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Properties Of SCC With Nano Silica And Cu Slag As Partial Replacement For Cement And Fine Aggregate.

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ABSTRACT

This study was conducted to investigate the effect of colloidal nanosilica on the properties of Self Compacting Concrete (SCC) partially replaced with Copper (Cu) slag as fine aggregate. Copper slag was replaced at constant level of 10% and 20 % of weight of Sand. Concrete mixes were produced by replacing Portland cement with colloidal Nano silica at 1%, 2%, and 3%. Tests on workability, compressive strength, splitting tensile strength, were conducted on concrete mixes. Due to the high specific surface area of nanosilica, increase in the percentage results in increase in water demand. The fresh properties of Cu slag and Nano silica replaced concrete mixes showed better filling and passing ability. The workability of the mixes increases with the replacement of Nano silica upto to 2%. The strength properties were generally improved with the increment of nanosilica content in the concrete mix. The addition of Nanosilica improves the micro structure of the mix and acts as activator to promote Pozzolanic action.

Keywords: SCC, cement, aggregate, copper

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INTRODUCTION

There is a rise in the concrete production cost mainly due to the scarcity of aggregates, river sand, and naturally available cementious material. The rapid increase in the natural aggregates consumption every year due to the increase in the construction industry worldwide because of that the aggregate reserves are being depleted rapidly [1]. Reports say that, without proper alternative aggregates being utilized in the near future, the concrete industry globally will consume 8–12 billion tons annually of natural aggregates after the year 2010 [2]. Such large consumption of natural aggregates will cause destruction of the environment. Therefore there is an urgent need to find and supply alternative substitutes for natural aggregates by exploring the possibility of utilization of industrial by-products and waste materials [3] in making concrete. To reduce such problems, lot of research work has been carried out to use industrial and agricultural waste as substitute for cement, fine aggregate and coarse aggregate.

Copper slag is one such industrial waste which is a by product of the manufacture of copper [4-7]. Large amount of copper slag are generated as waste worldwide during the copper smelting process. The world copper production is currently about 14.98 million tons and it is estimated that for every ton of copper produced, about 2.2tons of copper slag is generated as a waste [8]. Current options of management of this slag are using waste slag as a cement replacement material, fine aggregate replacement material and coarse aggregate replacement material [9-15] in concrete depends upon the properties of the material.

It is reported that the microstructure of the cement paste can be significantly improved by adding pozzolanic materials such as, fly ash, silica fume, metakaolin and rice husk ash (RHA) [16]. Silica fume, a by-product from silicon alloy or Ferro silicon alloy, rich in SiO2 content is a highly pozzolanic material. The addition of nanosilica accelerates the hydration process and also reacts with Calcium Hydroxide and produces more amounts of Calcium-Silicate-Hydrates thereby improving the mechanical properties [17]. The incorporation of nanosilica in concrete resulted in higher compressive strength [18-20, 22], increase in tensile strength and bending strength [20-24] and improvement in abrasive resistance than that of normal concrete to a considerable level.

Self compacting concrete is a special type of concrete which has been used for the past three decades. SCC with its special characteristics properties can be used to overcome the problems faced in normal concrete. Lack of density, proper compaction, workability, durability properties in normal concrete is improved by SCC. It is also a flowing concrete, which is able to consolidate under its own weight. It is well suitable for sections with congested reinforcement and the highly fluid nature of SCC makes it easy to be poured in places where human access is difficult. Workability and mechanical properties of cu slag replaced SCC was studied, in which cu slag was replaced at the range of 20-40 % of cement [25]. The effect of different mineral additions on the rheology and compressive strength of SCC was studied [26-28]. Although many researchers have been studied on using copper slag, silica fume and RHA, in the production of normal and high strength concrete, not much research have been carried out on SCC with slag and silica fume replacement. In this present work SCC mix was prepared with 10 and 20 % fine aggregate replaced with cu slag, and cement replaced with silica fume in the range of 1-3%. The fresh and hardened properties of SCC mix with slag, silica fumes were studied and reported.

