INFLUENCE OF RECYCLED CONCRETE AGGREGATES AND COAL BOTTOM ASH ON GREEN PROPERTIES OF HIGH VOLUME FLY ASH BASED SELF COMPACTING CONCRETE

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ABSTRACT. The current investigation focuses on green behaviour of High Volume Fly Ash **(**HVFA) based Self Compacting Concrete (SCC) prepared with Recycled Concrete Aggregates (RCA) and Coal Bottom Ash (CBA) as replacement of Natural Coarse Aggregates (NCA) and Natural Fine Aggregates (NFA) respectively. In order to estimate the green properties, various tests like slump flow, flow time, V-Funnel, J Ring, L Box and visual stability tests have been performed on freshly made HVFA based SCC. The results prove that the workability of HVFA based SCC gets reduced with the addition of RCA along with CBA. The time taken by Slump test, J-Ring test and V-Funnel test for SCC mix made with full replacement level of NCA with RCA has been increased by 95%, 63% and 28.5% respectively whereas a decrease in flows of Slump and J-Ring tests has been restricted to maximum of 15% compared to the control concrete. In general the workability has attained an equivalent figures for HVFA based SCC mixes up to ≤ 50% replacement levels of RCA with a constant amount of CBA(10%) compared to the control HVFA based SCC mix.

Keywords: High volume fly ash, Self-compacting concrete, Recycled concrete aggregates, Workability

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INTRODUCTION

In recent years Self-Compacting Concrete (SCC) has gained high recognition across world. It reduces the concern raised due to noise, as unlike Normal Vibrating Concrete (NVC) it doesn't require any external vibrations [1-3]. Moreover the introduction of SCC has cut down the overall period of concrete construction in most of civil engineering projects [4-7]. Due to its superior fresh properties it possesses enough viscosity to manage any bleeding and segregation as it flows in uniform level under the gravity force [8-10].

According to earlier investigations, the global production of Fly Ash (FA) is estimated more than around 800 million tons per year. Most of the estimated amount of FA has been dumped in the landfills which further consequences in scarcity of prime lands and deterioration of environment [11]. Coal bottom ash (CBA) is also a primary by-product which has been generated from the thermal power plants however its amount is nearly quarter to that of FA [12]. The utilisation of High Volume Fly Ash (HVFA) and CBA in place of Portland Cement (PC) and Natural Fine aggregates (NFA) respectively has sorted the aforementioned concerns partially as it has not been fully implemented in developing countries. Moreover the regular generation of FA and CBA from thermal power plants has pushed the researchers to find a more reliable solution [7, 12]. Further, Recycled Concrete Aggregates (RCA) is obtained by crushing the concrete debris obtained from Construction and Demolition (C&D) wastes. The required nominal size can be obtained by proper gradation of waste crushed concrete. Despite, of having higher water absorption and lower density compared to NCA, it is possible to make concretes with satisfactory performance by adopting proper mixing and proportioning of its constituents [13-14]. Incorporation of FA not only increases the workability but also supports in dipping the additional water which has been added to attain the desired workability [17-18, 20, 25]. Further, it has been observed from earlier studies that SCC made with RCA results in significant drop in workability [16, 19, 23, 24]. However in an earlier investigation the combined utilization of HVFA and RCA also shrinks the workable nature [21-22].

RESEARCH SIGNIFICANCE AND OBJECTIVES

Many studies have been conducted in which fresh behaviour of SCC made with either HVFA/CBA/RCA has been assessed as mentioned in earlier section. It has been reported in the preceding section, wherein brief literature on the subject has been presented, that there is almost no information available on the fresh behaviour of SCC made with the combination of all three bi-products i.e. HVFA, CBA, RCA. In addition to this, it is proposed to recommend most appropriate combination of constituents in relation to replacement level of FA, CBA and RCA for best performance towards fresh behaviour of SCC. The workability tests have been conducted on all SCC mixes containing different replacement levels of NCA with RCA. Fly ash and CBA have been used in fixed proportion as partial replacement of PC and NFA respectively.

MATERIALS AND METHODS

Cement

Portland cement of 43 grade has been used during entire experimental programme. The chemical composition of PC of grade 43 confirms Indian Standard: IS 269.The physical and chemical properties of the PC are shown in Table 1(a) and Table 1(b) respectively.

