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An investigation on properties of sustainable self-compacting concrete with by-products and waste materials

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Abstract:* *This study investigates the effect of using several mineral materials as a partial replacement of ordinary Portland cement (PC) on mechanical properties and durability of self-compacting concrete (SCC). Four types of replacement material were used in the study to produce sustainable SCC, silica fume (SF), rise husk ash (RHA) and two types of blast furnace slag powder (GGBS). The results of tested mixes were compared to control mix (mix with 0% replacement material). The experiments were carried out to determine filling ability, passing ability, segregation resistance on fresh state and mechanical properties, durability on hardened state. The results of properties for fresh and hardened state of mixes containing SF or RHA improved in comparison to control mix. The experimental studies for mixes containing GGBS recorded decline in results of fresh and hardened concrete tests. The optimum levels of replacing PC by RHA and SF was 10% and 20% respectively. These results suggest that RHA acts as highly pozzolanic material.

***Keywords*: Compressive strength, V-funnel, Hardened.**

I. INTRODUCTION

Concrete is one of the most important construction materials worldwide. Cement is the main material in production of concrete. Recently, the cost of cement production substantially increased. Which lead to difficulties in facing the requirements of urban development? On the other hand, the production process of cement increases rate of carbon dioxide emissions and its consequences on environmental pollution. Therefore, new orientations are developing towards using of alternatives to cement totally or partially. The world is moving ahead to the using of wastes as partial replacement of cement in concrete production. The recycling of wastes very important process in order to reduce environmental pollution. Many types of waste materials are usable for replacing cement such as industrial wastes (fly ash, blast furnace) and agriculture wastes (rice husk ash).

Generally, concrete is placed inside the formwork and compacted by a vibrator or a steel bar. Compaction process is necessary to remove the entrapped air and to produce homogeneous concrete with required strength and durability. While SCC is a type of concrete which is compacted without using vibrator. SCC is compacted under its own-weight without vibration. First appearance of self-compacting concrete was in Japan in 1980 but it was firstly used in Sweden in 1990 through European Commission and then it began to spread worldwide [1]. During the last ten years, Egypt and some Arab countries started using SCC as well.

SCC is cohesive enough to avoid segregation and bleeding [2]. Segregation and durability properties of concrete are decreased by reducing voids between aggregate and cement paste [3]. To achieve homogeneity and sustain required fresh state properties in the process of SCC production, the size of aggregate must be reduced and cement content to be increased.

Despite that using SCC appears advantages such as reducing effort of casting, easy placing at dense reinforcement areas and decreasing the construction period, It is necessary to check some of its properties of concrete such as filling ability, passing ability and segregation resistance [3]. The demand on SCC in construction is increasing obviously due to its improved mechanical properties, durability and the additional economic & environmental benefits. However, there are some disadvantages for SCC such as high heat resulting from chemical reactions, increasing creep, shrinkage problems and cost of construction. These disadvantages happened due to increasing cement content in concrete. The problems resulting from increasing cement content can be solved by using some fine materials to replace cement partially [2-3] such as fly ash (FA), GGBS, SF, RHA, etc.

It is very important to study the physical and chemical properties of sustainable materials used in partial replacement of cement in SCC. In addition to studying fresh state properties and hardened state properties extensively as well.

Rice husk is an agricultural waste material consisted as an output of the milling of rice. RHA is produced by burning of rice husk at controlled temperature. The produced RHA contain high percentage of silica exceeds 90% with large surface area. RHA can be used as supplementary material due to its richness with silica. Combination between silica existed in RHA with calcium

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hydroxide has excellent resistance to acidic environments.

There are different researches on the effect of using FA or RHA as a cementitious material in SCC, which studied the effect of added material on fresh and hardened properties of SCC. These studies indicates that the dosage of used RHA is limited by (5-10%) of the weight of cement [3]. Furthermore, other studies were carried out to determine the effect of using RHA by (0-30%) of the total cementitious material on mechanical properties of SCC [4-7]. RHA found to be more cost effective than PC in SCC [1]. Researchers also investigated that SCC has lower durability than normal concrete .SCC is more resistant to corrosion, freeze thaw cycles and sulphate attack [8].

This experimental study investigated the effect of partial replacement of PC by SF, RHA and GGBS on SCC. Cement was replaced by (0-40%) of its weight. The fresh properties, hardened properties were obtained. The fresh properties are filling ability, passing ability and segregation resistance. The hardened properties such as compressive strength, the splitting tensile strength, flexural strength, bond strength, modulus of elasticity and permeability were tested.

II. OBJECTIVES OF THE STUDY

The main objective of this experimental study is to determine the optimum Level for replacing PC by one of used waste materials (SF, RHA, BFSA and BFSW). Also to replace SF completely by RHA and GGBS to produce sustainable SCC.

III. MATERIALS AND METHODS

A. *Materials*

1. *Cement*

Cement used was CEM I 52.5 N with physical and chemical properties shown in Table 1. The cement test was done according to the standard specifications ES4756/1 2013 [9] and BSEN197/1 2011 [10].

