A BRIEF STUDY ON THE STRENGTH PROPERTIES OF CONCRETE MODIFIED WITH SILICA FUME AGGREGATES AND IRON OXIDE (NANO MATERIAL)

[1]S. RAMESH REDDY, [2]B.UMAPRASAD, [3]Dr. V. BHASKAR DESAI

[1]*Professor, Dept. of Civil Engineering, Brindavan Institute of Technology & Science, Kurnool, A.P and Research Scholar JNTUA College of Engineering, Anantapuram-515002, A.P.*

[2]*M.Tech Student, JNTUA College of Engineering, Anantapuram – 515002, A.P*

[3]*Professor, Dept. of Civil Engineering ,JNTUA College of Engineering, Anantapuram-515002, A.P.*

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Abstract - *In the last decade nanotechnology has been gathering spectacular amount of attention in the field of building materials. The incorporation of nano sized particles in a small amount to the building materials can influence their properties significantly and it can contribute to the creation of novel and sustainable structures. A mix design was done for M20 grade concrete by IS code method. ACC 53 grade cement was used and natural aggregate is fully replaced with Silica fume aggregates. In this experimental investigation partial replacement of cement (11%) with three number of pozzolanic materials like silica fume, slag and fly ash in equal proportions along with varying percentages of Nano iron oxide at 0, 0.5, 1, 1.5 and 2% on 11% of pozzolanic materials. The iron oxide nano particles acted as a filler which improve the micro structural properties of a cementitious composite and it reduced its total porosity and thus increasing the density of the composite.. Because of pozzolanic action, silicon dioxide reacts with free lime during hydration and produces more C-S-H gel. After 28 days, various tests has been carried out i.e compressive strength test, flexural strength test, modulus of elasticity test, impact test, Mode-II fracture test for concrete. The concrete made with nano iron oxide in combination of three numbers of pozzolanic materials yielded better results.*

Key Words: Silica fume aggregates, admixtures, ACC 53 grade, concrete, iron oxide, various tests

1 .INTRODUCTION -The recent advancements in the construction industry necessitate development of new materials. Light weight aggregate has been the subject of extensive research particularly from the industrial and agricultural waste which would otherwise create problem for disposal. The most important characteristic of light weight aggregate is its lower thermal conductivity, lower density. An attempt is made to prepare artificial light weight aggregate concrete using cold bonded Silica Fume aggregate and the density is around 1000Kg/M^3.

The basic purpose of using Nano sized materials in concrete is to improve compressive and flexural strengths at early age; it is possible due to the high surface to volume ratio. It also helps to improve the pore structure of concrete. Nano sized materials help to reduce porosity as they absorb less water compared to traditional cementitious materials. The presence of Nano materials reduces the amount of cement content in concrete than the conventional concrete. This can be achieved without sacrificing strength characteristics; thereby it is possible to produce ecofriendly concrete.

Fig-1.1: pellet drum machine

Fig-1.2: Silica fume aggregates

2. Review of literature

Aggarwal and Giare (1) investigated that critical strain energy release rate in Mode-II is less than half of that Mode-I or Mode-III indicating that in the case of fibrous composites, the fracture toughness tests in Mode-II may be more important than the tests in mode-I and Mode-III.

Prakash Desai, Raghu Prasad B.K, and Bhaskar Desai V (2) arrived at double central notched specimen geometry which fails in predominant Mode-II failure, they also made finite element analysis to arrive at stress intensity factor. Using this DCN geometry lot of experimental investigation using cement paste, mortar, plain concrete have been studied. Details of this geometry are presented in Plate 2.1.

