COST EFFECTIVE ANALYSIS OF SCC WITH BOTTOM ASH AND FLY ASH

Rajesh Kumar[1], Omesh Thukral[2], SP Singh[3]

1. Chandigarh College of Engineering & Technology (Diploma Wing), Chandigarh, India
2. Punjab Urban Planning & Development Authority (PUDA) Punjab, India
3. Dr B R Ambedkar National Institute of Technology, Jalandhar, India

ABSTRACT. Use of alternate filling material is still a matter of concern to develop self compacting concrete (SCC) because of the higher cost of conventional filling materials i.e. silica fume, slag, mica etc. Although fly ash and bottom ash are waste products, there exist a considerable potential to convert this waste to wealth. Therefore, the present investigation was aimed to develop SCC using fly ash as partial replacement of cement @25% & 50% and bottom ash as partial replacement of sand @10%, 20% & 30% respectively and to study its fresh & mechanical properties. To qualify the mix to be SCC w/p ratio was increased from 0.39 to 0.44 & 0.53 for mixes with 20% and 30% replacement level of sand with bottom ash, respectively. It has been found from the study that it is possible to develop SCC, using bottom ash a waste by-product of 26.37 MPa 28-days compressive strength at 50% cement replacement with fly ash & at 30% sand replacement with bottom ash. This reduces the cost of SCC by 23%. Similarly SCC of 28-days compressive strength 35.85 MPa with 25% fly ash and 30% bottom ash replacement level decreased the cost by 1.57% when compared to SCC without bottom ash. Ultimately minimizing the mining of natural sand and reducing adverse impact on our environment.

Keywords: Self-compacting Concrete, Bottom Ash, Fly ash, Natural Sand.

Dr Rajesh Kumar is a Lecturer of Civil Engineering at Chandigarh College of Engineering & Technology (CCET-26), Chandigarh, India. His research interests are self-compacting concrete, behaviour of recycled concrete and composite material.

Er Omesh Thukral is a Junior Engineer at Punjab Urban Planning & Development Authority (PUDA) Punjab, India. His area of interest is self-compacting concrete and constructional techniques.

Dr S P Singh is a Professor of Civil Engineering at Dr B R Ambedkar National Institute of Technology Jalandhar, India. His research interests are fatigue behavior of concrete composites and recycling of material in concrete.

INTRODUCTION

During the recent past, the use of self-compacting concrete (SCC) has increased in the construction industry not only due to enhanced compressive strength but also due to improvement in all other properties of the concrete including improved long-term durability to provide serviceability and performance throughout the life of the structure. An important improvement of health and safety is also achieved through elimination the use of vibrators and a substantial reduction of environmental noise loading on and around a site. The composition of SCC mixes includes substantial proportions of fine-grained inorganic materials and this gives possibilities for utilization of mineral admixtures, which are currently waste products with no practical applications and are costly to dispose [14].

Mix Design of SCC

Self Compacting Concrete preparation requires a special type of mix design due to its properties. The successful development of SCC must ensure a good balance between deformability and stability. Researchers have set some guidelines for mix proportioning of SCC, which include:

- Reducing the volume ratio of aggregate to cementitious [12].
- Increasing the paste volume and water-cement ratio (w/c).
- Carefully controlling the maximum coarse aggregate particle size and total volume.
- Using various viscosity enhancing admixtures (VEA) [12].

Basic Principle

The basic principle for development of SCC can be illustrated as shown below:

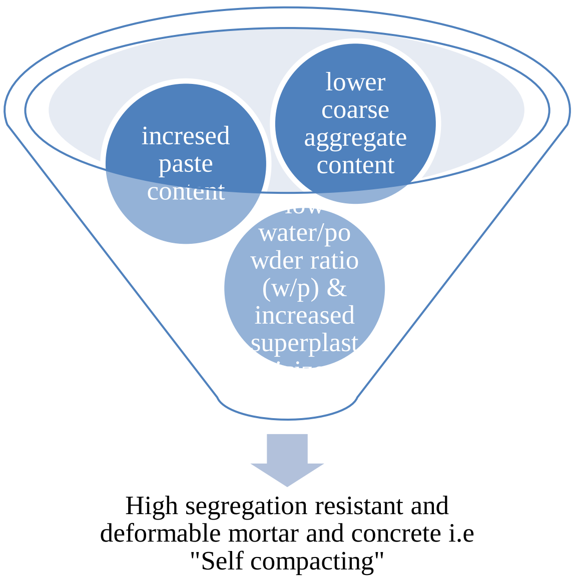


Figure 1 Basic Principle for Development of SCC

Mix designs often use volume as a key parameter because of the importance of the need to over fill the voids between the aggregate particles. Some methods try to fit available constituents to an optimized grading envelope. Another method is to evaluate and optimize the flow and stability of first the paste and then the mortar fractions before the coarse aggregate is added and the whole SCC mix tested.