MATERIALS

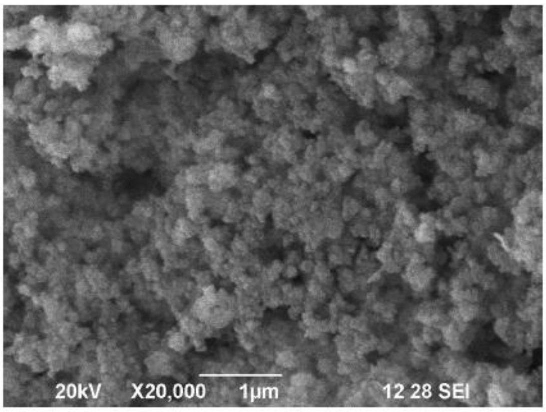
Ordinary Portland cement of grade 53 was used in this study. Fine aggregate used were river sand which passes through IS 4.75 mm sieve. Coarse aggregate consist of 16 mm well graded gravel stones. Copper slag used in this work was brought from Sterlite Industries Ltd, Tuticorin, Tamil Nadu, India. Silica fumes are available in the form of compacted dry powder or colloidal suspension. Silica fume obtained from an electric arc furnace in the manufacturing of Ferro silicon alloy was used. The silica fume was used as a partial replacement of cement in the SCC mixes. The SEM image of silica fumes is shown in Figure 1. Specific gravity and specific surface of the silica fume are 2.051 and 16,000 m2/ kg, respectively. The sieve analysis of sand and copper slag is shown in Figure 2. Super plastizer BASEF master glenium SKY 8233 was used in the SCC mix. It is a chemical admixture based on poly carboxylic ether. The mix proportion for control SCC mix (M-50) without slag and silica fumes replacement is 1:1.69:1.86:0.33:0.45. Physical and chemical properties of cement, fine aggregate, coarse aggregate, copper slag, silica fume and super plastizer are given in Table 1and Table 2.

Table 1: Physical Properties of Cement, FA, CA, Cu slag, Silica Fumes

Physical properties	Cement	FA	CA	Cu slag	SF
Specific gravity (g/cm^3)	3.15	2.77	2.69	3.59	1.9
Percentage of voids	-	-	-	34	-
Water absorption %	-	1.06	0.4	0.4	-
Moisture content %	-	2.4	0.25	0.13	-
Fineness modulus	-	3.18	3.46	3.28	-
Bulk density (Kg/m^3)	950	1500	1450	1900	350
Fineness	2 %	-	-	-	-

Table 2: Chemical Properties of cement, Cu slag, Nano silica

Chemical Properties	Cement	Cu slag	SF
SiO_2	21.8	25.84	91.7
Fe_2O_3	3.8	68.29	0.9
Al_2O_3	4.8	0.22	1
CaO	68.3	0.15	1.68
Na_2O	0.21	0.58	-
K_2O	0.46	0.28	-
Mn_2O_3	0.9	0.22	-
TiO_2	0.25	0.41	-
SO_3	2.2	0.11	0.87
CuO	-	1.2	-
Loss on Ignition	2	6.59	-
Insoluble residue	0.4	14.88	-



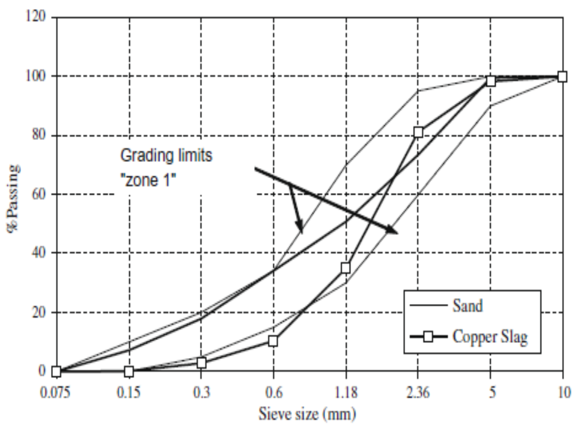


Figure 1: SEM image of Nano silica [17]; Figure 2: Sieve analysis of sand and copper slag [28]