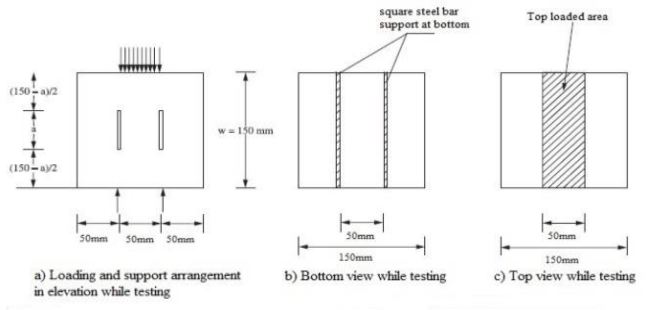

Fig-2.1: Details of DCN specimen geometry

Thorenfeldt, E (3) reported that Light Weight Aggregate Concrete has a faster hardening factor in the initial setting phase than conventional concrete, normally reaching 80 % of the 28 day strength within 7 days. The strength growth from 28 to 90 days is generally low and decreases with increasing concrete strength level. This is assumed to be a consequence of the strength limiting effect of the light weight aggregate.

Weigler, H. and Karl, S. Stahlleichtbeton (4) reported that Air entraining agents can be used with Light Weight Aggregate Concrete. It's use reduces the density proportionally to the weight of the paste it replaces, enhances the workability and reduces the segregation and bleeding.

From the brief literature summary conducted here it appears that much less attention has been paid earlier on the study of cold bonded Silica Fume aggregate concrete modified with Nano material such as Nano Fe_2O_3. Hence the present investigation has been under taken.

3. Objectives

- Determining of solution for disposal of industrial wastes hazardous to environment as a useful material in the construction industry.
- By replacing of coarse aggregate in concrete to produce light weight concrete.

4. Materials used The following materials were used for preparing the concrete mix.

1. ACC cement of 53 grade
2. Fine aggregate i.e sand
3. Coarse aggregate i.e silica fume aggregate(cold bonded)
4. Fly ash
5. Silica fume
6. Slag
7. Water
8. Nano iron oxide

4.1 Cement: ACC 53 grade cement with specific gravity 3.26 is used as binder.

S.NO	Name of the material	Properties of materials	
1	Cement	Specific gravity	3.26
		Initial setting time	50 minutes
		Final setting time	460 minutes
		Normal consistency	30%
		Fineness of Cement	5%
2	Fine aggregate	Specific gravity	2.4
3	Coarse (silica fume)aggregate	Specific gravity	1.14

Silica fume aggregates: Silica fume is a by product in the form of smoke results from electric furnaces of producing Silicon metal or ferrosilicon alloys. Silicon and ferrosilicon alloys are produced in electric furnaces and the raw materials are quartz, coal and wood chips. Before the mid 1970's nearly all silica fume was discharged into atmosphere. After environmental concerns necessitated collection and land filling became economically justified to use Silica Fume in various applications. Because of chemical and physical properties it is a very reactive pozzolana. Silica fume consists primarily of amorphous (non-crystalline) silicon dioxide (SiO2). The individual particles are extremely small, approximately 1/100th the size of an average cement particle. Because of its fine particles, large surface area, and the high SiO_2 content, silica fume is a very reactive pozzolana. An attempt is made to produce cold bonded Silica fume pellets to use as light weight aggregate.

One of the common techniques while producing the light weight aggregate is by agglomeration technique. In agglomeration technique the pellets is formed by agitation granulation and compaction. The agitation method is not taking any external force rather than the rotational force. With the increasing dosage of water in the binder the cohesive force of the particles increases. Here attempts have been made to form pellets of Silica Fume with various proportions of lime and cement mixing with water. Pelletization of Silica Fume was done by using a rotating drum with fixed blades with adjusting inclination. The percentage of binder content is taken by the weight of Silica Fume.

Typical physical characteristics of Silica fume aggregates

Aggregate Size mm : 10-16mm

Bulk Density : 645-755 kg/m3

Shape : Round pellets

4.3 Casting of specimens:

The M20 concrete mix is designed using ISI method which gives a mix proportion of 1:1.49:2.88 with water cement ratio of 0.50. Four different mixes other than conventional mix adopted here are designated as follows.