Table 1(a) Physical composition of PC

PARAMETERS	TEST VALUE (%)	RECOMMENDED VALUE (%)
Ratio of lime to silica, alumina and iron oxide	0.90	1.02 (max) ,0.66 (min)
Ratio of alumina to iron oxide	1.58	0.66 (min)
Insoluble residue	1.1	2 (max)
Magnesia	2.6	6 (max)
Total sulphur content	1.3	2.5 (max)
Total loss of ignition	1.2	5 (max)
Total alkali	0.49	0.6 (max)
Chloride content	0.08	0.1 (max)
Calcium oxide	61.3	--
Magnesium oxide	2.6	
Silica	20.1	
Aluminium oxide	6.80	
Ferrous oxide	4.30	
Silicon trioxide	1.3	

Table 1(b) Chemical properties of PC [13]

CHARACTERSTICS	UNITS	RESULTS OBTAINED	PERMISSIBLE RANGE (IS: 8112-1989)
Specific gravity	--	3.15	3.10 – 3.15
Fineness	cm2/gm	2340	2250 (min)
Soundness	Mm	3	10 (max)
Normal Consistency	**%**	34	30 – 35
Setting Time	Minutes	65	30 (min)
		410	600 (max)
Compressive Strength	MPa	23	23.00 (min)
		35.5	33.00 (min)
		45.1	43.00 (min)

Fly ash

For the current investigation programme Class F-FA has been used as replacement of PC in all SCC mixes. The concrete made with FA levels more than equal to 30% are considered to be HVFA based mixes [10,22,26]. The chemical composition of Class F-FA confirms Indian Standard: 1727 (1967) and ASTM C-618 (1991). Fly ash was obtained from Ropar Thermal Power Plant, Punjab, India. The physical and chemical properties of FA are presented in Table-2

Table 2 Physical and Chemical properties of FA [13]

COMPOSITION	WEIGHT (%)
SiO_2	56.50
Al2O3	17.70
Fe2O3	11
CaO	3.20
MgO	5.40
Loss of ignition	1.20
Specific gravity	2.38

Natural fine aggregates

Natural river based sand was used having maximum particle size of 4.75 mm. The NFA was procured from Pathankot quarry, Punjab (India). The NFA used in the entire SCC mixes were stored under normal environmental conditions. The results of particle size gradation and physical properties of NFA are shown in Table 3

Table 3 Particle size gradation and Physical properties of NFA

SIEVE SIZE (mm)	MASS REATAINED (Kg)	CUMULATIVE MASS REATINED	CUMULATIVE MASS (%)	CUMULATIVE PASSING (%)
10	0	0	0	100
4.75	0	0	0	100
2.36	0.48	0.48	48	52
1.18	0.264	0.744	74.4	25.6
0.6	0.113	0.857	85.7	14.3
0.3	0.063	0.92	92	8
0.09	0.057	0.977	97.7	2.3
Pan	0.023	1	100	0
Fineness modulus (FM)				3.978
Specific gravity				2.75
Water absorption (%)				1.25

Coal bottom ash

Coal bottom ash was obtained from Ropar Thermal Power Plant, Punjab, India. The particle size gradation and chemical composition of coal bottom ash is presented in Table-4(a) and Table-4(b) respectively

Table 4(a) Particle size gradation of CBA

SIEVE SIZE (mm)	MASS RETAINED (Kg)	CUMULATIVE MASS RETAINED	CUMULATIVE MASS (%)	CUMULATIVE PASSING (%)
10	0	0	0	100
4.75	0	0	0	100
2.36	0.51	0.51	51	49
1.18	0.265	0.775	77.5	22.5
0.6	0.107	0.882	88.2	11.8
0.3	0.057	0.939	93.9	6.1
0.09	0.042	0.981	98.1	1.9
Pan	0.019	1	100	0

Table 4(b) Chemical composition of CBA [12]

COMPOUND	WEIGHT (%)
Silica (SiO_2)	57.76
Alumina (Al_2O_3)	21.58
Iron oxide (Fe_2O_3)	8.56
Potassium oxide (K_2O)	1.08
Calcium oxide (CaO)	1.58
Magnesium oxide (MgO)	1.19
Sulphur (SO_3)	0.02
Sodium oxide (Na_2O)	0.14

Natural coarse aggregates

The aggregates were crushed manually and further graded according to the size specified for NCA. In all SCC mixes the maximum size of 10 mm was used throughout the experimental programme[28]. The results of physical properties and particle size distribution are shown in Table-5(a) and 5(b).

