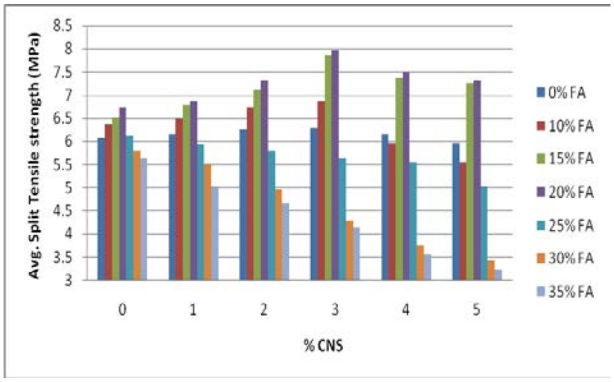


Fig-5-%CNS Vs Avg. Split tensile strength

Effect of fly ash and CNS on Flexural strength

Beam specimens of Size 700mmx150mmx150 mm were casted and tested after 28 days of curing for two point loading dividing beam in three equal parts to get the region of pure bending and tested in universal testing machine of 100 t capacity. The flexural strength is calculated according to IS 456-2000(BIS, 2000) and IS 516-1959 (BIS, 1959) using relation

$$Б_b = PL/bd^2$$

Where $Б_b$ is the modulus of rupture (N/mm^2), P is the maximum load, L is the span, and b and d are the dimensions of the section. Experimentally it is found thatthe maximum Flexural strength of concrete is observed at cement replacement by 10% P-63 FA+ 10% P-100 FA + 3% CNS which is increased by 41.64 % at 28 days, it has been increased for all mixes after addition of fly ash and CNS from 1% to 5 % compared to cc , it is due to good bonding between fly ash and CNS, as normally it is observed that the strength gaining of fly ash added mixes is less at early age but here CNS has filled the pore spaces and microstructure of composite has been improved and there is good interlocking of aggregate due to addition to CNS.

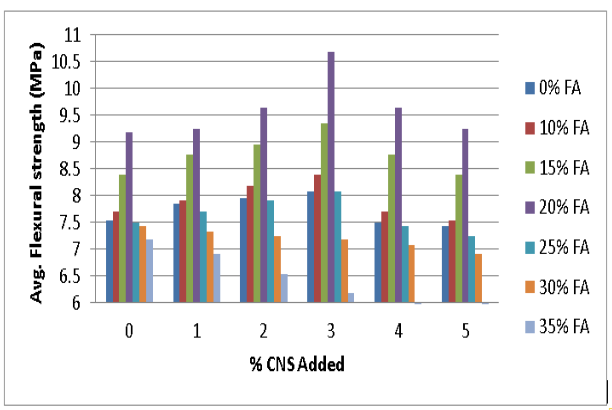


Fig-6 -%CNS Vs. Avg. Flexural strength

Effect of fly ash and CNS on density of Concrete.

The densities of hardened concrete with various percentage of fly ash replacement and % CNS added is shown in fig-7.The density of mix goes on increasing as the percentage of CNS increases and at 3% addition of CNS it goes up to 27.78x10^3 Kg/m^3 at 28 days of curing and thereafter at 4% and 5% addition of CNS it decreases but it has been improved compared to cc also it has been observed that the density goes on increasing with addition of fly ash and CNS with respect to cc. Density increases because of improved interlocking at interfacial transition zone of aggregate and cement paste .

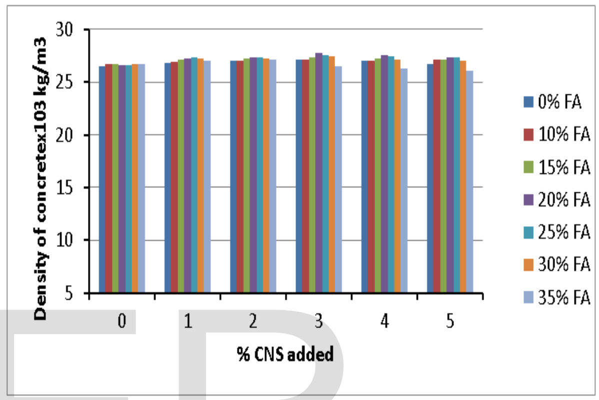


Fig-7-Density of CNS added concrete at 28 days

Effect of fly ash and CNS on modulus of elasticity of Concrete

The modulus of elasticity of different specimens of concrete is calculated according to IS 456-2000(BIS, 2000) using the formula

$$E = 5000\, f_{ck}^{0.5}$$

Where f_{ck} is the compressive strength after 28 days of curing. Modulus of elasticity goes on increasing up to 3% addition of CNS and 20% addition of fly ash as shown in fig 8 and it was having maximum value of 43.45 X 10^{3}N/mm^2 it has increased by 5.97% compared to cc and it has increased by 12.21% compared with standard value for M60 grade of concrete.