Name of the MIX	% Volume replacement of Coarse aggregate	% of cement replacement by admixtures in equal proportions	% of Nano (FE_2O_3) on 11% of cement	% of cement
UP0	100	0	0	100
UP1	100	11	0.5	88.945
UP2	100	11	1.0	88.890
UP3	100	11	1.5	88.835
UP4	100	11	2	88.780

To proceed with the experimental program initially steel moulds of size 150x150x150 mm were cleaned brushed with machine oil on all inner faces to facilitate easy removal of specimens afterwards. First fine aggregate and cement along with admixtures silica fume, slag, fly ash and Nano iron oxide in required percentages were mixed thoroughly and then Silica fume aggregates were added with them. All of these were mixed thoroughly by hand mixing. Each time 150X150X150mm cube specimens out of which 12 no of DCN specimens with replacement of cement by 11% of its weight by pozzolanic materials (Silica fume, fly ash and Slag) and Nano iron oxide with varying percentages (0%, 0.5%, 1%, 1.5% and 2%) on 11% weight of cement and 5no's of different mixes for each of 3 no's of plain cubes, 3 no's of plain beams were caste. The concrete was poured into the moulds in three layers with each layer being compacted thoroughly with tamping rod 25 times each time to avoid honey combing. Finally all specimens were kept on the table vibrator after filling up the moulds up to the brim. The vibration was effected for 7 seconds and it was maintained constant for all specimens and all other castings. The steel plates forming notches were removed after 3 hours of casting carefully and neatly finished. After 28 days of curing the specimens were taken out of water and were allowed to dry under shade for few hours.

4.4Testing of specimens

4.4.1 Compressive strength of cubes:

Compressive strength of cubes shall be calculated by dividing load taken by the specimen by the cross sectional area. Values of compressive strength at different percentages of iron oxide are given in table 1 below.

4.4.2 Flexural strength:

Flexural strength is one measure of the tensile strength of the concrete. The flexural strength can be determined by standard test method of third point loading or center point loading. In this study, four beams of size 100*100*500 mm were used to find the flexural strength. The values are presented in table 2.

4.4.3 Modulus of elasticity:

The theoretical modulus of elasticity has been calculated using IS code formula.

$$E=5000*\sqrt{f_{ck}}$$ (refered in 5)

Where f_{ck}= Characteristic Compressive strength of concrete in N/mm^2

The modulus of elasticity values have been calculated from the empirical formula suggested by Takafumi is

$$E=k_1k_2*1.486*10^{-3} * f_{ck}{}^{1/3} *\gamma^{2}$$ (refered in 6)

Where f_{ck} = Compressive strength in N/mm^2, γ = Density in Kg/m^3, K_1= 0.95 (correction factor corresponding to coarse aggregate), K_2= 1.026, (correction factor corresponding to mineral admixtures)

4.4.4 Mode II fracture test

For testing DCN specimens of size 150x150x150mm, notches were introduced at one third portion centrally during casting. The compression test on the DCN cubes was conducted on 3000KN digital compression testing machine. The rate of loading applied is 0.5 KN/sec. Test results shown in table 5 and graphically vide in fig.4.Uniformly distributed load was applied over the central one third part between the notches and square cross section steel supports were provided at bottom along the outer edges of the notches, so that the central portion could get punched/sheared through along the notches on the application of loading.