Table 5(a) Physical properties of NCA

PHYSICAL CHARACTERISTICS	CORRESPONDING VALUE
Fineness modulus	6.925
Specific gravity, g/cm^3	2.64
Aggregate Impact Value (%)	16.35
Aggregate Crushing Value (%)	15.80
Water Absorption (%)	0.68

Table 5(b) Particle size distribution of NCA

SIEVE SIZE (mm)	MASS RETAINED (Kg)	CUMULATIVE MASS RETAINED	CUMULATIVE MASS (%)	CUMULATIVE PASSING (%)
80	0	0	0	100
40	0	0	0	100
20	0	0	0	100
16	0	0	0	100
12.5	0	0	0	100
10	200	200	10	90
6.3	1500	1700	85	15
4.75	250	1950	97.5	2.5
Pan	50	2000	100	0

Water

Water having pH value varying from 6.5 - 8.5 was used during casting and curing of SCC mixes. The water used for SCC mixes was complied with relevant Indian Standards.

Recycled concrete aggregates

The physical nature of RCA affects the workability of concrete mixes [20,21,27]. The gradation of RCA has been kept identical to NCA throughout the investigation. The results of particle size gradation and physical properties of RCA are shown in Table-6

Table 6 Particle size gradation and Physical properties of RCA

SIEVE SIZE (mm)	MASS RETAINED (Kg)	CUMULATIVE MASS RETAINED	CUMULATIVE MASS (%)	CUMULATIVE PASSING (%)
80	--	0	0	0
40	--	0	0	0
16	--	0	0	100
12.5	--	0	0	100
10	400	400	13.3	86.7
6.3	2000	2400	80	20
4.75	440	2840	94.7	5.3
Pan	160	3000	100	0
Fineness modulus (FM)			6.88	
Specific gravity, g/cm^3			2.44	
Aggregate impact value (%)			30.43	
Aggregate crushing value (%)			25.6	
Water absorption (%)			5.65	

TEST METHODS & PROPORTIONS

Fresh properties of SCC mixes were evaluated using the slump-flow, J-ring, L-box, and V-funnel tests. The results of these tests as well as their acceptable ranges satisfies the EFNARC guidelines.

Slump flow test

The slump test was performed to find out the flow-ability and viscosity of SCC. The permissible value provided by EFNARC guidelines for T_{500} ranges between 2 -5 seconds whereas the spread of the flow ranges between 650 – 800 mm.

J-ring test

This test was done to find out the passing ability of SCC. The difference between the values of slump flow and J- ring test indicates the passing ability of concrete. A difference less than 25 mm indicates good passing ability whereas difference greater than 50 mm indicates the poor passing ability.

V–funnel test

This test was performed to evaluate the flow-ability of SCC. According to EFNARC guidelines its value should lie between 6-12 seconds. The workability of SCC will be higher if the time taken to pass through the V-funnel apparatus is less than the recommended value.

L –box test

This test was also conducted to find out both flow-ability and passing ability of SCC. The ratio h_2/h_1 generally varies from 0.8-1.0, where lower and higher value of ratio depicts poor and ideal workable behaviour of SCC respectively. Herein, where h_2 depicts the height of concrete at the end of horizontal portion and h_1 depicts the height at the start of horizontal portion of L-box apparatus.

MIX DETAILS AND PROPORTIONS

A total number of 5 SCC mixes containing different replacement levels of RCA and a constant amount of FA (50%) were prepared. The replacement level of NFA with CBA has been kept at 10% in all combinations. The level of replacement of NFA with CBA has been selected from previous studies, since the same content doesn't offers any negative impact on overall performance of SCC [7,12]. The details of the SCC mixes along with the replacement levels of constituents with mix notations are presented in Table 7. A notation of 'H' for HVFA (≥30% FA) has been mentioned in designating of all SCC mixes. The replacement levels of NCA with RCA were varied as 25%, 50%, 75% and 100%. The control mix CHF-R0 comprises 50% replacement of PC with FA with no replacement of NFA and CNA. Likewise, SCC mix CHB-R25 comprises 10% of CBA and 25% of RCA by weight i.e. (PC50% + FA50% + CBA10% + NFA90% + CNA75% + RCA25%). A similar approach has been adopted for designating other SCC mixes. After satisfying the *EFNARC* guidelines, control SCC mix was finalised by conducting several trials. All SCC mixes were prepared with constant Water/Binder (w/b) ratio of 0.45. The proportions of SCC mixes were carried out using equivalent volume approach.