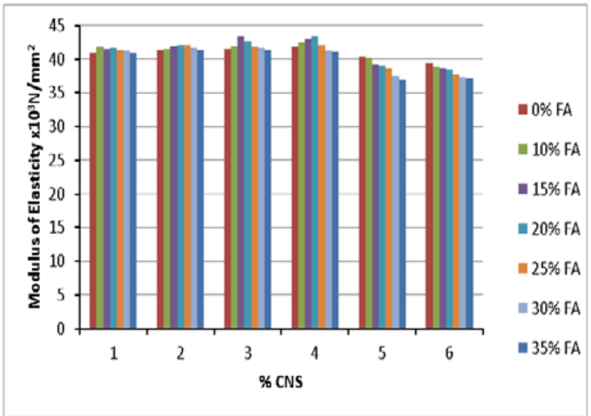
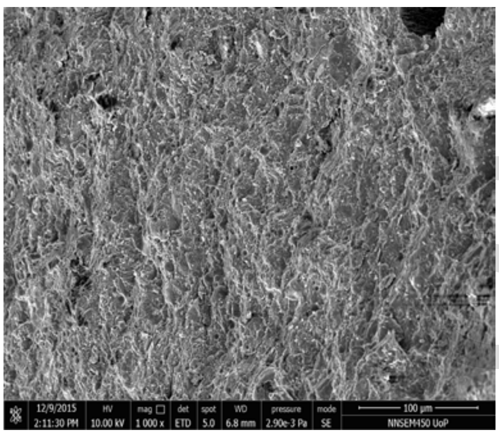
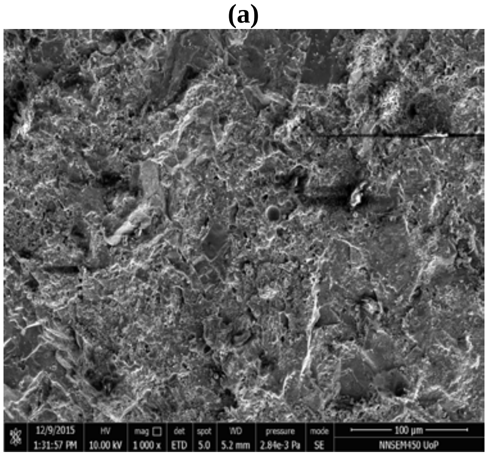


Fig-8 Modulus of elasticity of CNS added concrete at 28d.

Scanning electron microscopy observations of hardened concrete after 56 days of curing



(a)



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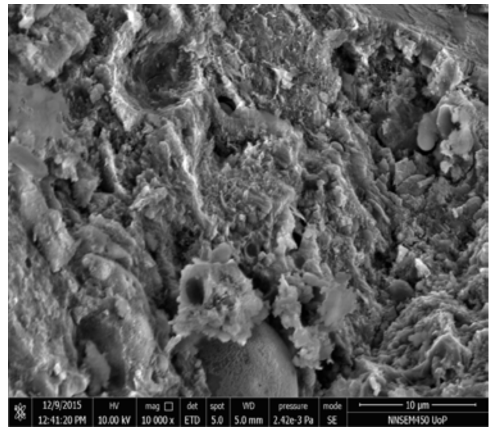
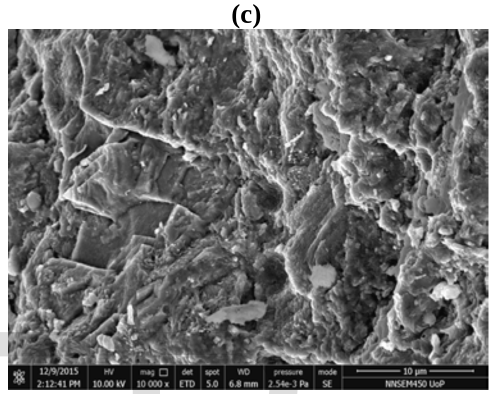


(c)



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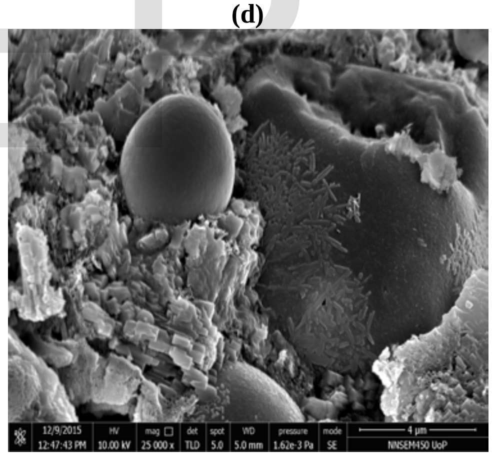