Experimental program

Mix design

In the present study 9 mix designs were investigated. Each mixture was made with water cement ratio of 0.45. Preliminary studies have been done in concrete cubes without copper slag and with 10 and 20 % replacement of fine aggregate with copper slag. In the next stage the effect of nanosilica substitution as a replacement for cement on the strength of copper slag were studied. The mix proportion of cement: Fine Aggregate (FA): Coarse Aggregate (CA): Fly Ash: Super plasticizer (SP) adopted was 1:1.69:1.86:1.64:3.6. Concrete cubes (150 mm ×150 mm ×150 mm) were prepared with different percentages of nanosilica (by

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weight) with a constant w/b ratio of 0.45. Cubes were cast by replacing cement with 1%, 2%, and 3% of colloidal nanosilica and the copper slag replacement for fine aggregate was kept at a constant value of 10% for one set and 20% for second set of mixes. The super plasticizer was added at a constant rate of 0.5%. Nine cubes and nine cylinders were casted for each mix to determine the compressive strength and split tensile strength at end of 7, 14 and 28 days.

Sample details

To evaluate the mechanical properties of SCC with cu slag and nano silica replacement three cubes of size 150 mm ×150 mm ×150 mm and three cylinders of size 150 mm ×300 mm were casted for each set. The sample details are as follows:

i. M-50 SCC without copper slag (Control specimen)
ii. SCC with 10 % cu slag (FA replacement) – $C10s\text{-}0_{NS}$
iii. SCC with 10 % slag and 1 % Nano silica (Cement replacement) – $C10s\text{-}1_{NS}$
iv. SCC with 10 % slag and 2 % Nano silica (Cement replacement) – $C10s\text{-}2_{NS}$
v. SCC with 10 % slag and 3 % Nano silica (Cement replacement) – $C10s\text{-}3_{NS}$
vi. SCC with 20 % cu slag (FA replacement) – $C20s\text{-}0_{NS}$
vii. SCC with 20 % slag and 1 % Nano silica (Cement replacement) – $C20s\text{-}1_{NS}$
viii. SCC with 20 % slag and 2 % Nano silica (Cement replacement) – $C20s\text{-}2_{NS}$
ix. SCC with 20 % slag and 3 % Nano silica (Cement replacement) – $C20s\text{-}3_{NS}$

For nine series of test, totally 81 cubes and 81 cylinders were casted and tested at 28 days. The designation of each specimen and mix proportions for each mix is given in Table 3.

Table 3: Mix proportions for Control specimen and SCC with slag and silica fume replacement

Specimen Details	Cement (Kg)	FA (Kg)	CA (Kg)	Cu slag (Kg)	Fly Ash (Kg)	SF (Kg)	Water (Liters)	Super plasticizer (ml)
SCC (M50)	15.18	25.625	28.325	-	5.062	-	6.875	136
$C10_S0_{NS}$	12.15	18.48	22.66	2.05	4.05	-	5.5	98
$C10_S1_{NS}$	12.03	18.48	22.66	2.05	4.05	0.122	5.5	98
$C10_S2_{NS}$	11.91	18.48	22.66	2.05	4.05	0.244	5.5	98
$C10_S3_{NS}$	11.78	18.48	22.66	2.05	4.05	0.366	5.5	98
$C20_S0_{NS}$	12.15	16.4	22.66	4.1	4.05	-	5.5	98
$C20_S1_{NS}$	12.03	16.4	22.66	4.1	4.05	0.122	5.5	98
$C20_S2_{NS}$	11.91	16.4	22.66	4.1	4.05	0.244	5.5	98
$C20_S3_{NS}$	11.78	16.4	22.66	4.1	4.05	0.366	5.5	98