Table 1 : Chemical composition and physical properties of OPC and SF

Chemical composition (wt. %)		
	PC	**SF**
Silica (Sio_2)	20.12	97
Alumina (Al_2O_3)	5.95	0.2
Lime (CaO)	62.58	0.2
Ferric oxide (Fe_2o_3)	3.39	0.5
Magnesia (MgO)	2.09	0.2
Sulphuric Anhydride (SO_3)	2.13	0.15
Loss on Ignition (LOI)	1.64	0.7
Physical properties		
Specific gravity	3.15	2.15
Color	Gray	Light gray

2. *Aggregate*

Natural quartzite sand was used as fine aggregate with specific gravity 2.67. Used coarse aggregate was local crushed limestone (dolomite) with maximum nominal size of 13 mm. The main properties of these aggregate were according to the requirements of Egyptian code of practice [11].

3. *Silica fume*

The silica fume used was supplied by the Ferro Silicon Alloys Factory in Edfu, Egypt. The chemical composition and physical properties shown in Table 1. RHA has smaller particle size compared to SF and GGBS.

4. *Rice husk ash*

Rice husk ash obtained from burning the husk under uncontrolled temperature. Experimental tests (EDX and TEM) were applied on produced RHA. This RHA is a kind of mesoporous amorphous siliceous material with 96.2 wt. % silica, pore size range from about 15.28 to 51.9 nm as shown in Figs.1-2.

5. *Blast furnace slag powder*

Blast furnace slag powder obtained from iron industry wastes. Types of blast furnace slag powder are BFSA and BFSW. First type BFSA obtained from slowly air cooled with specific gravity 3.5. Second type BFSW obtained from rapid cooling by water or quenching molten slag with specific gravity 2.6.

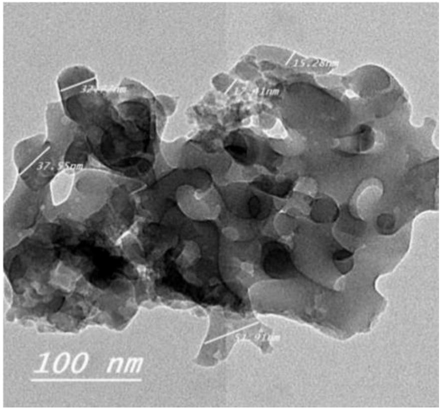
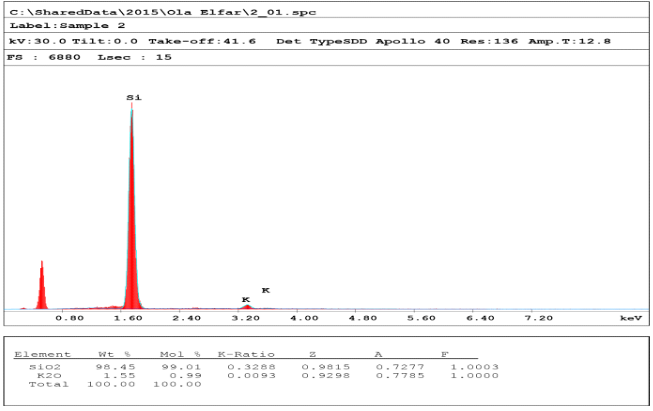


Fig.1: TEM Test



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C:\SharedData\2015\Ola Elfar\2_01.spc
Label:Sample 2
kV:30.0 Tilt:0.0  Take-off:41.6   Det TypeSDD Apollo 40  Res:136  Amp.T:12.8
FS  :  6880   Lsec  :  15
```