Table 1: Compressive strength

Name of the mix	% Volume replacement of coarse aggregate	% of admixtures in equal proportions	% Nano (FE_2O_3) on 11% of cement	% of cement	compressive strength in N/mm^2	% increase or decrease of compressive strength
UP0	100	0	0	100	14.22	0
UP1	100	11	0.5	88.945	17.89	25.81
UP2	100	11	1	88.890	20.21	42.09
UP3	100	11	1.5	88.835	20.86	46.69
UP4	100	11	2	88.780	19.66	38.25

.**Table 2:** Flexural strength of beams

Name of the mix	% replacement of coarse aggregate	% of admixtures	% Nano(FE_2O_3) on 11% of cement	% of cement	Flexural strength in N/mm^2	% increase or decrease of flexural strength
UP0	100	0	0	100	1.6973	0
UP1	100	11	0.5	88.945	1.8329	8.369
UP2	100	11	1	88.890	1.976	16.461
UP3	100	11	1.5	88.835	2.259	33.177
UP4	100	11	2	88.780	2.110	24.31

Table 3: Modulus of elasticity

Name of the mix	% replacement of coarse aggregate	% of admixtures	% FE_2O_3 on 11% of cement	% of cement	Modulus of elasticity in N/mm^2 $E=5000*\sqrt{fck}$	Modulus of elasticity based on empirical formula $E=k_1k_2*1.486*10^{-3} * f_{ck}{}^{1/3} *\gamma^2$ $K_1= 0.95$, $K_2= 1.026$	% increase or decrease of modulus of elasticity by IS code formula
UP0	100	0	0	100	1.885	1.32	0
UP1	100	11	0.5	88.945	2.114	1.26	12.147
UP2	100	11	1	88.890	2.247	1.26	19.2047
UP3	100	11	1.5	88.835	2.283	1.28	21.1140
UP4	100	11	2	88.780	2.216	1.25	17.559

Table 4: Density

Name of the mix	% Volume replacement of coarse aggregate	% of admixtures in equal proportions	% Nano (FE_2O_3) on 11% of cement	% of cement	Density in Kg/cum	Percentage increase or decrease in density
UP0	100	0	0	100	2000	0
UP1	100	11	0.5	88.945	1957.93	-2.15
UP2	100	11	1	88.890	1963.48	-2.35
UP3	100	11	1.5	88.835	1970.37	-1.4815
UP4	100	11	2	88.780	1951.38	-2.431

Table 5: Ultimate loads in Mode-II fracture test

Name of the mix	% replacement of coarse aggregate	% admixtures	% iron oxide	a/w=0.3		a/w=0.4		a/w=0.5		a/w=0.6	
				Ultimate load in KN	% increase or decrease of ultimate load	Ultimate load in KN	% increase or decrease of ultimate load	Ultimate load in KN	% increase or decrease of ultimate load	Ultimate load in KN	% increase or decrease of ultimate load
UP0	100	0	0	86.33	0	83	0	60.67	0	57.33	0
UP1	100	11	0.5	96	11.20	92	10.84	64	5.48	60	4.657
UP2	100	11	1	103	19.305	97.6	17.590	68	12.081	61.33	6.977
UP3	100	11	1.5	114	32.051	106	27.710	71	17.02	69.50	13.37
UP4	100	11	2	94	8.8845	88	6.02	62	2.192	58.33	1.1691

