Effect of Effective Porosity and Saturated Water Absorption on Rice Husk Ash-Filtered Sand Self-Compacting Concrete

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Abstract- *Experiments were conducted to study the effect of rice husk ash and filtered sand on the durability properties such as effective porosity and saturated water absorption. In this study M_{70} grade concrete with rice husk ash, filtered sand and superplasticizer were used. Cement and sand was replaced at the levels of 5%, 10%, 15%, 20% and 25%, 50%, 75%, 100% respectively. From the test results, it was observed that rice husk ash SCC and rice husk ash filtered sand SCC has shown better performance than conventional concrete.*

Keywords:

Durability, Self-Compacting Concrete (SCC), Rice Husk Ash (RHA), Filtered Sand (FS)

1.0 INTRODUCTION

Concrete is a widely used construction material for various types of structures due to structural stability and strength. All the materials required producing such huge quantities of concrete come from the earth's crust. Thus, it deflects its resources every year creating ecological strains. On the other hand, human activities on earth produce solid wastes in considerable quantities of over 2500/MT per year, including industrial wastes, agricultural wastes and wastes from rural and urban societies. Recent technological development has shown that these materials are valuable as inorganic and organic resources and can produce various useful products. Amongst the solid wastes, the most prominent ones are fly ash, blast furnace slag, rice husk ash, silica fume and demolished construction materials.

From the middle of 20th century, there had been an increase in the consumption of mineral admixtures by the cement and concrete industries. This increasing demand for cement and concrete is met by partial cement replacement. Substantial energy and cost savings can result when industrial by-products are used as a partial replacement for the energy intense Portland cement. The use of by-products is an environmental–friendly method of disposal of large quantities of materials that would otherwise pollute land, water and air. The current cement production rate of the world, which is approximately 1.2 billion tones/year, is expected to grow exponentially to about 2 billion tones/year by 2015. Most of the increase in demand will be met by the use of supplementary cementing materials.

Prior to 1970, RHA was usually produced by uncontrolled combustion and the ash so produced was crystalline and possessed poor pozzolanic properties. In 1973, Mehta published the first of several papers describing the effect of pyro processing parameters on the pozzolanic reactivity of RHA. Based on his research, Pitt designed a fluidized bed furnace for controlled burning of rice husks. By burning the rice husks under a controlled temperature and atmosphere, a highly reactive RHA was obtained. The utilization of RHA as a pozzolanic material in cement and concrete provides several advantages, such as improved strength and durability properties, reduced materials cost due to cement savings and environmental benefits related to the disposal of waste materials.

The main components of concrete are cement, sand & coarse aggregate. The production of cement adds pollution to the environment is a well-known fact to civil engineers. River sand which is used as fine aggregate is becoming very scarce, sand mining is discouraged to save the rivers of our country. Because of these environmental and economic reasons it requires thinking about the use of industrial wastes as alternative materials in concrete production, which not only reduce the cost of production of concrete but also controls the pollution relatively.

Rice plant is one of the plants that absorbs silica from the soil and assimilates it into its structure during the growth (Smith et al., 1986). Rice husk is the outer covering of the grain of rice plant with a high concentration of silica, generally more than 80-85%.

Surface soils from tank beds, agricultural fields and village common lands have been excavated and washed to produce a kind of artificial sand in order to meet the enormous demand known as filtered sand. Only source materials with suitable strength, durability and shape characteristics should be considered. Production generally involves screening and possible washing. Separating into discrete fractions, recombining and blending may be necessary.

Therefore the utilization of Rice Husk Ash (RHA) & Filtered Sand (FS) in concrete for the replacement of cement & sand, environmentally and economically advantageous. In the present study Portland cement and sand was replaced by RHA and FS at various percentages to study strength and durability properties like saturated water absorption, effective porosity.

2.0 EXPERIMENTAL PROGRAMME

2.1 Materials used

Cement: ordinary Portland cement of 53 grade confirming to IS: 12269-1987 was used for the present experimental investigation. The cement was tested as per the Indian standards IS: 4031-1988. The test results are given in Table 1.