Table 7 Mix Notations and Details of SCC Mixes

MIX CODE	MIX DESCRIPTION
CHB-R0 (Control)	50%PC+50%FA+0%CBA + 100%NFA + 100%CNA+0%RCA
CHB-R25	50%PC+50%FA+ 10%CBA+90%NFA + 75%CNA+25%RCA
CHB-R50	50%PC+50%FA+ 10%CBA+90%NFA + 50%CNA+50%RCA
CHB-R75	50%PC+50%FA+ 10%CBA+90%NFA + 25%CNA+75%RCA
CHB-R100	50%PC+50%FA+ 10%CBA+90%NFA + 0%CNA+100%RCA

RESULTS AND DISCUSSIONS

The workability tests as mentioned in previous section have been conducted on base SCC mix CHF-R0 for reference. The performance of control SCC mix CHB-R0 has been found to be equivalent to that of base *SCC mix CHF-R0* as inclusion of CBA in place of NFA has not deteriorated the overall nature. Therefore, for the present investigation SCC mix CHB-R0 is considered as the control SCC mix for comparison with other SCC mixes.

The SCC mixes containing different combinations of RCA along with constant amount of CBA (10%) with NFA and FA (50%) with PC were tested by Slump flow, J-ring, V-funnel, and L-box tests for workability. In general, with the incorporation of RCA in place of NCA in different proportions (25%, 50%, 75% and 100%) results in overall decrease in workability of HVFA based SCC mixes made with CBA. For example, in case of slump flow test, for SCC mixes CHB-R25 and CHB-R50 the T_{500} values have been noticed to be higher than that of control SCC mix CHB-R0 by around 17% and 52% respectively. Further, slump values of SCC mixes containing 75% and 100% of RCA in place NCA has been increased by 1.8 to 1.9 times in relative to the control SCC mix CHB-R0. For the same test, an identical behaviour for flow spreads has been observed for the aforementioned SCC mixes. The maximum drop in the flow spread has been observed for SCC mix CHB-R100 whereas the least reduction has been noticed for SCC mix CHB-R25. For the SCC mixes prepared with intermediate and high levels of NCA with RCA (CHB-R50 and CHB-R75) shows the similar behaviour as mentioned in previous paragraph on comparison to control SCC mix CHB-R0.

J-Ring test was conducted to evaluate the passing ability of HVFA based SCC made with RCA and CBA. For SCC mix containing 25% RCA (CHB-R25) the T_{500} value has been noticed to be equivalent to that of the control SCC mix CHB-R0. Likewise, for SCC mix CHB-R50 the T_{500} value has been observed to be higher approximately by 36.6% than that of control SCC mix CHB-R0. Further, a significant increase of around 53.3% and 63.3% in slump values has been observed for SCC mixes containing 75% and 100% of RCA in place NCA (CHB-R75 and CHB-R100) respectively in relative to control SCC mix CHB-R0. Alike trends of flow spreads have been observed for the above-mentioned SCC mixes. The least flow spread has been noticed for SCC mix containing 100% RCA (CHB-R100) whereas the least variation has been observed for SCC mix containing 25% RCA (CHB-R25) in relative to control SCC mix ChB-R0. Furthermore, similar nature has been observed for the SCC mixes containing 50% and 75% RCA in place of NCA (CHB-R50 and CHB-R75) to that of control SCC mix CHB-R0. According to some of the previous investigations, the SCC mixes made with NCA and CBA also follows identical changes as experienced in the current study. The observations for slump flow and J-ring test has been found to be similar to that of SCC mixes made with NCA where in similar reductions in workability have been reported [9,18].

In case of V-funnel test, all SCC mixes have shown good passing ability without bleeding and segregation. For SCC mixes CHB-R25 and CHB-R50 the flow time values has been noticed to be exceeded compared to that of control SCC mix CHB-R0 by 3.1% and 17.4% respectively. Further, for SCC mixes containing 75% and 100% of RCA (CHB-R75 and CHB-R100) in place of NCA an increase in flow time values of an order of 26.9% and 28.5% has been observed respectively in relative to control SCC mix CHB-R0. For L-box test, the passing ability of SCC mixes containing 25% and 50% RCA (CHB-R25 and CHB-R50) has been found to be lower by 4.1% and 8.1% respectively in contrast to the control SCC mix ChB-R0. Moreover, a decrease of about 12.2% and 14.3% in passing ability has been noticed in SCC mixes containing 75% and 100% RCA as a substitution for NCA (CHB-R75 and CHB-R100) respectively with respect to the control mix CHB-R0.

For V-funnel and L-box test it has been found that the observed time (in seconds) and ratio (h2/h1) is almost alike to that of SCC mixes made with NCA where in similar decrements in workability have been reported [10,15].