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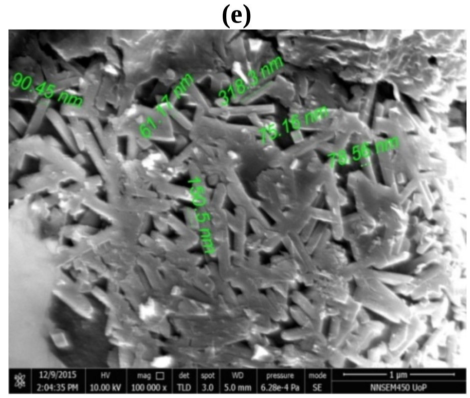
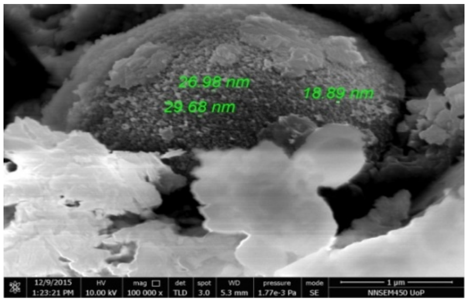
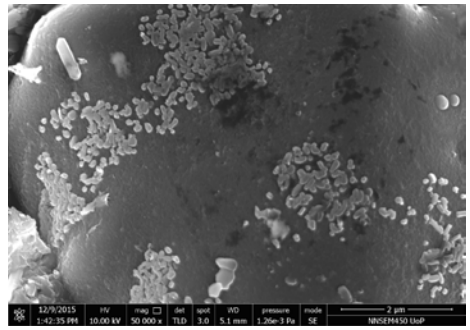


(f)



(g)



(h)

Fig-9-SEM images of **(a)** c c, **(b)** cc with 10% fly ash**, (c)** cc with formation of C-S-H gel **(d)** cc with 1% CNS, **(e)** cc with 2% CNS showing activation around sand particles**,(f)** cc with 3% CNS showing good dispersion inside the concrete,
(g) cc with 4% CNS showing formation of balling effect around the aggregates
(h) cc with 5% CNS showing problem in dispersion of CNS

Fig 9(a) and 9(b) shows scanning electron microscopy (SEM) images of cc (i.e. 100% cement,90% cement+10%FA and 0% CNS) The image shows dense calcium silicate hydrate (C-S-H)gel formed after 56 days around the sand particles.Fig9(c) shows improvement in formation of C-S-H gel after addition of 10% fly ash which indicate homogeneous microstructure .SEM images of 1% addition of CNS is shown in fig 9(d) which indicates activation of CNS particles inside the matrix at interfacial transition zone of aggregate interface, fig 9(e) shows SEM image of 2% addition of CNS particle shows bulging of CNS particles around the sand particles and in small amount they are stickup with the aggregates. Fig 9(f) shows the SEM image of 3% addition of CNS which indicates good dispersion and bonding characteristic in the cementitious material and due to this compressive, flexure and split tensile strength property of the high strength concrete has been improved. Fig 9(g) shows SEM image of 4% addition of CNS particle forming balling effect of the concrete due to bad dispersion characteristic of CNS particles and it starts reducing the strength of concrete. Fig 9(h) shows SEM image of 5% addition of CNS particle which are not getting properly mix and not dispersed throughout the concrete due to which bonding characteristic of aggregates and cement paste is not good.

Conclusions

a]As percentage CNS increases workability of fresh concrete goes on decreasing. With increase in percentage fly ash workability goes on increasing but with increase in percentage CNS with increased fly ash content workability is found to be decreasing, so it is necessary to use super plasticizer to improve the workability of the concrete for maintaining slump value in between 80 to 100mm

b] As compared to controlled concrete(cc) the compressive strength increased by 8.48%, 11.90 % 13.46 % after addition of 1%, 2% and 3% CNS along with 20% fly ash after 56 days of curing

c] As compared to cc the flexural strength and split tensile strength has been increased by 41.64% and 30.92 % respectively due to good bonding of cementitious material with CNS, better particle distribution and microstructure has been improved due to filling of voids by CNS particles.

d] The modulus of elasticity has been increased by 5.97% with respect to controlled concrete and it has been improved by 12.21% with standard value of M60 grade of concrete also density of concrete has been increased by 4.67 % this is due to improved particle packing density of the concrete and good bonding at interfacial transition zone of aggregate interface.

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