Sl.No	PROPERTIES	Obtained Values	Requirement as per IS -12269
1	Fineness	2.59	Not more than 10%
2	Soundness	1.00 mm	Not more than 10 mm
3	1.Initial Setting Time	71.00 min	Not less than 30 min
	2. Final Setting Time	438.00 min	Not more than 600 min
4	Compressive strength	53.36 N/mm^2	Not less than 53 N/mm^2
5	Standard Consistency	31%	
6	Specific Gravity	3.12	

Table 1: Physical Properties of Cement

Fine Aggregates: Natural river sand as per IS: 383-1987 was used. The physical properties and sieve analysis of fine aggregate are presented in Table 2.

Sl.No	Properties	Results
1	Fineness Modulus	2.855
2	Specific Gravity	2.62
3	Water Absorption	1.0%
4	Zone	II

Table 2: Physical Properties of Fine Aggregates (Natural Sand)

Filtered Sand IS: 383-1987 was used. The physical properties obtained on conducting sieve analysis and specific gravity tests for Filter Sand and for different replacement levels of sand by Filter Sand is presented in Table 3. The amount of silt content in sand to be used in concrete should be less than 5% according to codal provisions (IS 383). If the amount of silt content is higher than 5% affects the strength of concrete. Hence the amount of silt content in the present filtered sand is investigated by using Hydrometer test (Table 4).

Sl. No	Fine Aggregate	Specific Gravity	Fineness Modulus	Zone
Fine Aggregate (NS+FS)				
1	100% sand+0%FS	2.62	2.855	Zone II
2	75% sand+25% FS	2.61	3.76	Zone II
3	50% sand+50% FS	2.19	3.51	Zone II
4	25% sand+75% FS	2.22	3.42	Zone II
5	0% sand+100% FS	2.46	3.40	Zone II

Table 3: Test Results of Fine Aggregates (Natural sand & Filtered sand)

% of Filter Sand	% of Silt	% of Clay	% of Finer Sand
25	14.3	39.19	46.51
50	28.8	38.29	32.91
75	42.5	32.10	25.40
100	49.87	24.87	25.26

Table 4: Hydrometer Test Results

Coarse Aggregates: Crushed Granite jelly of size 12.5mm down confirming to IS: 383-1987 was used (Table 5).

Sl. No	Particulars of the test	Results
1.	Fineness modulus	6.54
2.	Specific Gravity	2.65

Table 5: Physical characteristics of Coarse Aggregates (12.5 mm down size)

Rice Husk Ash: The rice husk ash obtained from Maddur (Mandya dist.). RHA used for investigation have tested in the Civil Aid and the chemical characteristics are given in Table 6.

Sl.No	Test Conducted	Results	Requirements as per IS:3812:2003	
			Siliceous Pulverized Fuel Ash	Calcareous Pulverized Fuel Ash
1	Silicon Dioxide(SiO_2)+Aluminum oxide(Al_2O_3)+iron oxide Fe_2O_3),Percentage by mass(min)	98.92%	70%	50%
2	Silicon dioxide(SiO_2),Percentage by mass(min)	94.08%	35%	25%
3	Magnesium oxide(Mgo),percent by mass,(max)	0.18%	5%	5%
4	Total Sulphur as sulphur trioxide(SiO_3),Percentage by mass(max)	0.29%	3%	3%
5	Calcium oxide percentage by mass,(Cao)	0.28%	5%	5%

Table 6: Chemical characteristics of Rice Husk Ash

Superplasticizer: Polycarboxylic ether based super plasticizer Glenium 6100 has been used in present research work.

2.2 Mix Proportioning

For the present investigation, High strength self-compacting concrete of grade M_{70} was aimed. To achieve this grade of concrete, OKAMURA (JAPANESE) METHOD of mix design was used.

NOTE: [C.SCC - Convention Self Compacting Concrete with only Cement & Natural Sand without RHA & FS].

The mix proportions obtained for C.SCC of M_{70} grade is 1:1.12:1.17 is been replaced by RHA & FS in place of cement & natural sand by different percentages, which is tabulated in Table 7.