Table 4: Typical acceptance criteria for SCC as per codal provision

Method	Unit	Typical range	
		Min	max
Slump flow test (filling ability)	mm	650	800
T_{50} cm Slump flow (filling ability)	sec	2	5
V-funnel test (filling ability)	sec	6	12
J-ring (passing Ability)	mm	0	10
L-Box (passing Ability)	(H_2/H_1)	0,8	1,0
U-Box (passing Ability)	$H_2\text{-}H_1$	0	30

SCC pasty phase test

SCC has special characteristics compared to other concretes. The parameters for each of these characteristics are independent of each other, so many test are done to measure the pasty phase characteristics of SCC. Based on the results of the pasty phase test we can measure the stability and workability of SCC. Also the stability can be compared with different grade of concrete at the end of the experiment. A concrete is said to be SCC based on its workability characteristics at its fresh state. In order to comply with the characteristics of SCC at its fresh state, concrete should possess some basic quality such as filling ability, passing ability and segregation resistance. Typical range of values for the workability properties of the fresh SCC according to codel provision is given in Table 4

J- ring test

J ring test denotes the passing ability of concrete. The J-Ring test (Figure 3), in conjunction with the Slump- Flow test, is one way to determine the passing ability of SCC, defined as the ability of the concrete to flow under its own weight to completely fill all spaces within the formwork. Slump cone is positioned either inverted or upright in the middle of the J-Ring and filled with concrete in a single lift. The cone is then lifted straight up and the diameter of the resulting circular flow of concrete is measured. A similar test is then run without the J-Ring in place and the difference in the flow diameters is recorded as the passing ability.

Figure 3: J-ring Test pasty phase test; **Figure 4: V-Funnel Test**

Figure 5: L - Box Test

V- funnel test

V-funnel equipment was placed on a level ground and the inner surface was moistened with sponge. About 1.2 liters of concrete mix was poured into the V-funnel (Figure 4) with the valve closed at the bottom. During the test no compaction or tapping of the body should be done. After 10 seconds the valve was opened and the concrete was allowed to flow under its own weight. The time taken for the complete withdrawal of concrete from the v-funnel is noted down.

L box test

L-box is another test which is used to determine the passing ability of fresh concrete. The vertical portion of L-box was completely filled with fresh concrete and allowed to settle for one minute. The doors at the base of the vertical segment of the L-box was opened and the concrete was allowed to flow through the horizontal segment of L-box (Figure 5) and the time for concrete to reach the 200 and 400 mm mark was noted. When the flow of the concrete was completely stopped, the height of the concrete from the base at the face of the vertical portion of the L-box was noted as H1 and the height of the concrete at the other face was noted as H2. The ration between H1 and H2was calculated as blocking ratio.

U box test

U box test is another pasty phase test which is used to check the flow characteristics of SCC. The inside surface of the apparatus was moistened, and surplus water was removed. Concrete was filled in the vertical section of the apparatus and allowed to settle for 1 minute. Sliding gate was lifted and the concrete was allowed to flow out into the other compartment. After the concrete has come to rest, measure the height of the concrete in the compartment was measured in two places as H1 and H2.

Slump flow and T_{50} test

A slump cone of size 200 mm diameter at the bottom and 100 mm diameter at the top and 300 mm height was filled with fresh concrete. The slump cone was lifted vertically and the concrete was allowed to form a circle of 500 mm diameter was noted as T50 time. Then the average of the final dimensions of the concrete in both perpendicular directions was calculated. The results of slump flow test and T50 test sow the workability of SCC. The pasty phase test results are tabulated in Table 5