EXPERIMENTAL PROGRAM

In the present study the procedure adopted to achieve self compacting concrete (SCC) mixes with the addition of bottom ash and increased use of fly ash

Material Used

The following materials were used in the present study.

Cement

Ordinary Portland cement (43 Grade) conforming to IS 8112: 1989 [7] was used. It's Chemical & physical properties are given in Table 1.

Table 1 Physical properties of Portland cement

PHYSICAL PROPERTY	TEST RESULT	REQUIREMENT OF IS:8112-1989
Fineness(m^2/kg)	274	225 (min)
Standard Consistency, %	29.5%	---
Initial Setting Time (minutes)	120	30 (min) as per IS:4031
Final Setting Time (minutes)	180	600 (max) as per IS:4031
Soundness (mm)	1.0	
Autoclave Expansion (%)	0.180	0.8 (max)
Specific Gravity	3.15	---
COMPRESSIVE STRENGTH (MPA)		
3-days	27.72	23.0 (min)
7-days	36.67	33.0 (min)
28-days	56.0	43.0(min)

Aggregates

Natural coarse river sand obtained from Pathankot conforming to Zone II as per *IS 383:1970* [3], with 4.75mm maximum size as fine aggregate and Crushed stone obtained from Anandpur sahib with 10mm maximum size as coarse aggregate were used in this study. The physical properties of the Aggregates are given in Table 2

Table 2 Physical properties of aggregates

PROPERTIES	FINE AGGREGATES (ZONE II as per IS 383)	COARSE AGGREGATES
Bulk Density (Compacted) kg/m^3	1705	
Bulk Density (Loose) kg/m^3	1570	1410
Specific Gravity	2.66	2.67
Water Absorption, %	1.2%	1.41%
Abrasion Value	-	23.2%
Soundness : Loss with Sodium Sulphate (5 Cycles)	-	1.4%
Estimate of Deleterious Material	-	Nil
Flakiness Index	-	27.3%
Elongation Index	-	34.7%

Fly Ash

Class F fly ash obtained from Guru Hargobind Thermal Plant, Lehra Mohabbat, Bathinda, Punjab was used. Fly ash is usually separated at the power plants & which qualify the fineness standard as per IS 3812: 2003 with retention of less than 34% on 45 micron sieve can be added as cementitious material in partial replacement of cement. The physical and chemical properties of fly ash are given in the Table 3.

Table 3 Physical and Chemical properties of fly ash

PHYSICAL PROPERTIES	TEST RESULTS	REQUIREMENT (IS: 3812-2003)
Color	Grey (Blackish)	-
Specific Gravity	2.22	
Fineness-specific surface in m^2/kg by Blaine's permeability method	369.7	Min 320
Particles retained on 45 micron IS Sieve (wet sieving) in percent	31%	Max 34%
Lime reactivity –	3.4%	
Average compressive strength at 28 days in N/mm^2.	82.5%	Not less than the 80% of the strength of corresponding plain cement mortar cubes
Soundness by autoclave test – Expansion of specimen in percent	0.23 %	Max 0.8
CHEMICAL PROPERTIES (% AGE BY WEIGHT)		
Silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) plus iron oxide (Fe_2O_3) in percent by mass.	74.88	Min 70 as per IS 1727
Silicon Dioxide (SiO_2) in percent by mass.	72.6	Min 35 as per IS 1727
Reactive silica in percent by mass.	41.48	Min 20 as per IS 1727
Magnesium Oxide (MgO) in percent by mass.	0.64	Min 5.0 as per IS 1727
Total Sulphur as sulphur trioxide (SO_3) in percent by mass.	0.31	Min 3.0 as per IS 1727
Available alkalis as sodium oxide (Na_2O) in percent by mass.	0.27	Min 1.5 as per IS 4032
Total Chlorides in percent by mass.	0.03	Max 0.05 as per IS 12423
Loss on ignition in percent by mass	1.61	Max 5.0 as per IS 1727

Coal Bottom Ash

Coal bottom ash is a waste product of thermal power plant which is dumped in landfill can be utilized in SCC as partial replacement of sand. Coal Bottom Ash obtained from Guru Hargobind Thermal Plant, Lehra Mohabbat, Bathinda (Punjab) having more than 34% retention on 45micron sieve was used. The physical properties of coal bottom ash are given in the Table 4

Table 4 Physical properties of bottom ash

PROPERTIES		OBSERVED VALUES
Bulk Density (Compacted) kg/m³		978
Bulk Density (Loose) kg/m³		796
Specific Gravity		1.95
Water Absorption, %		1.6%
	Bottom ash only	1.62 (confirming to Zone IV as per IS383)
Fineness Modulus	90% Coarse Sand + 10 % Bottom Ash	2.63 (confirming to Zone II as per IS383)
	80% Coarse Sand + 20 % Bottom Ash	2.31 (confirming to Zone III as per IS383)
	70% Coarse Sand + 30 % Bottom Ash	2.23 (confirming to Zone III as per IS383)

Super plasticizer

FOSROC AURAMIX 400 is polycarboxlic-ether based high performance super plasticizer intended for applications where high water reduction and long workability retention are required. Properties of super plasticizer are given in Table 5.