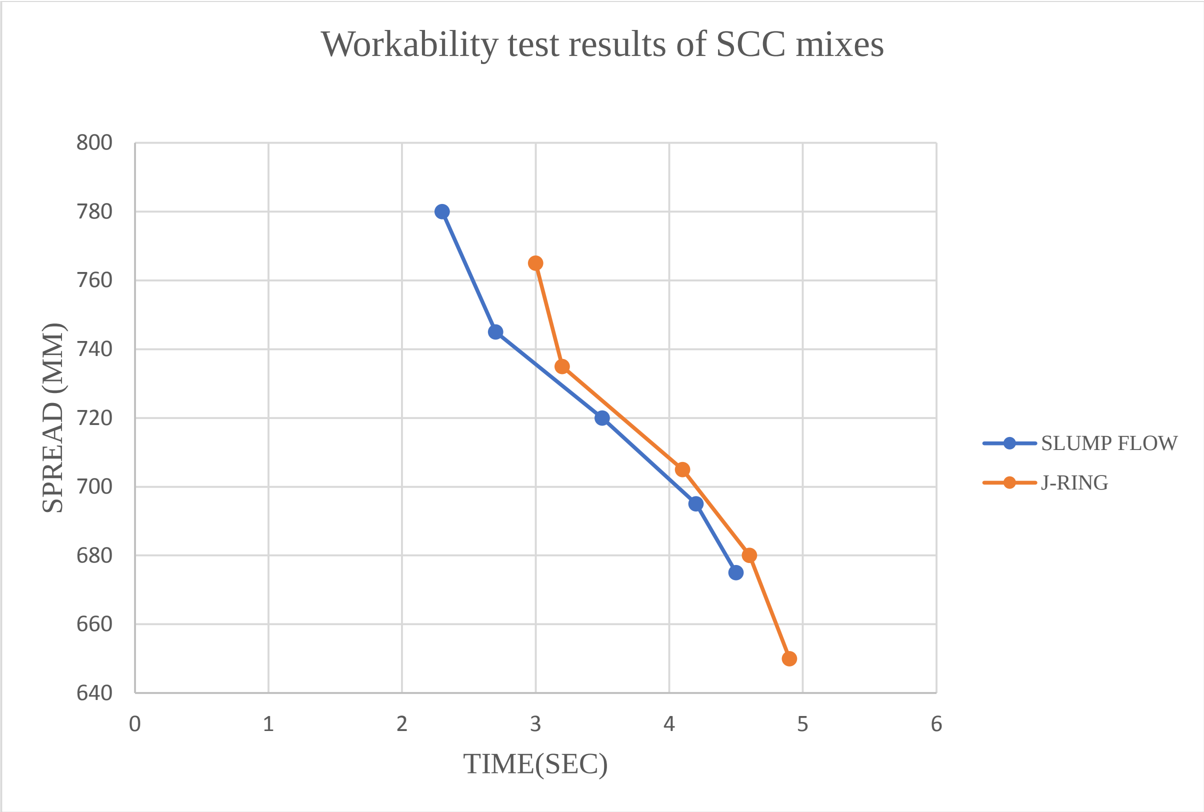
CONCLUDING REMARKS

The findings of the current research lead to the following outcome:

The workability of all HVFA based SCC mixes prepared with varying content of RCA and fixed amount of CBA has deteriorated in comparison to control SCC mix. The worst performance in aspect of workability has been identified for SCC mix CHB-R100 whereas the comparable performance has been noticed for CHB-R25 compared to control SCC mix CHB-R0. The maximum deviation in slump tests (T500 and Flow spread) has been found for SCC mix CHB-R100 while the least changes have been witnessed for CHB-R25. Alike trends of workability behaviour has been witnessed for J-Ring (T500) tests for the above said SCC mixes. The variation in slump and T500 values has been found to be constrained maximum by 50% for SCC mixes made up to 75% replacement of NCA with RCA respectively. For V-funnel and L-box tests SCC mixes, the noticed times are found to be proportional with increased content of RCA in all SCC mixes. Further it has been concluded from the results of fresh properties that incorporation of RCA up to 25% doesn’t impart any negative effect on the workability behaviour of SCC as all conditions have been satisfied in accordance to EFNARC.

Table 8 Workability test results for SCC mixes

DESIGNATION	SLUMP FLOW		J-RING		V-FUNNEL	L-BOX
	T500 (s)	SPREAD (mm)	T500 (s)	SPREAD (mm)	FLOW TIME (s)	PASSING ABILITY (H2/H1)
ChF-R0 (Base)	*2.7*	*740*	*3.0*	*695*	*4.7*	*1.0*
ChB-R0 (Control)	2.3	780	3.0	765	6.3	0.98
ChB-R25	2.7	745	3.2	735	6.5	0.94
ChB-R50	3.5	720	4.1	705	7.4	0.90
ChB-R75	4.2	695	4.6	680	8.0	0.86
ChB-R100	4.5	675	4.9	650	8.1	0.84



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