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Effective utilization of Rice Husk Ash and Copper slag as partial replacement for cement and fine aggregate in SCC.

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ABSTRACT

This study aims to investigate the fresh and hardened properties of self Compacting Concrete (SCC) partially replaced with Copper (Cu) slag and Rice Husk Ash (RHA). Copper slag was replaced at constant level of 10% and 20 % of weight of Sand. Concrete mixes were produced by replacing cement with RHA at 1%, 2%, and 3% of weight of cement. Fresh concrete properties namely the slump flow, workability, passing and filling ability of SCC were studied. Hardened concrete test namely compressive strength test, splitting tensile strength test, were conducted on concrete specimens.

Keywords: rice husk ash, copper, SCC, slag.

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INTRODUCTION

Natural resources are depleting worldwide at the same time new by products are being generated by various industries which could have a promising future in construction industry as partial or full substitute of either cement or aggregates. Lot of research work has been carried out to use industrial and agricultural waste as substitute for cement, fine aggregate and coarse aggregate. Many slags have cementitious or pozzolanic properties which trigger the researchers to use it in cement or concrete. Copper slag is a by-product obtained during the matte smelting and refining of copper [1-4]. Copper slag finds its use in abrasive tools for sand blasting, roofing granules, cutting tools, abrasives, tiles, glass, filling material in road base construction, railway ballast, asphalt pavements and cement and concrete industries [5, 6]. 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 [7]. 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 [8-14] in concrete depends upon the properties of the material. In the case of construction industry there has been a growing trend toward the use of waste as supplementary cementious materials. The common pozzolanic agent from industry and agriculture by product such as fly ash and rice husk ash are becoming active area of research [15].

Rice husk is one of the main agricultural residues obtained from the outer covering of rice grains during the milling process. It constitutes 20% of the 500 million tons of paddy produced in the world [16]. RHA generally referred to an agricultural by-product of burning husk under controlled temperature of below 800 °C. The process produces about 25% ash containing 85% to 90% amorphous silica plus about 5% alumina, which makes it highly pozzolanic. "Study conducted indicated that concrete with RHA required more water for a given consistency due to its absorptive character of the cellular RHA particles [17]. The partial inclusion of rice husk ash (RHA) for cement is found to be durable, environmental friendly and economically viable [18]. The rice husk ash had no useful application and had usually been dumped into water streams and caused pollution and contamination of springs until it was known to be a useful mineral admixture for concrete [19, 20]. Generally, mineral admixtures have a favourable influence on the strength and durability of concrete [21].

Self-compacting concrete is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The use of SCC in concrete structures increasingly has become prevalent in recent years. SCC offers many advantages for the precast, prestressed concrete industry and for cast-in situ construction. 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. 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 [22]. The effect of different mineral additions on the rheology and compressive strength of SCC was studied [23-26].

Many researchers have been studied on using copper slag and RHA, in the production of normal and high strength concrete, not much research have been carried out on SCC with slag and RHA replacement. In this present work SCC mix was prepared with 10 and 20 % fine aggregate replaced with cu slag, and cement replaced with RHA in the range of 1-3%. The fresh and hardened properties of SCC mix with slag, RHA were studied and reported.

MATERIALS

OPC of grade 53 was used in this study. River sand with a specific gravity of 2.66 and fineness modulus of 2.91 was used as the main fine aggregate for this study and copper slag as replacement material. 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 Rice husk, obtained from rice processing mills when properly burnt at temperature lower than 700°C generates rice husk ash (RHA) containing reactive amorphous silica content. The silica content in RHA is approximately 90% and is most suited for use as a Pozzolan to improve the microstructure of the interfacial transition zone (ITZ) between the cement paste and the aggregate in SCC. The

RHA with particle size of 150 μmm was used as a partial replacement of cement in the SCC mixes. The SEM image of RHA is shown in Figure 1. 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 replacement of cement and fine aggregate is 1:1.69:1.86:0.33:0.45. Physical and chemical properties of cement, fine aggregate, coarse aggregate, copper slag, RHA and super plastizer are given in Table 1 & 2.