Table 5 Specifications of super plasticizer (for SCC)

PROPERTIES	RESULTS
Appearance	Light yellow
Volumetric mass @20°C	1.105kg/litre
Chloride content	Nil
Alkali content	Less than 1.5g Na_2O equivalent/litre

Water

Normal potable water conforming to the requirements of IS: 456-2000 [4] was used in the present study.

MIX PROPORTION OF SCC

The mix design of SCC (SCCF25B0) with 0% bottom ash having 25% fly ash in total powder content and Normal concrete mix (NCF25B0) having 25% fly ash in total powder content were taken from a project (Purab Premium Apartments) of GMADA, at SAS Nagar Punjab. In SCC fine aggregates were partially replaced by bottom ash (0 to 30% by weight at the increment of 10%), all the 5 mixes including normal concrete mix were prepared with increased percentage (@50%) of fly ash in total powder content. The compositions of all the mixes are given in Table 6 to 10. The mixes (normal & SCC) had constant coarse aggregate content, fine aggregate, cement and fly ash for particular bottom ash content. The SCC mixes were designated as SCCFxxBvv where “xx” represents fly ash percentage in the total powder content & “vv” represents the percentage of replacement of fine aggregate with bottom ash. The Normal concrete mixes were designated as NCFaaBnn where “aa” represents fly ash represents fly ash percentage in the total powder content & “nn” represents the percentage of replacement of fine aggregate with bottom ash.

Table 6 Composition of normal concrete mixes

MIX	CEMENT (kg/m^3)	FLY ASH (kg/m^3)	CA (kg/m^3)	SAND (kg/m^3)	S.P (kg/m^3)	S.P (%age)	WATER (kg/m^3)	W/P ratio
NCF25B0	280	90	1170	759	2.96	0.8	152	0.41
NCF50B0	185	185	1170	759	2.1	0.57	152	0.41

Table 7 Composition of SCC Mixes @ 0% bottom ash

MIX	CEMENT (kg/m^3)	FLY ASH (kg/m^3)	CA (kg/m^3)	SAND (kg/m^3)	BOTTOM ASH	S.P (kg/m^3)	S.P (%age)	WATER (kg/m^3)	W/P ratio
SCC F25B0	375	125	735	899	0	4	0.8	205	0.41
SCC F50B0	250	250	735	899	0	3.5	0.7	205	0.41

Table 8 Composition of SCC Mixes @ 10% bottom ash

MIX	CEMENT (kg/m^3)	FLY ASH (kg/m^3)	CA (kg/m^3)	SAND (kg/m^3)	BOTTOM ASH	S.P (kg/m^3)	S.P (%age)	WATER (kg/m^3)	W/P ratio
SCCF25B10	375	125	735	809.1	89.9	4	0.8	205	0.41
SCCF50B10	250	250	735	809.1	89.9	3.5	0.7	205	0.41

Table 9 Composition of SCC Mixes @ 20% bottom ash

MIX	CEMENT (kg/m^3)	FLY ASH (kg/m^3)	CA (kg/m^3)	SAND (kg/m^3)	BOTTOM ASH	S.P (kg/m^3)	S.P (%age)	WATER (kg/m^3)	W/P ratio
SCCF25B20	375	125	735	719.2	179.8	4	0.8	219	0.44
SCCF50B20	250	250	735	719.2	179.8	3.5	0.7	219	0.44

Table 10 Composition of SCC Mixes @ 30% bottom ash

MIX	CEMENT (kg/m^3)	FLY ASH (kg/m^3)	CA (kg/m^3)	SAND (kg/m^3)	BOTTOM ASH	S.P (kg/m^3)	S.P (%age)	WATER (kg/m^3)	W/P ratio
SCCF25B30	375	125	735	629.3	269.7	4	0.8	264	0.53
SCCF50B30	250	250	735	629.3	269.7	3.5	0.7	264	0.53

Casting of Specimens

Cube of size 150x150x150 mm were cast having mix proportions as given in Table 6 to 10. Weighed quantities of cement and fly ash (as per mix design) were dry mixed in a tray for about 5 minutes. A uniform color was obtained without any cluster of cement, fly ash and bottom ash particles. Required quantities of coarse and fine aggregates were then mixed in dry state. The mix of cement and fly ash was added to the mix of coarse and fine aggregate and these were mixed thoroughly until a homogeneous mix was obtained. Water was then added in three stages:

- 50% of total water to the dry mix of concrete in first stage.
- 40% of water and super plasticizer to the wet mix.
- Remaining 10% of water was sprinkled on the above mix and it was thoroughly mixed in the mixer.