```
Element     Wt %      Mol %   K-Ratio       Z           A          F
  SiO2      98.45     99.01   0.3288      0.9815      0.7277     1.0003
   K2O       1.55      0.99   0.0093      0.9298      0.7785     1.0000
  Total    100.00    100.00
```

Fig. 2: EDX Test

6. *Lime stone*

The LSP used in this research was supplied by Tora Company, with specific gravity 2.71

7. *Super plasticizer*

The super plasticizer used in this research is Viscocrete-3425. The super plasticizer (SP) was supplied by Sika Company.

IV. MIX PROPORTIONS

In this study, four by product and waste materials (SF, BFSA and BFSW, RHA) were used as partial replacement material for PC. Table 2 shows proportions and classifications of seventeen mixtures.

The control mix with (0%) replacement material. The quantity of cement used for control mix was 550 kg/m^3.

Four groups of mixes were classified according to type of replacement material.

PC was replaced in each group with percentage varying between (10, 20, and 30 to 40%) by weight of cement. The quantity of SP and LSP and water content kept constant for all mixes. Dosage of SP and LSP was 4% and 15% of cement weight respectively. Water to binder ratio was kept constant at 0.35 of cementitious material for all mixes. All mixtures were compared to the control mix and the comparison was according to fresh and hardened concrete tests.

Fresh concrete tests were determined from slump flow, spread diameter T_{50} cm, J-Ring, V-Funnel, V-funnel T_5 min, Fill box, L-Box and Orimet. While hardened concrete tests were indicated by compressive strength, splitting tensile strength, bond strength, and flexural strength, modulus of elasticity and permeability tests. SCC requires longer time for mixing to assure that all components are mixed properly.

Table 2 : Mixture proportions of self-compacting concrete mixes (kg/m^3)

Mixes	Groups	OPC Content	Aggregate		Fine material				LSP	SP	W
			Fine	Coarse	SF	RHA	BFSA	BFSW			
S0	G0-PC	550	651.3	796	0				82.5	25.3	221.38
S1	G1-SF	495	641.6	784.2	55				82.5	25.3	221.38
S2		440	631.9	772.4	110				82.5	25.3	221.38
S3		385	622.2	760.5	165				82.5	25.3	221.38
S4		330	612.6	748.7	220				82.5	25.3	221.38
S5	G2-RHA	495	643.6	786.6		55			82.5	25.3	221.38
S6		440	635.9	777.2		110			82.5	25.3	221.38
S7		385	530.2	648		165			82.5	25.3	221.38
S8		330	522.5	638.6		220			82.5	25.3	221.38
S9	G3-BFSA	495	653.4	798.6			55		82.5	25.3	221.38
S10		440	655.5	801.1			110		82.5	25.3	221.38
S11		425	747.94	1121.92			165		82.5	25.3	221.38
S12		400	748.79	1123.18			220		82.5	25.3	221.38
S13	G4-BFSW	475	743.64	1115.46				55	82.5	25.3	221.38
S14		450	741.86	1112.79				110	82.5	25.3	221.38
S15		425	740.08	1110.12				165	82.5	25.3	221.38
S16		400	738.3	1107.45				220	82.5	25.3	221.38

V. SAMPLE PREPARATION