Table 1: Physical Properties of Ingredients used in SCC

Physical properties	Cement	FA	CA	Cu slag	RHA
Specific gravity (g/cm^3)	3.15	2.77	2.69	3.59	2.11
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	-
Fineness	2 %	-	-	-	-

Table 2: Chemical Properties of cement, Cu slag, RHA

Chemical Properties	Cement	Cu slag	RHA
SiO_2	21.8	25.84	94
Fe_2O_3	3.8	68.29	0.37
Al_2O_3	4.8	0.22	1.2
CaO	68.3	0.15	2.93
Na_2O	0.21	0.58	-
K_2O	0.46	0.28	0.5
Mn_2O_3	0.9	0.22	-
TiO_2	0.25	0.41	-
SO_3	2.2	0.11	0.3
CuO	-	1.2	-
Loss on Ignition	2	6.59	5.81
Insoluble residue	0.4	14.88	-

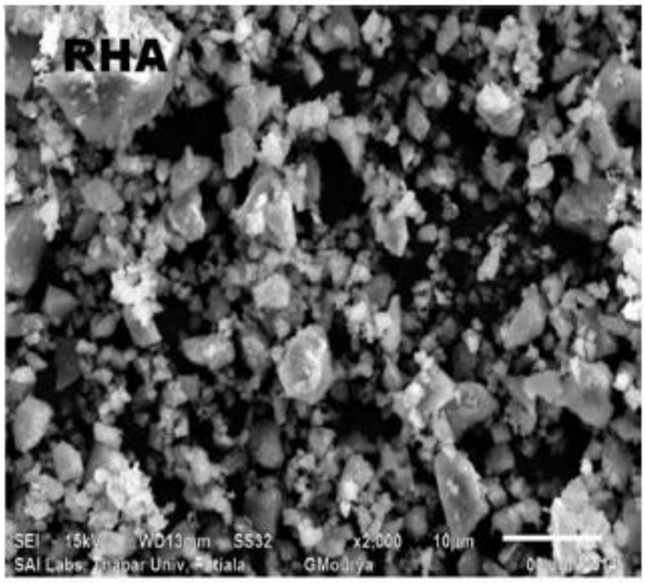

Figure 1 SEM image of Rice Husk Ash [27]

Experimental Investigation

Mix design

Totally 9 mix designs were investigated. Each mixture was made with water cement ratio of 0. 5. Preliminary studies have been done in concrete cubes without copper slag (Control Mix) and i the next study fine aggregate was replaced with copper slag at 10 and 20 % of weight of Sand. In the next stage RHA was used as partial replacement for cement and the effect of RHA on the strength of copper slag SCC 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 RHA (by weight) with a constant w/b ratio of 0. 5. Cubes were cast by replacing cement with 1%, 2%, and 3% of RHA 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. One set of casted specimen are shown in Figure 2

Figure 2 Casted Specimen (one set)

Specimen details

To evaluate the mechanical properties of SCC with cu slag and RHA 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. For nine series of test, totally 81 cubes and 81 cylinders were casted and tested at 7, 14 and 28 days. The designation of each specimen and mix proportions for each mix is given in Table 3and 4.

Table 3: Specimen ID and Replacement details

Specimen Details	Cement (%)	FA (%)	Cu slag (%)	RHA (%)
SCC (M50)	100	100	-	-
$C10_S0_{RHA}$	100	90	10	-
$C10_S1_{RHA}$	99	90	10	1
$C10_S2_{RHA}$	98	90	10	2
$C10_S3_{RHA}$	97	90	10	3
$C20_S0_{RHA}$	100	80	20	-

$C20_{S}1_{RHA}$	99	80	20	1
$C20_{S}2_{RHA}$	98	80	20	2
$C20_{S}3_{RHA}$	97	80	20	3

Table 4: Mix proportions for Control specimen and SCC with slag and RHA replacement

Specimen Details	Cement (Kg)	FA (Kg)	CA (Kg)	Cu slag (Kg)	Fly Ash (Kg)	RHA (Kg)	Water (Liters)	Super plasticizer (ml)
SCC (M50)	15.18	25.625	28.325	-	5.062	-	6.95	136
$C10_{S}0_{RHA}$	12.15	18.48	22.66	2.05	4.05	-	5.75	98
$C10_{S}1_{RHA}$	12.03	18.48	22.66	2.05	4.05	0.122	5.75	98
$C10_{S}2_{RHA}$	11.91	18.48	22.66	2.05	4.05	0.244	5.75	98
$C10_{S}3_{RHA}$	11.78	18.48	22.66	2.05	4.05	0.366	5.75	98
$C20_{S}0_{RHA}$	12.15	16.4	22.66	4.1	4.05	-	5.75	98
$C20_{S}1_{RHA}$	12.03	16.4	22.66	4.1	4.05	0.122	5.75	98
$C20_{S}2_{RHA}$	11.91	16.4	22.66	4.1	4.05	0.244	5.75	98
$C20_{S}3_{RHA}$	11.78	16.4	22.66	4.1	4.05	0.366	5.75	98