Fresh Properties of SCC & Normal Concrete

For determining the self-compacting properties slump-flow tests were performed twice and the average measurement was considered.

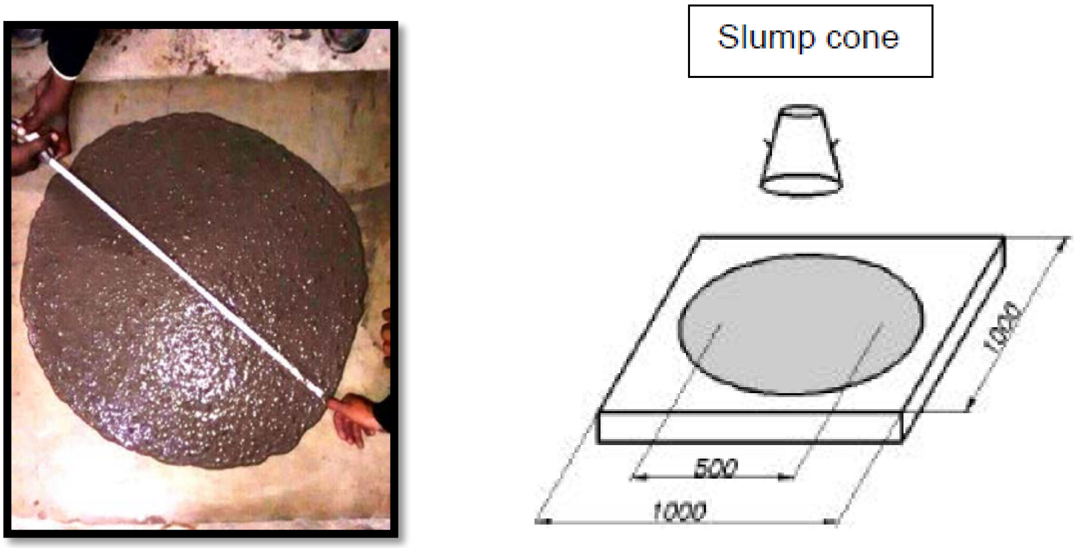


Figure 2 Measuring the Slump Flow of SCC

RESULTS AND DISCUSSION

The cube specimens were tested for compressive strength at the age of 7, 28 & 56 days and results of normal concrete mixes and SCC mixes, flow properties and compressive strength are presented here. The cost analysis of SCC was carried out to develop economical & sustainable SCC using Bottom Ash as partial replacement of sand & Fly Ash as partial replacement of cement.

Effect of Bottom Ash & Fly Ash on the Horizontal Slump Flow

The slump flow test is suitable to evaluate the Flowability of a fresh SCC mix. Figure 3 shows the variation of slump flow diameter with various percentages of bottom ash and fly ash. The slump flow test describes the flowability of a fresh mix in unconfined conditions. EFNARC (2005) [2] suggested a slump flow value ranging 660-750mm for SF2 which is suitable for many normal applications (e.g. walls columns). At slump flow >750mm, the concrete might segregate, and at <660mm, the concrete might have insufficient flow to pass through highly congested reinforcement. All the mixes in the study conform to the above range. The slump flow diameter of all the mixes were in the range of 675-740mm. all the mixes could be designated as SCC mixes.