Firstly, slump flow, V-funnel, J-ring, Orimet, L-box, and fill-box tests were done on fresh concrete and after that SCC casted in moulds. The equipment used for fresh concrete tests were obtained according to EFNARC [12].The concrete specimens were cured by immersing in water until the day of testing. Compressive strength, splitting strength, flexural strength, bond strength, modulus of elasticity and permeability were determined. Compressive strength test applied on cubic specimen of size (150x150x150mm) after 7, 28, 56 and 91 days. While bond strength, splitting strength and modulus of elasticity were carried out on concrete cylinders (300x150mm) at 28-day age. Flexural strength were tested on beams (500x100x100mm) at 28-day age of concrete. Finally, cubic specimen (150x150 x150 mm) were tested at 28-day age to determine permeability.

VI. RESULTS AND DISCUSSION

A. *Fresh state properties*

The workability, filling ability, passing ability and segregation resistance were represented by slump flow, V-funnel, J-ring, Orimet, l-box, and fill-box tests. The results of these tests were presented in Table 3. All mixes results were compared to control mix.

All results were compared to standard limits of SCC as shown in Table 4. Control mix recoded 650 mm for slump test, 4 sec. for spread T50cm test, 8 sec. for v-funnel test, 5sec. for Orimet test and the difference in height in J-ring is 1cm.

B. *Filling ability*

Filling ability of SCC mixtures indicated by slump flow test, spread diameter T_{50} cm, orimet and v-funnel test. As shown in Table 3 values of these tests for all mixes are within standard limits mentioned in Table 4. When PC was partially replaced by (SF, RHA, BFSA, BFSW), the filling ability of SCC mixtures was slightly increased as shown in Figs 3-6. It's noticed that by increasing percentage of partial replacement of PC by waste materials (SF, RHA, BFSA and BFSW) filling ability increases. Figure 3 which represent slump flow results shows that optimum level for partial replacement of PC by (SF, RHA, BFSA and BFSW) in concrete mixes was 40%. Spread diameter T_{50cm} results show that optimum levels for partial replacement of PC by (SF, RHA, BFSA and BFSW) in concrete mixes were (10, 40, 40 and 30%) respectively as seen in Fig.4. Figure 5 represents v-funnel test results shows that optimum level for partial replacement of PC by (RHA, BFSA and BFSW) was 40% while for SF was 30%. Values of Orimet test show that optimum levels for partial replacement of PC by (SF, RHA, BFSA and BFSW) in concrete mixes were (30, 40, 40 and 30%) respectively as seen in Fig.6. Thus, replacing PC by waste material increase filling ability and workability for mixes.

Table 3 : Results of fresh SCC

Mixes	Group	Test methods							
		Slump flow	T_{50cm}	J-Ring	V-Funnel	V-Funnel T_{5min}	Orimet	Fill box	L-box
		(mm)	(Sec)	(Bj)(cm)	(sec)	(sec)	(sec)	(%)	(h2/h1)
S0	G0-PC	650	4	1	8	11	5	90	0.82
S1	G1-SF	650	3	0.7	7	10	5	90	0.84
S2		680	4	0.6	6	8	5	92	0.85
S3		700	5	0.5	5	4	4	94	0.87
S4		710	5	0.3	6	6	5	95	0.88
S5	G2-RHA	650	5	0.8	7	10	3	90	0.82
S6		670	5	0.7	6	9	5	92	0.83