SCC fresh concrete 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

Table 4: Acceptance limit for SCC as per codal provision (EFNARC)

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
U-Box (passing Ability)	H_2-H_1	0	30

Passing Ability 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.

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 4) 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 H_1 and the height of the concrete at the other face was noted as H_2. The ration between H_1 and $H_2$was calculated as blocking ratio.

Figure 3 J-ring pasty phase test

Figure 4 L - Box Test

Figure 5 V-Funnel Test

Flow Ability 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 5) 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.

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 H_1 and H_2.

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 RHA

Specimen ID	Slump Flow Test		V-Funnel test (sec)	J-Ring (sec)	L-Box	U-Box	Remark
	Slump (mm)	T_{50} slump (sec)					
SCC	680	2	1.6	4	0.12	0	satisfied

$C10_{S}0_{RHA}$	720	2.6	1.9	5	0.15	0.5	satisfied
$C10_{S}1_{RHA}$	715	2.5	1.7	6	0.18	7	satisfied
$C10_{S}2_{RHA}$	688	3.6	1.5	7	0.29	16.5	satisfied
$C10_{S}3_{RHA}$	580	4.5	1.3	8	0.37	Blocking	-
$C20_{S}0_{RHA}$	670	8	1.6	7	0.19	0.1	satisfied
$C20_{S}1_{RHA}$	700	4.4	2.4	8	0.17	0	satisfied
$C20_{S}2_{RHA}$	682	2.7	1.5	8	0.16	1	satisfied
$C20_{S}3_{RHA}$	590	2.9	1.8	10	0.3	Blocking	-

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 cylinders were for tested for Split tensile strength.

Compression test

The compressive strength test of self compacting concrete specimens with different replacement level of copper slag and RHA 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

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
$C10_{S}0_{RHA}$	7.94	32.9	47.3	57
$C10_{S}1_{RHA}$	7.8	40.4	54.6	59.5
$C10_{S}2_{RHA}$	7.78	46.9	54.6	61.6
$C10_{S}3_{RHA}$	7.87	40.8	47.8	53.2
$C20_{S}0_{RHA}$	7.97	34.3	48.2	59.2
$C20_{S}1_{RHA}$	7.9	43.5	54.3	61.2
$C20_{S}2_{RHA}$	7.96	46.5	59.5	62
$C20_{S}3_{RHA}$	8.01	39.5	48.3	57.3

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 RHA replacement were presented in Table 5. All the SCC exhibited satisfactory slump flow in the range of 500-800 mm. All the fresh concrete properties were in good agreement with the codal values listed in Table 4. Workability was found to be low for SCC with maximum percentage of RHA replacement i.e $C20_{S}$ 3_{RHA}. Therefore the workability decreases with the increase in RHA content.

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 RHA 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 RHA 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 RHA 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 RHA in 20 % slag concrete at 7, 14 and 28 days of curing.