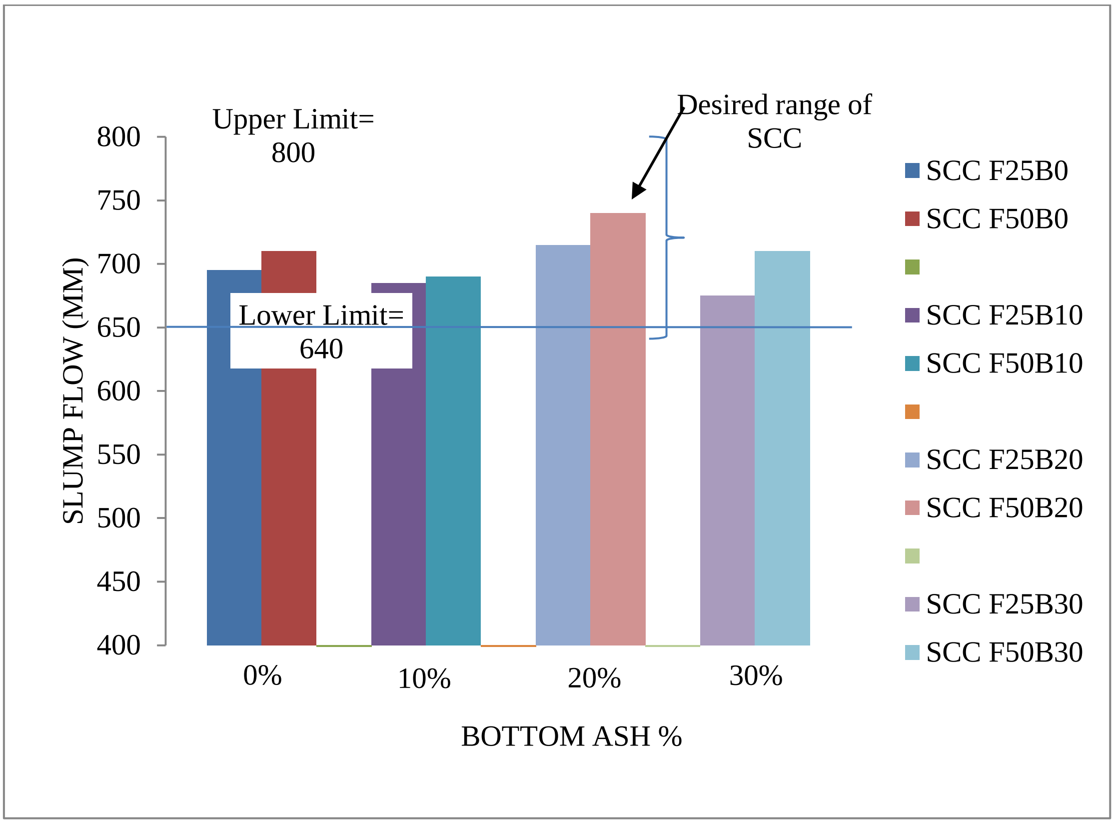


Figure 3 Slump Flow Diameter versus Bottom Ash Percentages for Various Fly Ash %age

Effect of Bottom Ash on Compressive Strength

The performance of hardened concrete of SCC mixes is assessed by measuring the compressive strength of cubes at the age of 7, 28 & 56 days.

The results of compressive strength for normal concrete mixes and SCC Mixes with different fly ash (25% & 50%) at different Bottom Ash %age are given in Table 11. The 7-days and 28-days compressive strength of mix NCF25B0 was 35.11 MPa and 50.67 MPa, respectively. With the increase in fly ash content, the strength of NCF50B0 gradually decreased to 20.44 MPa and 41.18 MPa at 7 & 28-days, respectively. This is a decrease of about 42% and 18.73% at 7 & 28-days respectively. It was observed that the percentage strength gain at age of 56days over the 28 days was slightly higher in concrete with 50% fly ash content against concrete with 25%fly ash content respectively and the decrease in compressive strength was reduced to 17.5%.

Figure 4 shows the variation of compressive strength with age for Normal concrete at different fly ash percentages. It indicates that the strength was found to increase with age for both the mixes. At 56-days, the percentage gain of strength for 50% fly ash content was higher as compared to mix with 25% fly ash content over the age of 28 days respective strength.

Table 11 Compressive strength of normal concrete & SCC mixes

MIX	STRENGTH (MPA) 7 DAYS	28 DAYS	56 DAYS
NCF25B0	35.11	50.67	57.48
NCF50B0	20.44	41.18	47.40
SCCF25B0	36.45	46.52	54.07
SCCF50B0	19.56	39.56	45.33
SCCF25B10	27.71	42.52	48.44
SCCF50B10	20.00	36.74	41.48
SCCF25B20	23.56	40.15	47.26
SCCF50B20	16.74	31.70	36.00
SCCF25B30	20.44	35.85	41.04
SCCF50B30	13.78	26.37	30.22