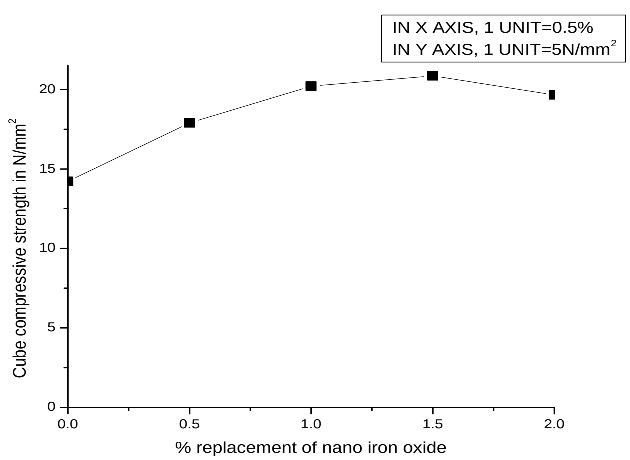

Chart-1: Compressive strength of cubes

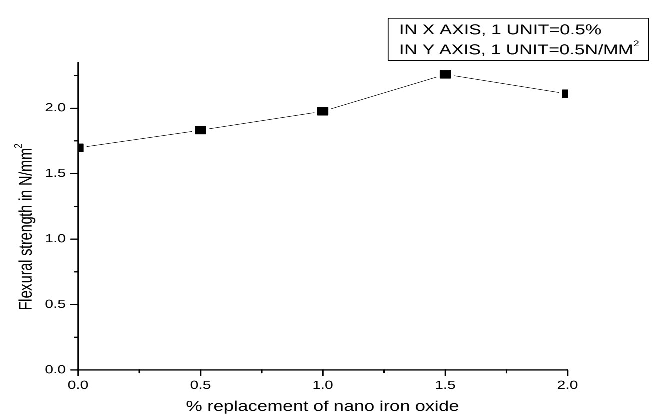

Chart-2: flexural strength

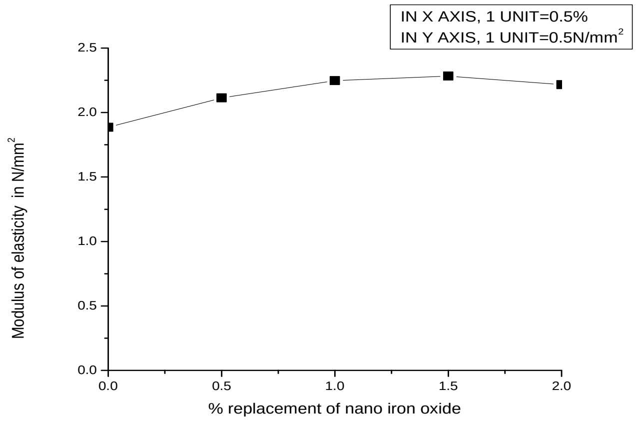

Chart- 3: Modulus of elasticity

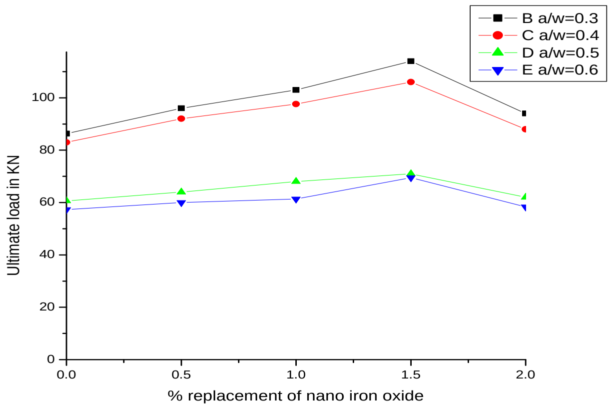

Chart-4: superimposed loads for different a/w ratios

5. Discussion of test results

5.1 Discussion of crack patterns in cubes, cylinders, beams and DCN specimens:

In case of cubes, the initial cracks are developed at top and propagated to the bottom with the increase in load and they are widened along the edges of cubes. In case of cylinders, the initial cracks are developed at top or bottom side with the increase in load the cracks are widened at central height. In the flexural beams all 12 beams have failed in flexural mode. As the load increases the flexural cracks initiates in the pure bending zone and the first cracks appears almost in the mid span. As the load increases, existing cracks propagated are observed and new cracks have developed along the span. Final failure occurs in the middle portion. The failure of the DCN specimen is such that the crack patterns obtained for DCN specimen geometry are mostly along the notch depths. During testing, for most of the specimen initial hair line cracks started at the top of one or both the notches, and as the load was increased further, the cracks widened and propagated at an inclination and sometimes to the middle of the top loaded zone. In a few cases, initial cracks started at the bottom of the one or both notches. As the load was increased propagation of these cracks at an inclination was observed along with the formation of cracks at top of the notches. These cracks finally propagated toward the middle of the top loaded zone leading to failure of the specimen. In some cases cracks formed either side at two edges of the supporting load bearing plate at the bottom or at the loaded length at top side. For most of the specimens with a/w = 0.3, 0.4, 0.5, 0.6, as the load was applied formation of initial hair line cracks at the top of one or both the notches was observed. With the increase of load propagation of these cracks in more or less vertical direction along with the formation of new cracks at the bottom of one or both the notches was observed.