Table 5: Fresh concrete properties of SCC replaced with Cu slag and Silica fumes

Specimen ID	Slump Flow Test		V-Funnel test (sec)	J-Ring (sec)	L-Box	U-Box	Remark
	Slump (mm)	T_{50} slump (sec)					
SCC	650	2	1.5	4	0.12	0	satisfied
$C10_{S}0_{NS}$	722	2.6	1.8	5	0.15	0.5	satisfied
$C10_{S}1_{NS}$	715	2.5	1.3	6	0.18	7	satisfied
$C10_{S}2_{NS}$	688	3.6	1.7	7	0.29	16.5	satisfied
$C10_{S}3_{NS}$	580	4.5	1.2	8	0.37	12	satisfied
$C20_{S}0_{NS}$	670	8	1.5	7	0.19	0.1	satisfied
$C20_{S}1_{NS}$	682	4.4	2.2	8	0.17	0	satisfied
$C20_{S}2_{NS}$	730	2.7	1.3	8	0.16	1	satisfied
$C20_{S}3_{NS}$	695	2.9	1.4	10	0.3	1	satisfied

Table 6: Average compressive strength of cubes at different curing ages

Mix ID	Weight (Kg)	Compressive Strength (Mpa)		
		7 days	14 days	28 days
SCC (Control Mix)	7.0	32.5	42	56.5
$C10_{S}0_{NS}$	7.94	34.9	47.3	58.5
$C10_{S}1_{NS}$	7.8	42.4	57.3	63.2
$C10_{S}2_{NS}$	7.78	48.9	58.9	67.6
$C10_{S}3_{NS}$	7.87	43.8	53.4	64
$C20_{S}0_{NS}$	7.97	34.3	48.2	59.2
$C20_{S}1_{NS}$	7.9	43.5	54.3	64.5
$C20_{S}2_{NS}$	7.96	46.5	59.5	69.5

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$C20_S3_{NS}$	8.01	39.5	48.3	65.2

SCC hardened phase test

After the pasty phase test the concrete was poured into cube and cylinder mould. After 24 hrs the concrete samples were removed from the mould and allowed to cure for 7, 14 and 28 days in curing tank. After the curing period the cube were subjected to compression load in compression testing machine and cylinder was tested in UTM to determine the Split tensile strength.

Compression test

The compressive strength test of self compacting concrete specimens with different replacement level of copper slag and silica fumes was done and the values of compressive strength were calculated at the age of 7, 14 and28 days. The values are tabulated in Table 6

Split tensile strength test

The split tensile strength test for cylinders was calculated as per IS516:1964. The universal testing machine was used for this test. The cylinder specimen was placed horizontally between the loading surfaces and the load was applied till the failure of the specimen.

RESULTS AND DISCUSSION

Pasty phase test

The fresh concrete properties (i.e.) the pasty phase test values of SCC with two different percentage of copper slag replacement and different level of silica fume replacement were presented in Table 5. The slump values which are the measurement of workability of fresh concrete, increases as the copper slag content increases. This increase is mainly due to the low water absorption of slag and the glassy surface in comparison with sand. But with the addition of silica fumes the workability decreases. Addition of nanosilica in concrete decreases the workability and this is mainly due to the fact that some portion of the mixing water is absorbed by nanosilica particles. Water molecules are attracted towards the nanosilica particles due to high specific surface area and high reactivity. Thus, a reduction in the slump value of SCC with cu slag and silica fume replacement ($C10_S3_{NS}$) was observed.

The other pasty phase test namely the L-box, V-funnel, U-box, J-ring test values indicate that the all nine concrete mixes with different percentage of cu slag and silica fume replacement satisfies the minimum requirement of self compacting concrete. It has better passing and filling ability compared to control mix.