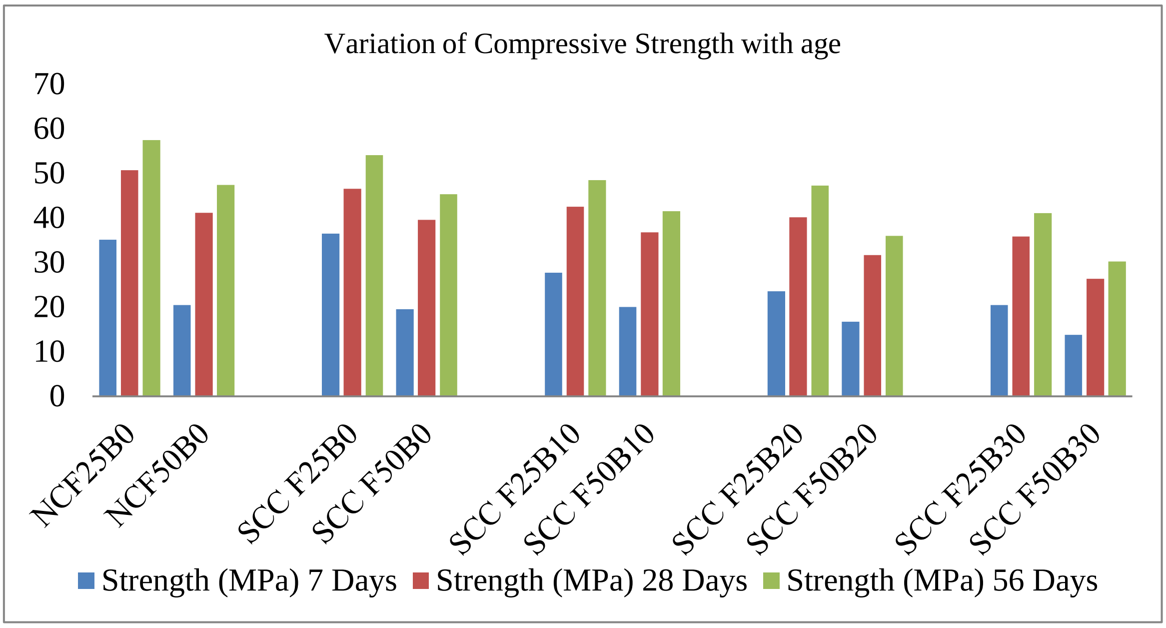


Figure 4 Variation of compressive strength with age for normal concrete

All the mixes showed strength gain at 28 days and beyond. The mixes with 25% and 50% fly ash gained strength in the order of 54.07 MPa and 45.33 MPa, respectively at 56-days. However, it was possible to produce SCC with a compressive strength of 39.56 MPa with 50% fly ash replacement. The bottom ash could be used up to 20% keeping in view the decrease of strength of about 14 to 20%, as they show higher decrease of strength. Fly ash percentage of 50% with bottom ash percentage up to 20% can be used for producing mix with strength ranging 30MPa to 36MPa. Thus, the optimum fly ash percentage without bottom ash was 50% and bottom ash percentage was up to 20% in the present study.

Effect of Bottom Ash on Water/Powder (W/P) Ratio

The influence of bottom ash on water/powder ratio of SCC mixes with various percentages of replacement of fine aggregate with bottom ash is presented in Figure 5. It shows that with the increase in bottom ash contents, the requirement for water is also increases which also affect the strength of concrete.

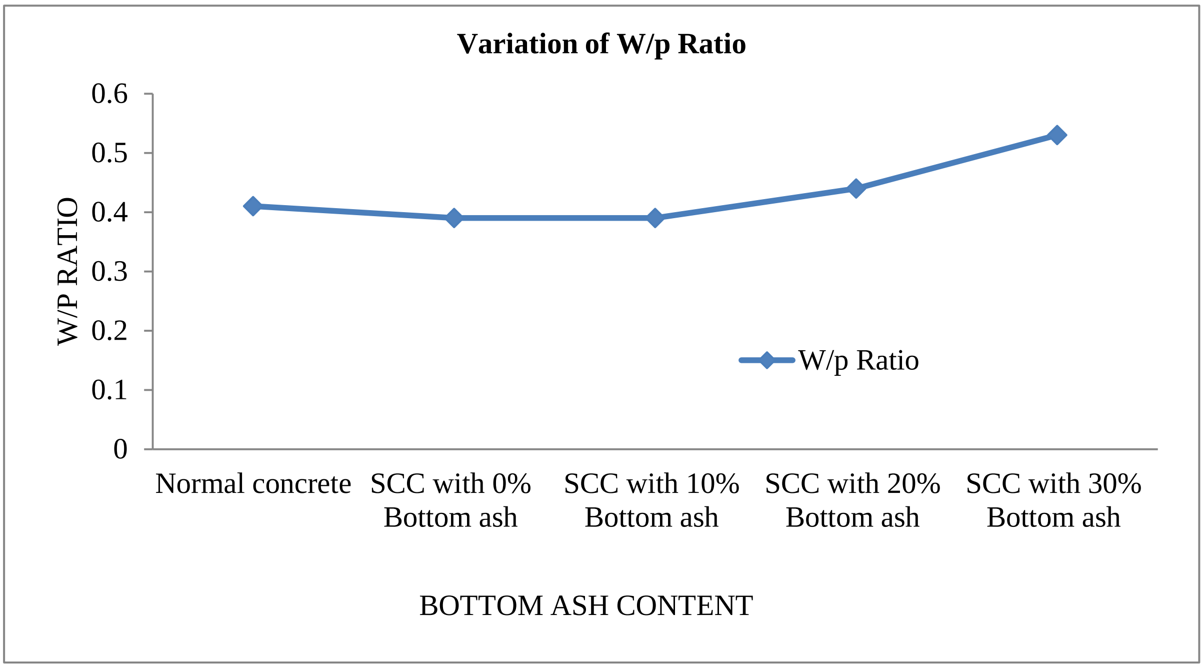


Figure 5 W/P Ratios in Normal Concrete and SCC With/Without Bottom Ash Contents as Partial Replacement of Fine Aggregates.