S7		680	5	0.55	6	8	4	93	0.85
S8		700	3	0.4	5	6	2	94	0.86
S9	G3-BFSA	650	5	0.9	8	11	5	90	0.8
S10		660	5	0.8	7	10	5	90	0.8
S11		670	4	0.65	6	9	5	92	0.8
S12		690	4	0.55	5	7	5	92	0.82
S13	G4-BFSW	650	5	0.85	6	8	5	90	0.83
S14		680	4	0.75	6	8	5	92	0.81
S15		690	3	0.6	5	7	3	92	0.83
S16		700	4	0.5	5	6	4	94	0.84

Table 4 : Performance criteria for fresh state SCC [12]

Test method	Typical range of values	Unit	Property

	min	Max		
Slump flow	650	800	Mm	Filling ability
The spread diameter (T_{50cm})	2	10	Sec	Filling ability
J - Ring	0	10	Mm	Passing ability
Orimet	0	5	Sec	Filling ability
V - Funnel	6	12	Sec	Filling ability
V – Funnel(T_{5min})	0	+3	Sec	Segregation resistance
Fill - Box	90	100	%	Passing ability
L - Box	0.8	1	(h2/h1)	Passing ability

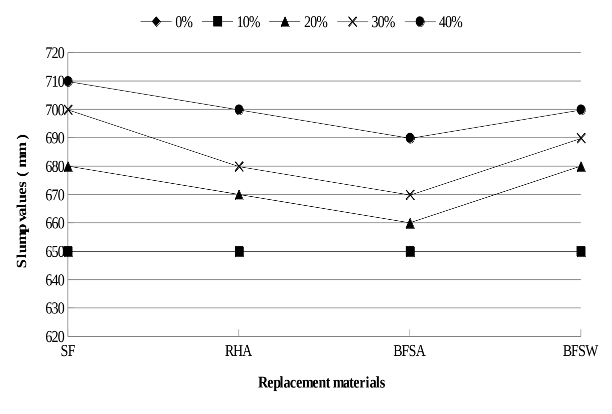

Fig. 3: slump flow values

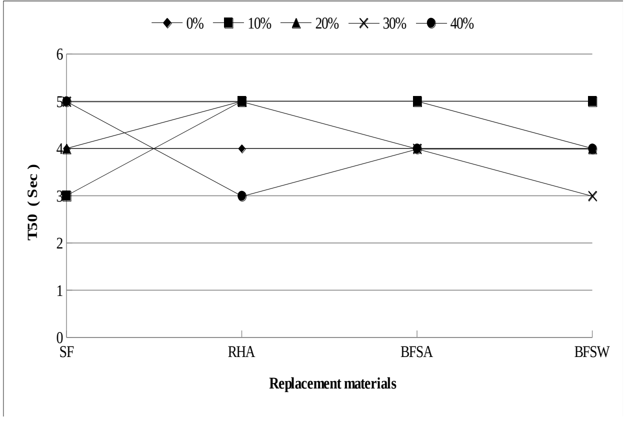

Fig. 4: spread diameter T_{50cm}

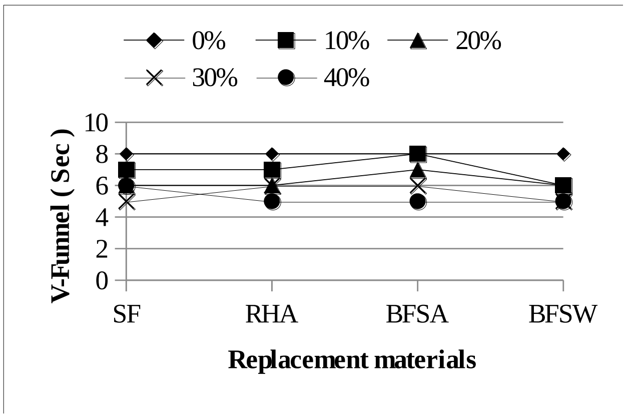

Fig. 5: V-funnel test values

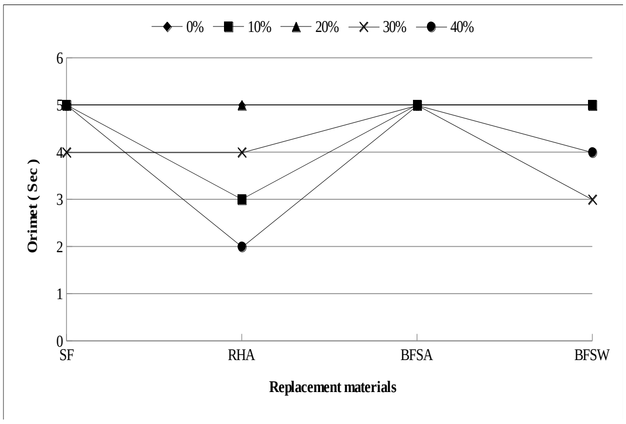

Fig. 6: Orimet value

1. *Passing ability*

Passing ability of SCC mixtures indicated by j-ring test, fill box and l-box test. As shown in Table 3, values of these tests for all mixes are within standard limits mentioned in Table 4. When PC was partially replaced by (SF, RHA, BFSA, BFSW), the passing ability of SCC mixtures slightly increased as shown in Figs 7-9 .These figures show that the passing ability increased by partial replacement of PC with (SF, RHA, BFSA and BFSW) in mixtures. It's also noticed that growing in passing ability occurs with increasing percentage of partial replacement of PC by chosen materials (SF, RHA, BFSA and BFSW). A fig 7-9 shows that optimum level for partial replacement of PC by (SF, RHA, BFSA and BFSW) in concrete mixes was 40%. Thus, partial replacement of PC by waste material increases passing ability for mixes.

2. *Segregation resistance*

Segregation resistance of SCC mixtures indicated by v-funnel (T_{5min}) test. As shown in Table 3, values of test for all mixes are within standard limits in Table 4. When PC is partially replaced by (SF, RHA, BFSA, BFSW), the segregation resistance of SCC mixtures slightly increases as shown in Fig.10. This figure shows that the segregation resistance increases by partial replacement of

PC with (SF, RHA, BFSA and BFSW) in mixtures. It is observed that segregation is reduced by increasing the percentage of partial replacement of PC by waste materials (SF, RHA, BFSA and BFSW). Figure 10 shows that optimum level for partial replacement of PC by (SF, RHA, BFSA and BFSW) in concrete mixes was 40%. Therefore, partial replacement of PC by waste material increases segregation resistance for mixes.

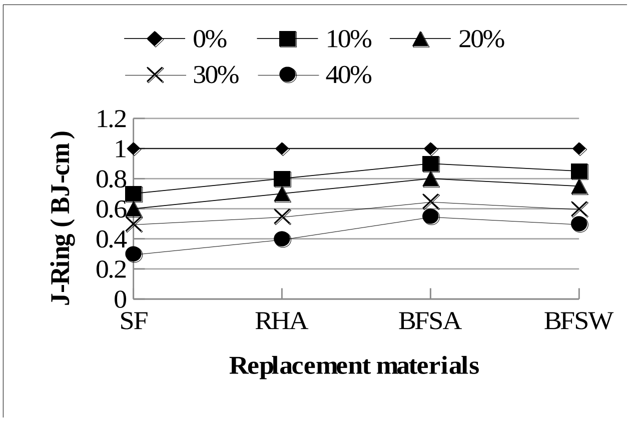

Fig. 7: J-ring value

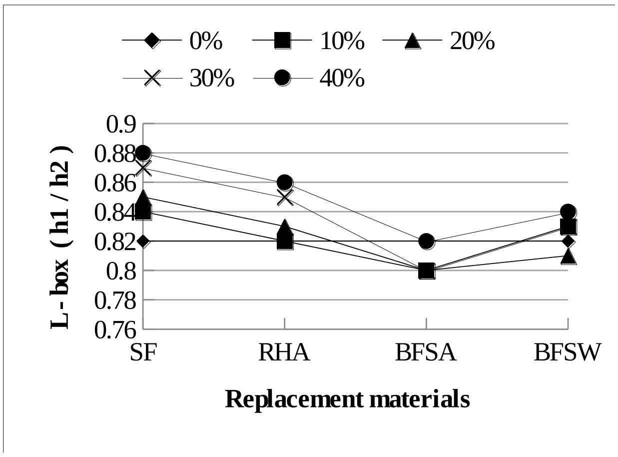

Fig. 8: L – box

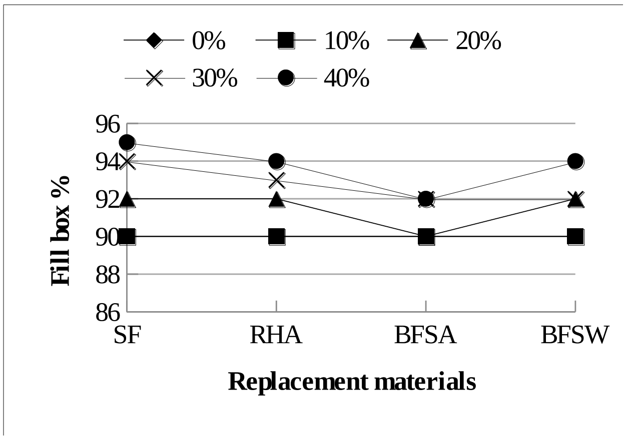

Fig. 9: Fill box

3. *Hardened concrete properties*

Compressive strength