Hardened concrete test

To study the effect of addition of nanosilica on the mechanical properties of SCC Slag Concrete, all the mixes were made with same water/binder ratio and workability. Figure 6 shows the variation of compressive strength due to the addition of nanosilica in 10 % slag concrete at 7, 14 and 28 days of curing. Similarly Figure 7 shows the variation of compressive strength due to the addition of nanosilica in 20 % slag concrete at 7, 14 and 28 days of curing. The strength of all concrete mixes increased with age. From the result, it was observed that the both the concrete mixes made with nanosilica exhibited higher compressive strength than control mix. The percentage increase of compressive strength in comparison to the control mix at various ages is presented in Table 7. The mixes $C10_S1_{NS}$, $C10_S2_{NS}$, $C20_S1_{NS}$ and $C20_S2_{NS}$ showed an improvement in compressive strength of 11.86%, 19.65%, 14.16%, 23.01% respectively with respect to the control mix SCC (M50) at 28 day. It was observed that the compressive strength enhanced up to 2% nanosilica replacement and then declined slightly with further addition of Nano Silica.

Table 7: Increase in compressive strength at various ages in comparison with control mix

Mix ID	7 days (%)	14 days (%)	28 days (%)
C10S0NS	7.38	12.62	3.54
C10S1NS	30.46	36.43	11.86
C10S2NS	50.46	40.24	19.65
C10S3NS	34.77	27.14	13.27
C20S0NS	5.54	14.76	4.78
C20S1NS	33.85	29.29	14.16
C20S2NS	43.08	41.67	23.01
C20S3NS	21.54	15.0	15.4

Table 8: Split tensile strength at different curing age

Mix ID	Weight (Kg)	Split Tensile Strength (Mpa)		
		7 days	14 days	28 days
SCC (Control Mix)	11.85	1.02	2.35	4.03
C10S0NS	12.98	1.85	3.45	4.82
C10S1NS	12.92	2.53	3.98	4.97
C10S2NS	12.9	2.65	4.21	5.12
C10S3NS	12.8	2.23	3.85	4.85
C20S0NS	13	2.12	3.25	4.91
C20S1NS	12.82	2.95	4.2	5.28
C20S2NS	12.7	3.25	4.6	5.43
C20S3NS	12.9	2.45	4.3	4.85

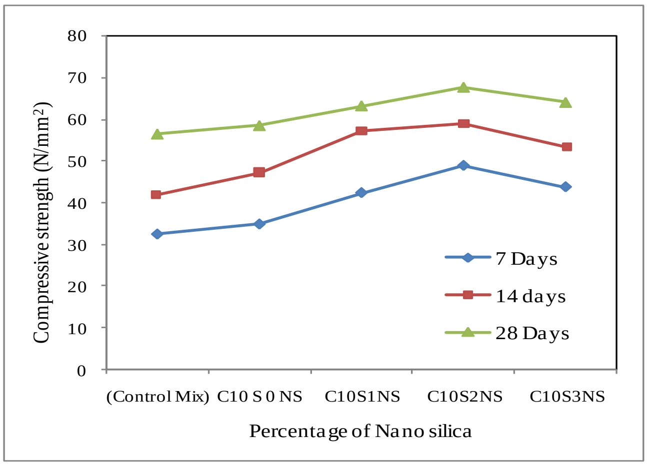

Figure 6: Compressive strength of 10 % cu slag SCC with different percentage of Nano silica

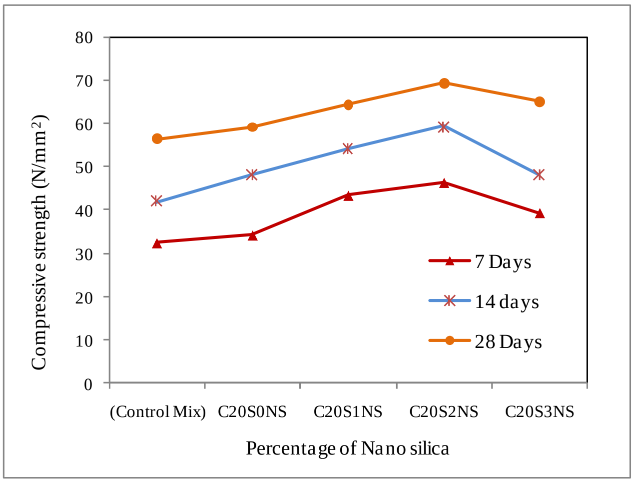

Figure 7: Compressive strength of 20 % cu slag SCC with different percentage of Nano silica