FINANCIAL IMPACT OF USING BOTTOM ASH AND FLY ASH IN SCC

Financial Impact

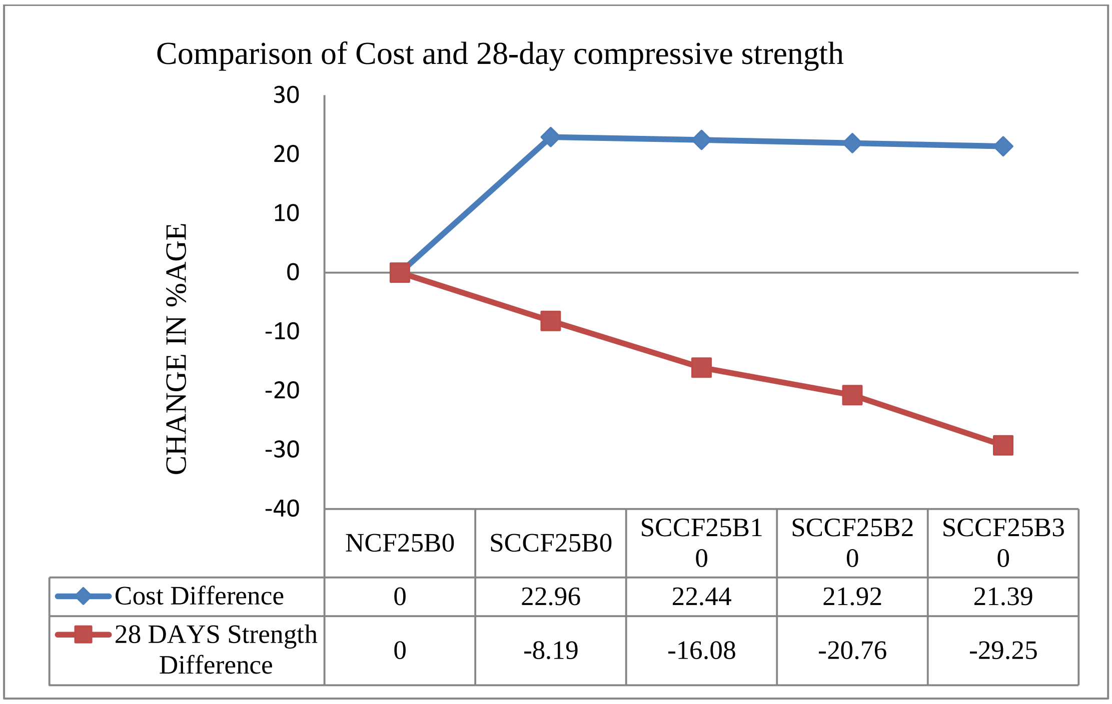
The major ingredients cost of Normal concrete mix and SCC mix having different percentages of bottom ash varying from 0% to 30% (with 25% fly ash contents as total powder content) are tabulated in Table 12 and 13. Cost difference from Normal control concrete (in Rs. And %age) is also tabulated in the table. It is observed from the table that the cost of SCC is reduced by partially replacing sand (fine aggregate) with bottom ash.

The major ingredient cost of SCC mix was 22.96% above that of normal concrete mix and with the use of bottom ash as partial replacement of sand, the cost difference was reduced to 22.44%, 21.92% and 21.39% at 10%, 20% and 30% replacement respectively. All the cost differences are calculated at the basis of prevailing market rates (in SAS Nagar, Punjab) of ingredients mentioned in the table 12 & 13.

Table 12 Major Ingredients Cost of Normal Concrete and SCC along with SCC Mixes having Different Bottom Ash Contents With 25% Fly Ash Contents as Total Powder Content

			NCF25B0		SCCF25B0		SCCF25B10		SCCF25B20		SCCF25B30	
INGREDIENTS	RATE AS PER SALES UNIT	RATE (RS./KG)	QTY	AMOUNT	QTY	AMOUNT	QTY	AMOUNT	QTY	AMOUNT	QTY	AMOUNT
Cement	Rs. 325 per 50 kg	6.5	280	1820	375	2437.5	375	2437.5	375	2437.5	375	2437.5
Fly Ash	Rate (incl. Carriage)	1.1	90	99	125	137.5	125	137.5	125	137.5	125	137.5
Sand	Rs. 950/ 1540 kg(cum)	0.6	759	455.4	899	539.4	809.1	485.46	719.2	431.52	629.3	377.58
Bottom Ash	Loading & carriage only	0.4	0	0	0	0	89.9	35.96	179.8	71.92	269.7	107.88
Coarse Aggregate	Rs. 1075/ 1410 kg (cum)	0.76	1170	889.2	735	558.6	735	558.6	735	558.6	735	558.6
Admixture	56.92	56.92	2.96	168.48	-	-	-	-	-	-	-	-
Fosroc Auramix400	136.8	136.8	-	-	4	547.2	4	547.2	4	547.2	4	547.2
Major ingredient cost			3432.08		4220.2		4202.22		4184.24		4166.26	
Cost Difference (in Rs.)			0		788.12		770.14		752.16		734.18	
Cost Difference (in %age of Normal concrete cost)			**0**		**22.96%**		**22.44%**		**21.92%**		**21.39%**	