Note: C.SCC-Conventional Concrete (0%RHA, 0%FS);
A Series-5% RHA; B Series-10% RHA; C Series-15% RHA; D Series-20% RHA;
A_o A_1 A_2 A_3 A_4 – 5% RHA, (100%NS+0%FS, 75%NS+25%FS, 50%NS+50%FS, 25%NS+75%FS, 0%NS+100%FS);
B_o B_1 B_2 B_3 B_4 – 10% RHA, (100%NS+0%FS, 75%NS+25%FS, 50%NS+50%FS, 25%NS+75%FS, 0%NS+100%FS);
C_o C_1 C_2 C_3 C_4 – 15% RHA, (100%NS+0%FS, 75%NS+25%FS, 50%NS+50%FS, 25%NS+75%FS, 0%NS+100%FS);
D_o D_1 D_2 D_3 D_4 – 20% RHA, (100%NS+0%FS, 75%NS+25%FS, 50%NS+50%FS, 25%NS+75%FS, 0%NS+100%FS).

Mix	Cement		RHA		NS		FS		CA		Water	SP	
	% age	Wt in Kgs	% age	Wt in Kgs	% age	Wt in Kgs	% age	Wt in Kgs	% age	Wt in Kgs	Water in Ltrs	% age	SP in ml
[illegible]	100	649.0	0	0	100	726.6	0	0	100	759.5	208.0	0.8	5192
A_0	95	616.5	5	32.4	100	726.6	0	0	100	759.5	208.0	0.8	5192
A_1	95	616.5	5	32.4	75	545.0	25	181.6	100	759.5	208.0	0.8	5192
A_2	95	616.5	5	32.4	50	363.3	50	363.3	100	759.5	208.0	0.8	5192
A_3	95	616.5	5	32.4	25	181.6	75	545.01	100	759.5	208.0	0.8	5192
A_4	95	616.5	5	32.4	0	0	100	726.6	100	759.5	208.0	0.8	5192
B_0	90	584.1	10	64.9	100	726.6	0	0	100	759.5	208.0	0.8	5192
B_1	90	584.1	10	64.9	75	545.0	25	181.6	100	759.5	208.0	0.8	5192
B_2	90	584.1	10	64.9	50	363.3	50	363.3	100	759.5	208.0	0.8	5192
B_3	90	584.1	10	64.9	25	181.6	75	545.0	100	759.5	208.0	0.8	5192
B_4	90	584.1	10	64.9	0	0	100	726.6	100	759.5	208.0	0.8	5192
C_0	85	551.6	15	97.3	100	726.6	0	0	100	759.5	208.0	0.8	5192
C_1	85	551.6	15	97.3	75	545.0	25	181.6	100	759.5	208.0	0.8	5192
C_2	85	551.6	15	97.3	50	363.3	50	363.3	100	759.5	208.0	0.8	5192
C_3	85	551.6	15	97.3	25	181.6	75	545.0	100	759.5	208.0	0.8	5192
C_4	85	551.6	15	97.3	0	0	100	726.6	100	759.5	208.0	0.8	5192
D_0	80	519.2	20	129.8	100	726.6	0	0	100	759.5	208.0	0.8	5192
D_1	80	519.2	20	129.8	75	545.0	25	181.6	100	759.5	208.0	0.8	5192
D_2	80	519.2	20	129.8	50	363.3	50	363.3	100	759.5	208.0	0.8	5192
D_3	80	519.2	20	129.8	25	181.6	75	545.0	100	759.5	208.0	0.8	5192
D_4	80	519.2	20	129.8	0	0	100	726.6	100	759.5	208.0	0.8	5192

Table 7: Mix proportions of RHA-FS SCC and Conventional SCC per m^3 by weight

3.0 TESTING OF SCC

It is important to mention that none of the test methods for SCC have yet been standardized and included in Indian Standard Code for the present. The following are some of the features of SCC mentioned in Indian standard code IS: 456-2000.

1. Slump flow: Minimum 600mm.

2. Sufficient amount of fines (<12.5mm) preferably in the range of 400kg/m^3 to 600kg/m^3.This can be achieved by having sand content more than 38% and using mineral admixture to the order of 25% to 50% by mass of cementitious materials.

3. Use of high range water reducing (HRWR) admixture and viscosity modifying agent (VMA) in appropriate dosages are permitted.

European guidelines for testing, covers number of parameters ranging from material selection, mixture design and testing methods like slump flow test, L-box test and V-funnel test as recommended by EFNARC for determining properties of SCC in fresh state. Most of Indian researchers are following these guidelines to determine the rheological properties of SCC mixes.

4.0 TESTING METHODS OF SCC

Different methods have been developed to characterize the rheological properties of SCC. No single method has been found until date, which characterizes all the relevant workability aspects. Each mix has been tested by more than one test method for the different workability parameters. Following are the tests recommended by European guidelines.