Table 5 represents the compressive strength test results for concrete specimens as explained in Figs 11-14. It is noticed that the compressive strengths for all mixes increased by increasing the number of curing days as shown in Figs 11-14. The development of rate for compressive strength by time differs according to type of replacement material and percentages. At an early stage, the rate of gain for compressive strength of SF and RHA based SCC before 28 days was higher than rates for control mix and mixes with BFSA and BFSW due to presence of higher percentage of silica. The higher percentage of silica helps the pozzolanic reactions occur at early ages .However, the rate of gain for compressive strength of SF and RHA based mixes after 28 days was lower than rates for BFSA and BFSW mixes. Comparing all mixes to control mix, SF and RHA mixes achieved higher results in compressive strength. The compressive strength of SF mixture is higher than RHA mixes. Replacing small dosage of PC by BFSA or BFSW decreases compressive strength in comparison to control mix, SF and RHA mixes. As shown from Fig. 13 and Fig. 14 the compressive strength of BFSW mixture slightly increase in comparison to BFSA mixes. It is observed that the optimum level was 20% for SF mixes and 10% for RHA mixes.

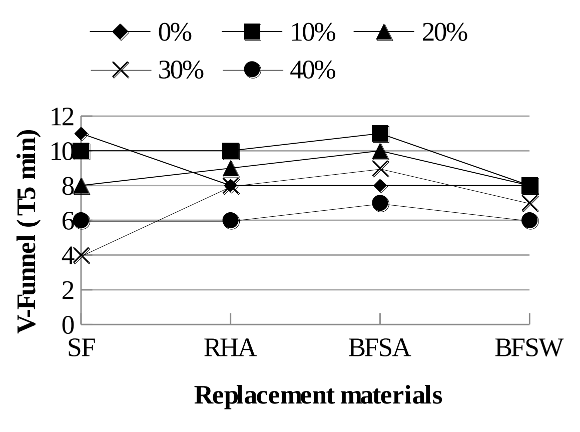

Fig. 10: V-funnel test (T5min) values

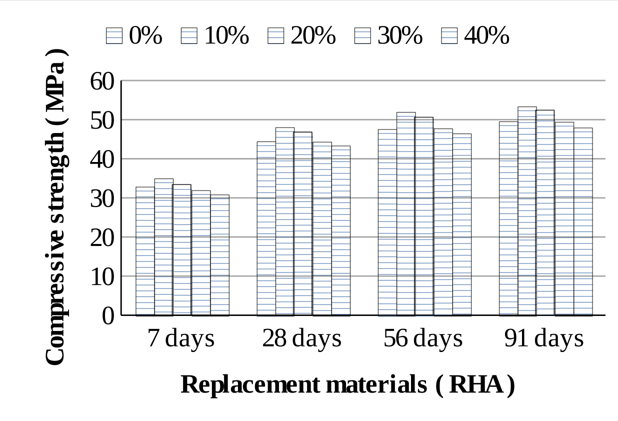

Fig. 12: Compressive strength of RHA mixes at all ages

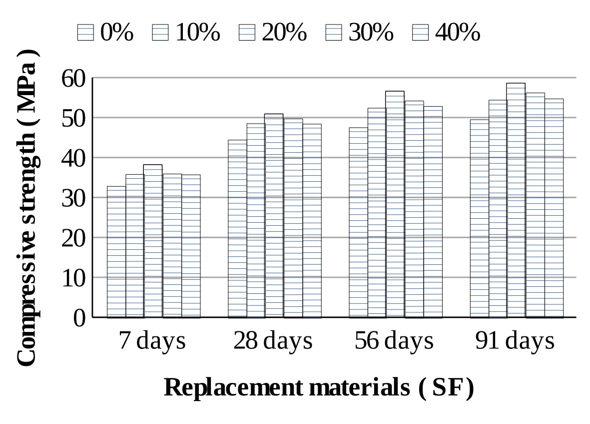

Fig. 11: Compressive strength of SF mixes at all ages

Table 5 : Results of hardened SCC

Mixes	Groups	Compressive strength (MPa)				Splitting tensile (MPa)	Flexural strength (MPa)	Bond strength (MPa)	Modulus of elasticity (GPa)
		7 days	28 days	56 days	91 days	28 days	28 days	28 days	28 days
S0	G0-PC	33.00	44.60	47,7	49.70	4.50	6.70	7.40	31.67
S1	G1-SF	36.00	48.70	52.60	54.60	4.90	7.50	8.10	35.06
S2		38.20	50.90	56.60	58.60	5.20	7.60	8.80	37.16
S3		36.10	49.90	54.40	56.40	4.90	7.50	8.30	35.93
S4		35.90	48.60	53.00	54.90	4.80	7.30	8.20	34.99
S5	G2-RHA	35.10	48.20	52.10	53.50	4.90	7.20	8.10	35.19
S6		33.40	46.80	50.60	52.40	4.70	7.00	7.80	34.16
S7		32.10	44.50	47.90	49.60	4.40	6.50	7.40	31.60
S8		31.00	43.50	46.60	48.10	4.30	6.40	7.20	30.89
S9	G3-BFSA	27.70	39.20	41.60	42.50	3.90	5.90	6.70	28.22
S10		25.10	35.30	37.60	38.90	3.60	5.30	6.10	25.42
S11		22.90	32.40	34.60	36.00	3.40	4.90	5.50	23.00
S12		20.60	29.30	30.90	32.40	3.00	4.30	5.10	21.10
S13	G4-BFSW	29.30	41.00	43.80	45.30	4.10	6.20	6.90	29.52
S14		26.70	37.10	39.80	40.90	3.80	5.60	6.40	27.08

S15		24.70	34.60	37.10	38.30	3.50	5.20	5.90	24.91
S16		22.20	31.20	33.40	34.50	3.20	4.60	5.40	22.15

4. *The splitting tensile strength*