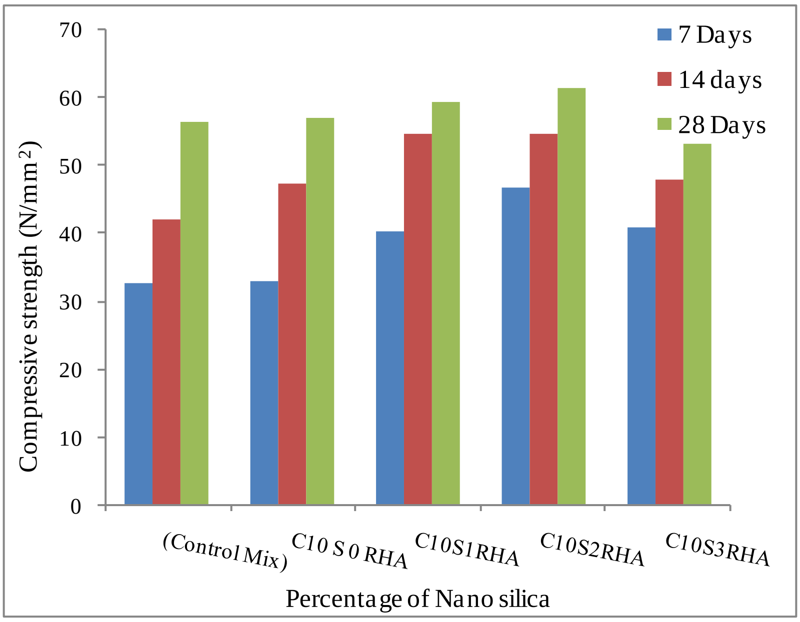

Figure 6 Compressive strength of 10 % cu slag SCC with different percentage of Nano silica

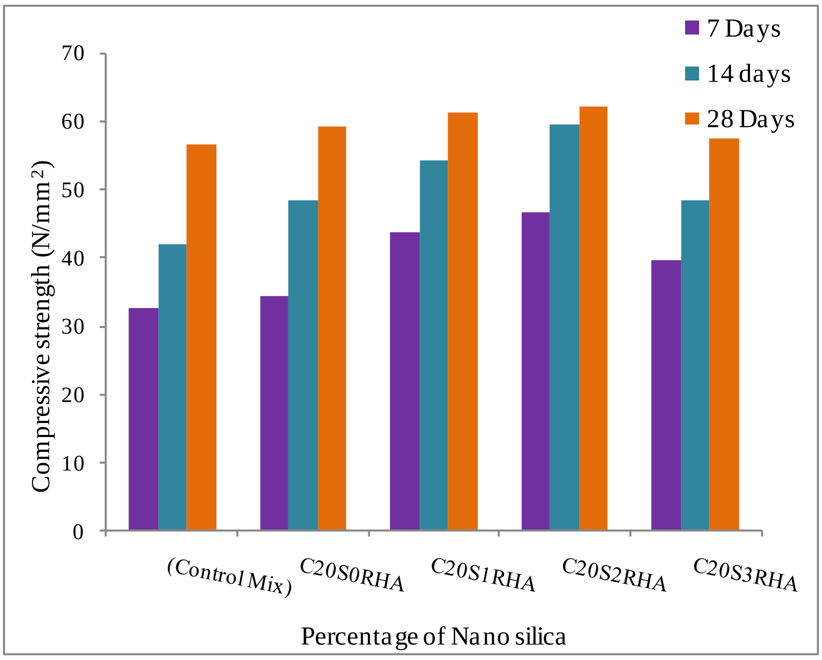

Figure 7 Compressive strength of 20 % cu slag SCC with different percentage of Nano silica

SCC mix developed compressive strength between 32-40 MPa for 7 days and 57-60 MPa for 28n days. Compressive strength increases with increase in percentage of RHA up to 2 % replacement after that there is a slight decrease in the strength. The highest level of long term compressive strength was developed for mix with 10 % slag and 2 % RHA ($C10_S2_{RHA}$). Compressive strength of SCC blended with RHA is higher compared to control mix. However it decreases with the increase in the percentage replacement of RHA. The improvement in the compressive strength is mainly due to the micro filling ability and pozzolanic activity of RHA. It reacts with calcium hydroxide and produces C-S-H gel, which help to reduce the porosity of concrete and improves the microstructure of concrete, and thereby increasing the compressive strength.

Table 7: 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
$C10_S0_{RHA}$	12.98	1.65	3.15	4.62
$C10_S1_{RHA}$	12.92	2.53	3.74	4.77
$C10_S2_{RHA}$	12.9	2.65	4.1	5.1
$C10_S3_{RHA}$	12.8	2.23	3.65	4.75
$C20_S0_{RHA}$	13	2.12	3.15	4.79
$C20_S1_{RHA}$	12.82	2.95	4.1	5.18
$C20_S2_{RHA}$	12.7	3.25	4.56	5.26
$C20_S3_{RHA}$	12.9	2.45	4.2	4.75

The splitting tensile strength of all the nine mixes is tabulated in Table 7. 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 $C10_S2_{RHA}$, $C20_S1_{RHA}$ and $C20_S2_{RHA}$ showed an increase in splitting tensile strength compared to the control mix.