A. Slump flow test- The slump flow test is used to assess the horizontal flow of SCC in the absence of obstructions. The test also indicates resistance to segregation. On lifting the slump cone, filled with concrete the average diameter of spread of the concrete is measured. It indicates the filling ability of the concrete.

B. V-funnel test- The flowability test of the fresh concrete can be tested with the V-funnel test, where by the flow time is measured. The funnel is filled with about 22kgs of concrete and the time taken for it to flow through the apparatus is measured. Shorter flow time indicate greater flowability.

C. L-Box test- This is a widely used test, suitable for laboratory and site use. It accesses filling and passing ability of SCC and serious lack of suitability can be detected visually. The vertical section of the L-box is filled with concrete, and then the gate is lifted to let the concrete flow into the horizontal section. Blocking ratio, it indicates passing ability of concrete or the dosage to which the passage of concrete through the bars is restricted.

5.0 TESTS CONDUCTED:

5.1 Saturated Water Absorption and Effective Porosity:

The water absorption and porosity values for various mixtures of concrete were determined on 100mm cubes as per ASTM C 642. The specimens were taken out of curing tank at 28 and 56 days to record the water saturated weight 'W_s'. The drying was carried out in an oven at a temperature of 105°C. The drying process was continued until the difference between two successive measurements agreed close. Oven-dried specimens were weighed after they cooled to room temperature 'W_d'. Using these weights, saturated water absorption (SWA) was calculated.

Saturated water absorption, SWA = $[(W_s \pm W_d)/W_d] \times 100$

Where; W_s = Weight of the specimen at fully saturated condition in kg

W_d = Weight of oven dried specimen in kg

The porosity obtained from absorption test is designated as Effective porosity. It is determined by using the formula,

Effective porosity = (Volume of voids/Bulk volume of specimen) x 100

The volume of voids was obtained from the volume of water absorbed by an oven dry specimen or the volume of water lost on oven drying of a water saturated specimen at 105°C to constant mass. The volume of specimen is given by the difference in mass of the specimen in air and it's mass under submerged condition in water.

6.0 RESULTS AND DISCUSSIONS

The slump flow characteristics, V-funnel & L-box of the mixtures satisfies the EFNARC requirement. Slump flow decreases with increase in RHA content along with FS. The RHA indicates the increase in the viscosity of concrete. The blocking ratio in L-box test were as per requirement of SCC mixes as laid down by EFNARC guidelines. The results are presented in Table 8.

Sl.No	Designation	Slump Values, mm	EFNARC Values	T_{500}, Slump	EFNARC Values	V-Funnel, Sec	EFNARC Values	H2/H1 Ratio	EFNARC Values
1	C.SCC	768		2.95		8.54		0.95	
2	A0	760		3.18		8.72		0.84	
3	A1	743		3.23		9.12		0.81	
4	A2	725		3.29		9.16		0.92	
5	A3	708		3.68		9.34		0.87	
6	A4	694		4.05		9.51		0.81	
7	B0	690		3.32		9.36		0.88	
8	B1	683		3.41		9.52		0.87	
9	B2	680	650-800 mm	3.62	2-5 Secs	9.48	6-12 Secs	0.89	0.8-1.0
10	B3	676		3.91		9.56		0.87	
11	B4	672		3.98		9.66		0.86	
12	C0	686		3.94		9.32		0.90	
13	C1	681		4.01		9.50		0.86	
14	C2	673		4.17		9.52		0.92	
15	C3	670		4.23		9.60		0.90	
16	C4	661		4.47		9.88		0.90	
17	D0	680		4.17		10.09		0.92	
18	D1	672		4.36		10.26		0.90	
19	D2	666		4.64		10.36		0.93	
20	D3	658		4.92		10.44		0.92	
21	D4	653		5.12		10.83		0.86	

Table 8: Test results of Fresh concrete

The fresh concrete properties compared to EFNARC specifications, the slump obtained from RHA-FS SCC is between 768 mm to 653mm. The V-Funnel time obtained from RHA-FS SCC is between 2.95 sec to 5.12 sec. The H_2/H_1 ratio obtained from RHA–FS SCC is between 0.945 to 0.862.The fresh concrete properties of RHA-FS SCC obtained are within the EFNARC specifications.