The splitting tensile strength test was applied on SCC at 28 day age. SCC splitting strength results are shown in Table 5 and Fig. 15. All mixes results were compared to control mix. Splitting strength differs according to type of replacement material (SF, RHA, BFSA and BFSW) and percentages (10 to 40%) of cement weight. It is noticed that splitting strengths of SF and RHA mixes achieved higher results in comparison to control mix. The splitting strength of SF mixture is more than RHA mixes. By replacing small dosage of PC with BFSA and BFSW, splitting strength decreased slightly. The splitting strength of BFSW mixture achieved results better than BFSA mixes. The optimum replacing percentage of PC by SF is 20% and 10% in case of using RHA, which are similar to the results obtained from compressive strength test.

There is existed relation between compressive strength and splitting strength. By statical analysis of results, the following equation were obtained The existing equations:

ACI 318-14 [13]:

{1}

Oluokun, F [14]:

{2}

M. Amin [15]:

{3}

The following equation obtained from splitting strength results:

{4}

$f$sp = Splitting tensile strength in (MPa)

fc_{28}= Compressive strength at 28 days age in (MPa)

5. *Flexural strength*

Table 5 and Fig. 16 show the results of flexural strength test. Flexural strength results increased for mixes containing SF or RHA as a replacement material to be higher than control mix. The flexural strength results of SF mixtures are higher than of RHA mixes. However, flexural strength results decrease for mixes contain dosage of BFSA or BFSW as a replacement material. The flexural strength values of BFSW mixtures are better than BFSA mixes. The optimum level of replacing PC by SF or RHA is 20% and 10% respectively similar to the splitting strength results.

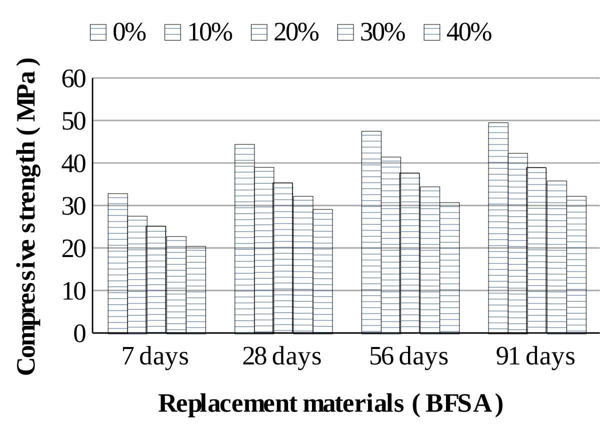

Fig. 13: Compressive strength of BFSA mixes at all ages

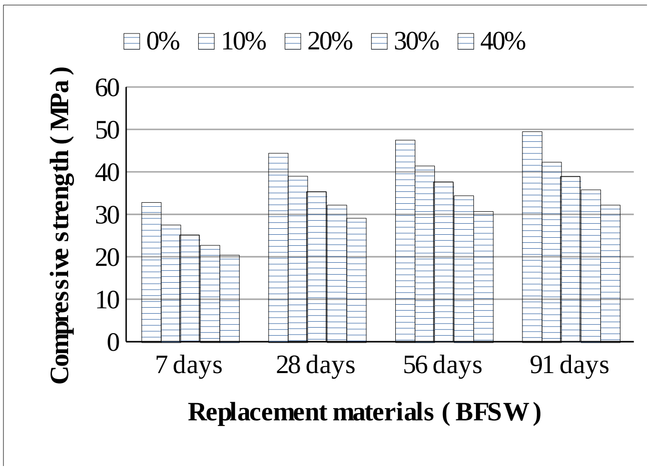

Fig. 14: Compressive strength of BFSW mixes at all ages

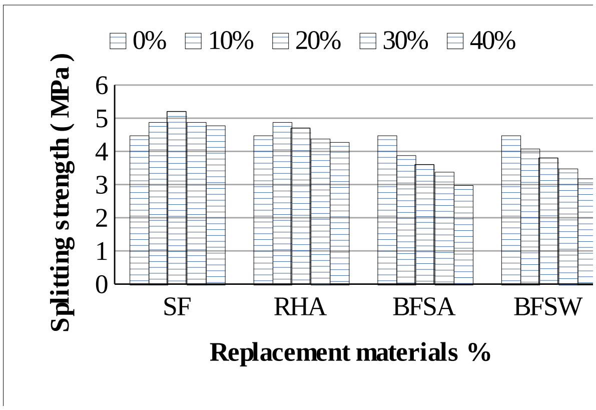

Fig.15: Splitting strength of all mixes

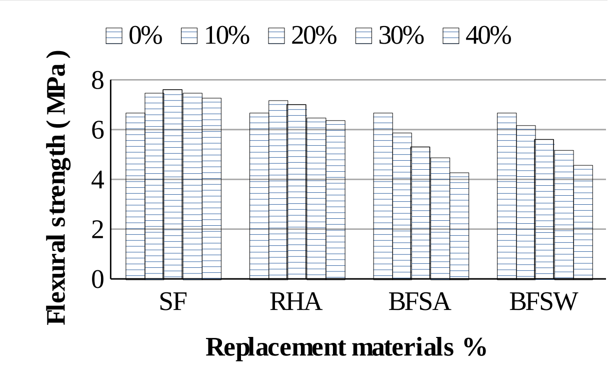

Fig. 16: Flexural strength of all mixes

6. *Bond strength*

Table 5 and Fig. 17 represent the bond strength results for SCC. The results indicate that mixes with replacement material SF or RHA give higher bond strength comparing to control mix and other mixes. It is noticed that bond strength of SF mixtures exceeds that of RHA mixes. Nevertheless, results decrease by replacing small dosage of PC with BFSA or BFSW by weight of cement comparing to control mix. With respect to previous result of compressive strength test and other strengths, the optimum level of partial replacement of PC with RHA in mixture is 10% and for SF mixes is 20%.

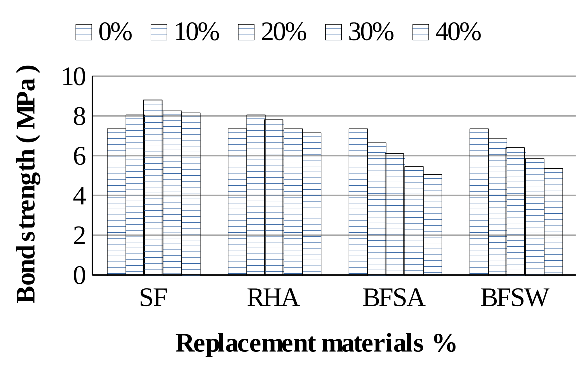

Fig. 17: Bond strength of all mixes

7. *Modulus of Elasticity*