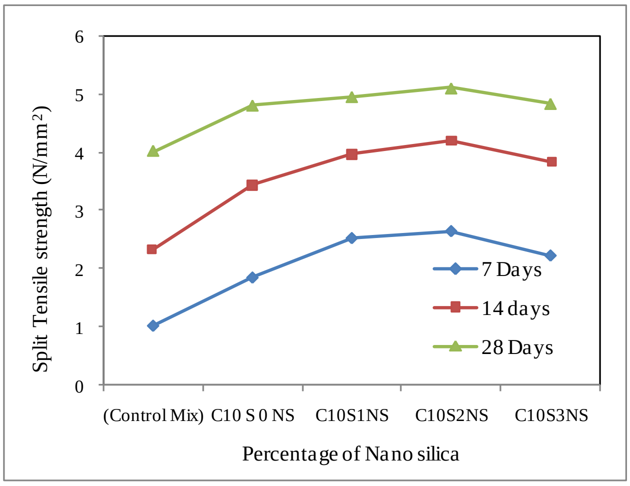

Figure 8: Split tensile strength of 10 % cu slag SCC with different percentage of Nano silica

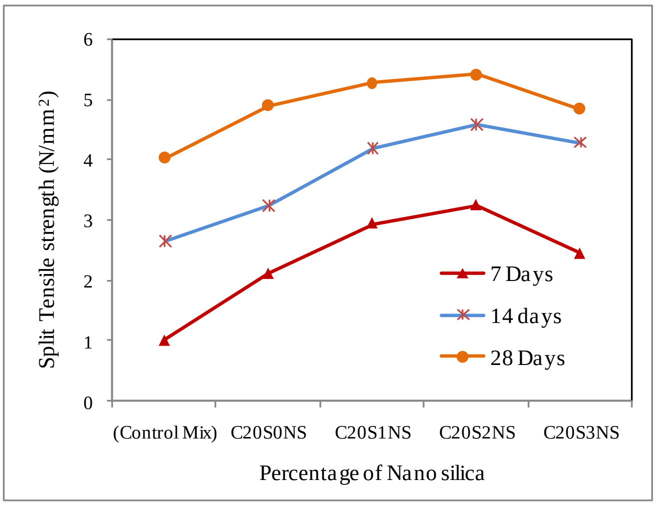

Figure 9: Split tensile strength of 20 % cu slag SCC with different percentage of Nano silica

The splitting tensile strength of all the nine mixes is tabulated in Table 8. The splitting tensile strength development is similar to the compressive strength development at all ages of curing. All the specimens show higher strength than control mix. Figure 8 and 9 shows the variation of splitting tensile strength due to the addition of nanosilica at all ages. The mixes $C10_S1_{NS}$, $C10_S2_{NS}$, $C20_S1_{NS}$ and $C20_S2_{NS}$ showed an increase in splitting tensile strength compared to the control mix.

CONCLUSION

In general, incorporation of copper slag fine aggregate increases the mechanical properties of Self Compacting Concretes which may be due to the strength characteristics of copper slag and the stronger bonding between copper slag aggregate and the cement paste matrix. The maximum compressive strength, splitting tensile strength was obtained in the sample containing 2% of nanosilica. The decrease in mechanical properties with greater than 2% nanosilica particles replacement is attributed to the reason that the quantity of nanosilica particles is higher than the quantity of liberated lime in the hydration process which results in leaching out of excess silica. At higher level of replacement of nanosilica, it acts as a cement replacement material used for filling the pores but does not involve in the hydration process.

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