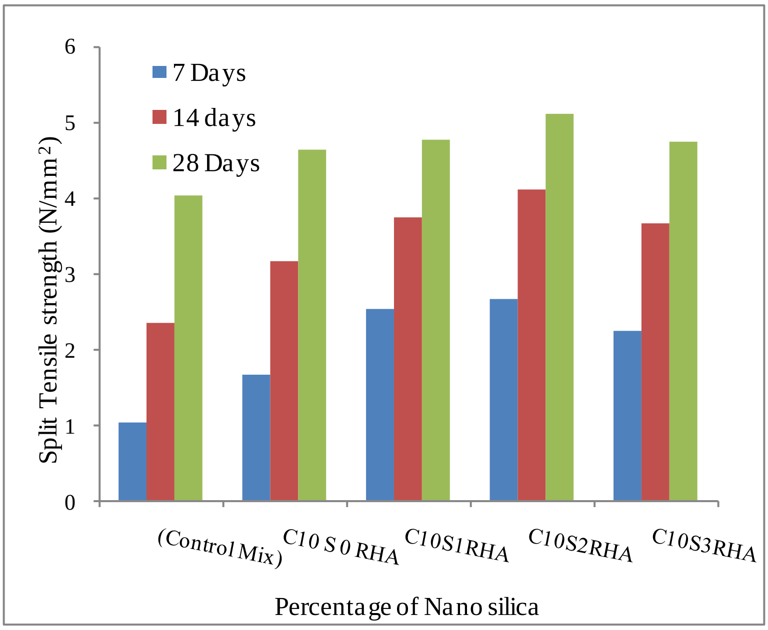

Figure 8 Split tensile strength of 10 % cu slag SCC with different percentage of Nano silica

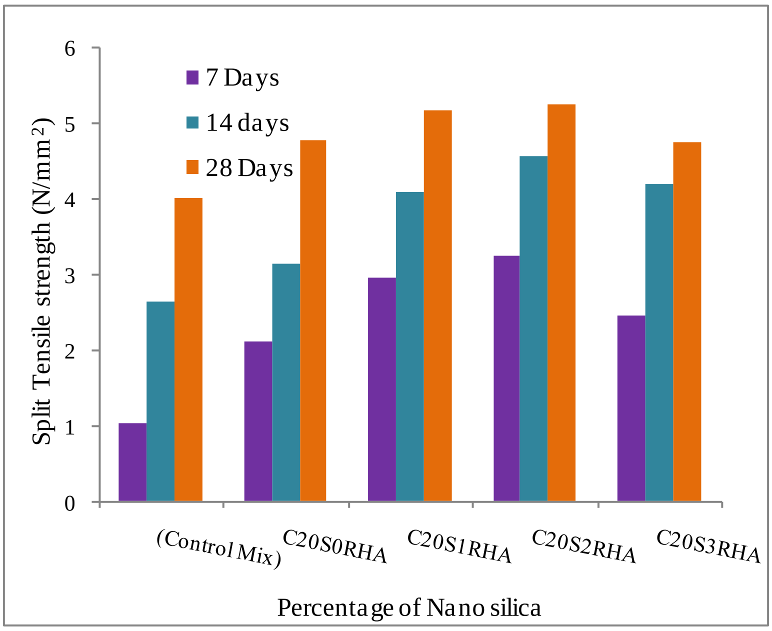

Figure 9 Split tensile strength of 20 % cu slag SCC with different percentage of Nano silica

CONCLUSION

Replacement of cement by RHA as a supplementary cementitious material, has positive effect on Cu slag replaced self-compacting concrete. Fresh properties results showed that workability decrease with increase in amount of RHA. Lowest workability was obtained by the mix containing 3 % RHA. Increases of about 44% strength at 7 d, 30% strength at 14 d and 9% strength at 28 d were observed with increases in RHA content from control mix to 10% slag and 2 % RHA cement replacement. Compressive strength of RHA replaced concrete increases with the increase in RHA percentage upto 2% replacement level, but the strength slightly decreases after that. The improvement in the compressive strength is mainly due to the micro filling ability and pozzolanic activity of RHA. A similar trend was shown for the split tensile strength. Split tensile strength increased up to 2 % replacement of cement by RHA.

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