The modulus of elasticity (E_c) measured at 28 days age for all mixes as shown in Fig. 18 and Table 5. Comparing to reference mix it is noticed that modulus of elasticity increased for mixes contains SF or RHA. On the other side, modulus of elasticity decreases for mixes in which BFSA or BFSW were used as a partial replacement material for PC comparing to control mix. Therefore, as observed previously in the results of modulus of elasticity, 10% is the optimum percentage for RHA and for SF mixes is 20 %. In view of hardened properties, there are some exist relation between compressive strength and modulus of elasticity. By statical analysis of results, the following equations were obtained. All values of E_c and $f c$ are in GPa. The existing equations:

ACI 363-14 [13]:

{5}

The following equation obtained from modulus of elasticity results:

{6}

E_C= Modulus of elasticity in (MPa).

f_{c28}= Compressive strength at 28 days age in (MPa).

8. *Permeability*

The permeability test was applied on cubic specimen of SCC at 28 days age and the results are shown in Fig. 19. The test results show the permeability values for control mix and other mixes with 20% replacement of PC weight by chosen material. The mixes with replacement materials SF or RHA achieve lower permeability .The decrease in permeability reached 32.5%, 28.3%, 9.3 %, and 25.1% for SF, RHA, BFSA and BFSW mixes respectively compared to control mix. With respect to the permeability results, it is observed that replacing a small dosage of PC by RHA or SF in the concrete mix had a great effect on the permeability of concrete. Therefore, by comparing permeability of control mix to other mixes with different replacement materials. It's noticed that partial replacement of PC by SF or RHA is the best.

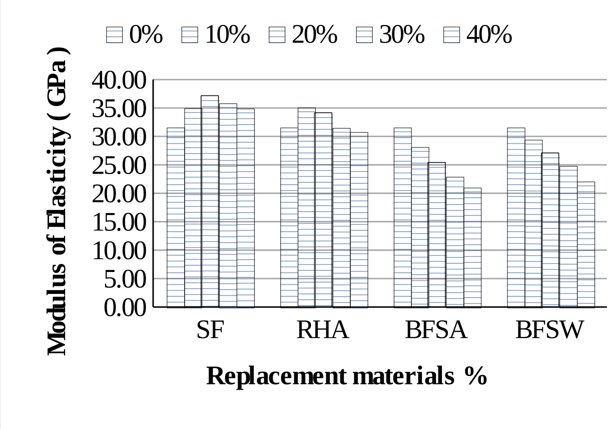

Fig. 18: Modulus of elasticity of all mixes

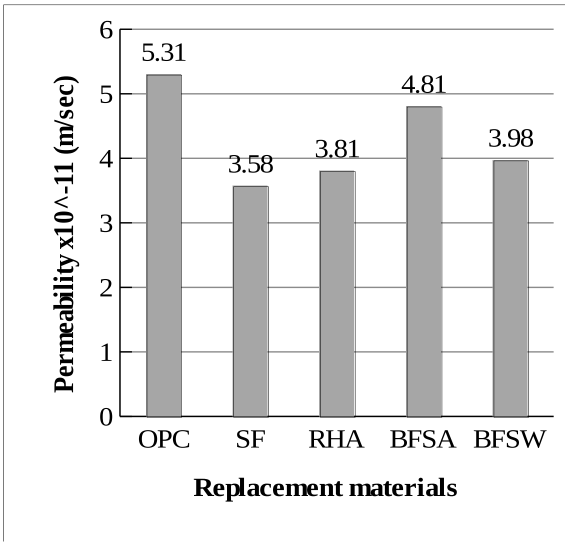

Fig. 19: Permeability values

VII. CONCLUSION

The following conclusion can be drawn from the results of this study:

- Partial replacement of PC by SF, RHA, BFSA and BFSW was very useful for fresh properties of SCC. Considering that workability, filling ability, passing ability and segregation resistance are increasing in comparison to control mix.
- Optimum level of partial replacement of PC with SF, RHA, BFSA and BFSW to increase fresh properties of SCC is 40%.
- Increasing percentage of partial replacement of PC from (10 to 40%) in mixtures with SF and RHA improves the mechanical properties and durability comparing to control mix.
- Mechanical properties and durability of SF mixtures is comparable with RHA mixes.
- Replacing small dosage of PC by BFSA or BFSW causes decreasing in mechanical properties and durability comparing to control mix.
- Comparing the mechanical properties results of BFSA mixtures with BFSW mixes shown that BFSW mixes achieve better result than BFSA mixes.
- The optimum level for partial replacement of PC with SF and RHA in SCC was 20% and 10% by weight of cement respectively.
- The optimum level for replacing PC with BFSW in SCC was 10% by weight of cement comparing to BFSA mixes.
- RHA can replace SF in producing sustainable SCC.

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