6.1 Saturated Water Absorption and Effective Porosity

Sl. no	Concrete	Percentage Replacement of		Designation	%age of SWA for different curing periods	
		RHA	FS		28 Days	56 Days
1	C.SCC	0%	0%	C.SCC	3.800	4.650
2	RHA-FS SCC (with 5% RHA & different levels of FS)	0%	0%	A_0	2.967	3.800
3		0%	0%	A_1	3.291	3.870
4		0%	0%	A_2	3.631	3.960
5		0%	0%	A_3	3.791	4.000
6		0%	0%	A_4	3.795	4.110
7	RHA-FS SCC (with 10% RHA & different levels of FS)	0%	0%	B_0	2.143	3.210
8		0%	0%	B_1	2.391	3.340
9		0%	0%	B_2	2.669	3.450
10		0%	0%	B_3	2.679	3.500
11		0%	0%	B_4	2.801	3.801
12	RHA-FS SCC (with 15% RHA & different levels of FS)	0%	0%	C_0	2.094	2.401
13		0%	0%	C_1	2.143	2.450
14		0%	0%	C_2	2.222	2.660
15		0%	0%	C_3	2.281	2.890
16		0%	0%	C_4	2.324	3.000
17	RHA-FS SCC (with 20% RHA & different levels of FS)	0%	0%	D_0	1.681	1.960
18		0%	0%	D_1	1.685	2.000
19		0%	0%	D_2	1.769	2.120
20		0%	0%	D_3	2.086	2.340
21		0%	0%	D_4	2.148	2.500

Table 9: SWA of Conventional SCC mixes (C.SCC) & RHA-FS SCC with different replacement levels of RHA and FS for curing periods of 28 and 56 days

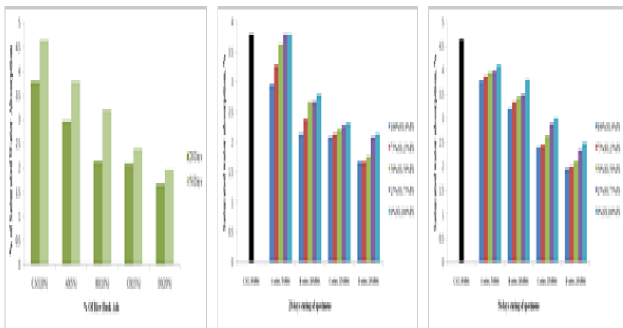

Fig 1: Comparison of SWA of conventional SCC (C.SCC) & RHA-FS SCC with different replacement levels of RHA and 0% of FS and with different replacement levels of FS for curing periods of 28 and 56 days

Sl. no	Concrete	Percentage Replacement of		Designation	%age of EP for different curing periods	
		RHA	FS		28 Days	56 Days
1	C.SCC	0%	0%	C.SCC	4.130	5.400
2	RHA-FS SCC (with 5% RHA & different levels of FS)	0%	0%	A_0	3.650	4.330
3		0%	0%	A_1	3.700	4.640
4		0%	0%	A_2	3.710	4.680
5		0%	0%	A_3	3.850	4.800
6		0%	0%	A_4	4.150	5.110
7	RHA-FS SCC (with 10% RHA & different levels of FS)	0%	0%	B_0	2.900	3.890
8		0%	0%	B_1	3.000	3.900
9		0%	0%	B_2	3.430	4.210
10		0%	0%	B_3	3.601	4.610
11		0%	0%	B_4	4.100	4.900
12	RHA-FS SCC (with 15% RHA & different levels of FS)	0%	0%	C_0	2.000	3.148
13		0%	0%	C_1	2.160	3.240
14		0%	0%	C_2	2.390	3.500
15		0%	0%	C_3	2.850	3.950
16		0%	0%	C_4	2.900	4.200
17	RHA-FS SCC (with 20% RHA & different levels of FS)	0%	0%	D_0	1.480	2.490
18		0%	0%	D_1	1.560	2.640
19		0%	0%	D_2	1.880	2.880
20		0%	0%	D_3	1.950	2.950
21		0%	0%	D_4	2.400	3.640

Table 10: Effective porosity of Conventional SCC mixes (C.SCC) & RHA-FS SCC with different replacement levels of RHA and FS for curing periods of 28 and 56 days