5.2 Influence of iron oxide on cube compressive strength

In the present study natural aggregate has been replaced with 100% cold bonded Silica fume aggregate. The variation of compressive strength verses varying percentage replacement at 0 , 0.5 ,1 ,1.5% and 2% on11% of cement with NanoFE$_2$O$_3$ in addition with constant 11% of three numbers of pozzolanic materials i.e., Silica fume, Slag and Fly ash in equal proportions at 28 days are shown in figures 1. From the above figures it may be observed that with the addition of iron oxide the cube compressive strength increases up to addition of 1.5% and with more addition of Nano FE_2O_3 the strength is decreased.

5.3 Influence of iron oxide on flexural strength of beam specimens

In the present study natural aggregate is fully replaced with Silica fume aggregates. The flexural strength of beams is increased continuously up to 1.5% addition of iron oxide and afterwards it is decreased. The results and tabulated in table 2 and shown in figures 2.

5.4 Influence of Nano iron oxide on modulus of elasticity

The modulus of elasticity results with various percentages of $FE_2O_3$are presented in table 3 for 28 days based on IS code methods . From the results it is observed that modulus of elasticity has been increased continuously up to 1.5% FE_2O_3 addition and afterwards it is decreased. It is also observed that the modulus of elasticity values calculated from IS codes are higher compared to empirical formula.

5.5 Discussion on the effect of FE_2O_3 on in plane shear strength

All the DCN specimens with different a/w ratios i.e 0.3, 0.4, 0.5 and 0.6 and with different percentages of FE_2O_3 were tested with load in Mode-II (in plane shear). The variations of ultimate loads and percentage increase or decrease in ultimate loads verses percentage replacement of cement with Nano $FE_2O_3$are presented in table 5which are presented for different a/w ratios after 28 days. From the above tables and diagrams it can be observed that for a given a/w ratio, the in plane shear strength increases with the Nano Iron Oxide content up to 1.5% addition and afterwards its gets decreased. Also as the a/w ratio is increased for the given Nano Iron oxide content the in plane shear strength gets decreased.

5.6 Influence of iron oxide on density

Density of modified concrete with Silica fume aggregates with Nano $FE_2O_3$is decreased to 5% compared to natural aggregate concrete.

6. Conclusions

- The target mean strength of M_{20} concrete is 26.60 N/mm^2. From the experimental study it is observed that the 28 days cube compressive strength of modified concrete with 100% Silica fume aggregate is 14.22 N/mm^2 .with replacement of cement by 11% with three numbers of pozzolanic materials i.e., Silica fume, Slag and Fly ash in equal proportions along with addition of Nano iron oxide in 0.5% intervals the cube compressive strength of modified concrete rises to 20.860 N/mm^2 at 1.5% nano iron oxide and afterwards it gets decreased.
- With the percentage of increase in Nano iron oxide and with constant 11% three pozzolanic materials in equal proportions replacing the cement, there is increase in flexural strength and Young's modulus upto1.5% and further increase in Nano iron oxide content there is decrease in both the values.
- It is observed that with the increase in the a/w ratio there is decrease in ultimate load and there is increase in ultimate loads up to 1.5% addition of Nano FE_2O_3 and further increase in Nano FE_2O_3 content there is decrease in ultimate loads for all a/w ratios.
- The light weight concrete prepared by 100% Silica fume aggregate as coarse aggregate is no way inferior to the natural aggregate and also

consumption of cement can be reduced by about 11%.

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