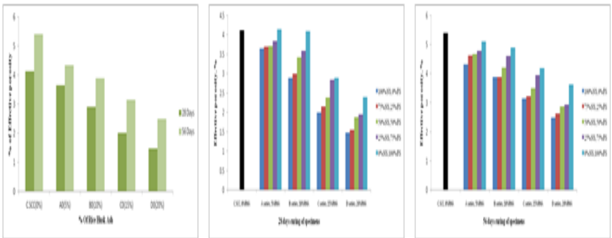

Fig 2: Comparison of EP of conventional SCC (C.SCC) & RHA-FS SCC with different replacement levels of RHA and 0% of FS and with different replacement levels of FS for curing periods of 28 and 56 days

Saturated water absorption (SWA) of C.SCC and RHA-FS SCC specimens.

In SCC with or without RHA the percentage of saturated water absorption (SWA) is quiet higher at 56 days of curing period when compared to 28 days of curing period.

The percentage of SWA in RHA-FS SCC decreases with the increase in RHA content when compared to C.SCC.

The replacement of sand by FS in RHA-FS SCC influences in increase of the SWA.

The SWA of RHA-FS SCC for different replacement level of FS from 0% to 100% with 5%, 10%, 15% and 20% of RHA varies between 3.8-4.1%, 3.2-3.8%, 2.4-3.0% and 1.96-2.5% respectively.

Hence the partial replacement of cement by RHA decreases the SWA in RHA-FS SCC, as small RHA particles improved the particle packing density of the concrete mix leading to a reduced volume of larger pores.

But the partial replacement of NS by FS increases the SWA may be due to the presence of silt content in FS increases the SWA.

<u>Effective Porosity (EP) of C.SCC and RHA-FS SCC specimens.</u>

In SCC with or without RHA the percentage of effective porosity is quiet higher at 56 days of curing period when compared to 28 days of curing period.

The percentage of effective porosity in RHA-FS SCC decreases with the increase in RHA content when compared to C.SCC.

The replacement of sand by FS in RHA-FS SCC influences in increase of the effective porosity due to the presence of silt content in it.

The effective porosity of RHA-FS SCC for different replacement level of FS from 0% to 100% with 5%, 10%, 15% and 20% of RHA varies between 4.3-5.1%, 3.89-4.9%, 3.148-4.2% and 2.4-3.6% respectively.

Hence the partial replacement of cement by RHA in RHA-FS SCC decreases the effective porosity, as small RHA particles improved the particle packing density of the concrete mix leading to a reduced volume of larger pores.
But the partial replacement of NS by FS increases the EP may be due to the presence of silt content in FS increases the EP.

7.0 CONCLUSIONS

- ✓ RHA contributes in the reduction of agricultural waste that is the main cause of environmental problems in agricultural countries. On the other hand, it is an approach to improve the quality of concrete without using costly additives such as silica fume, GGBFS etc.

- ✓ Due to the presence of RHA in SCC along with FS, the required strength of SCC is obtained to actual values, after 56 days of curing unlike normal concrete which attains the strength at 28days.

- ✓ The presence of RHA reduces the slump, with the increase in quantity of RHA in SCCs the reduction in slump also increases. The addition of FS along with RHA further reduces the slump. For D_4-Mix (20% RHA+100% FS) the slump reduced frrom768 mm (Conventional SCC mix) to 653 mm.
- ✓ The T_{500} time increases with the increase in percentage of RHA. The presence of FS further increases the T_{500} time i.e., 2.95 sec to 5.12 sec.
- ✓ The increase of RHA affects the consistency of flow of SCC. The presence of FS along with RHA, add to the increase in reduction of consistency of flow.
- ✓ The V Funnel time increases with the increase in percentage of RHA. The presence of FS further increases the V Funnel time.
- ✓ The partial replacement of cement by RHA decreases the SWA and EP in RHA-FS SCC, as small RHA particles improved the particle packing density of the concrete mix leading to a reduced volume of larger pores. But the partial replacement of natural sand by FS increases the SWA and EP may be due to the presence of silt content in FS increases the SWA.
- ✓ The RHA-FS SCC with only replacement of cement by RHA (upto 20%) and without the replacement of natural sand by filter sand decreases the saturated water absorption and effective porosity.
- ✓ Hence the RHA-FS SCC with replacement of cement by RHA is more durable than the RHA-FS SCC with replacement of natural sand by filter sand.

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