Figure 6 shows the variation of cost and 28-day compressive strength of SCC mix having different bottom ash percentage (with 25% fly ash) with respect to cost & strength of normal concrete.



	NCF25B0	SCCF25B0	SCCF25B10	SCCF25B20	SCCF25B30
Cost Difference	0	22.96	22.44	21.92	21.39
28 DAYS Strength Difference	0	-8.19	-16.08	-20.76	-29.25

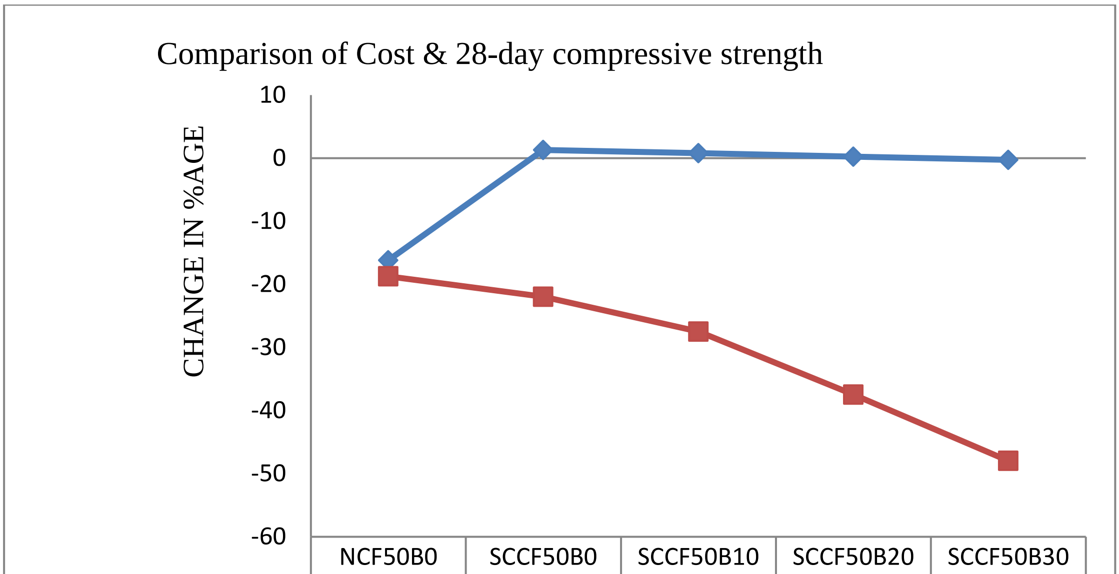
Figure 6 Variation of cost and 28 days compressive strength of concrete mix with varying percentage of bottom ash (25% fly ash)

With the increase in fly ash contents from 25% to 50%, the major ingredient cost of normal concrete (NCF50B0) was reduced by 16.17%. Whereas the cost of SCC mix with 0% bottom ash was observed to be just 1.3% costlier than normal concrete mix and with the use of bottom ash the cost was further reduced and the difference was reduced to 0.78%, 0.26% at 10% & 20% replacement respectively (after increasing fly ash contents to 50% of total powder contents). With the replacement of 30% sand with bottom ash and 50% cement with fly ash the SCC mix (SCCF50B30) was 0.27% cheaper than the normal concrete but fails to gain the required strength of the target grade at 28 days.

Table 13 Major ingredients cost of normal concrete and SCC along with scc mixes having different bottom ash contents with 50% fly ash contents as total powder content

			NCF50B0		SCCF50B0		SCCF50B10		SCCF50B20		SCCF50B30	
INGREDIENTS	RATE AS PER SALES UNIT	RATE (Rs./kg)	QTY	Amount	QTY	Amount	QTY	Amount	QTY	Amount	QTY	Amount
Cement	Rs. 325 per 50 kg	6.5	185	1202.5	250	1625	250	1625	250	1625	250	1625
Fly Ash	Rate (incl. Carriage)	1.1	185	203.5	250	275	250	275	250	275	250	275
Sand	Rs. 950/ 1540 kg(cum)	0.6	759	455.4	899	539.4	809.1	485.46	719.2	431.52	629.3	377.58
Bottom Ash	Loading & carriage only	0.4	0	0	0	0	89.9	35.96	179.8	71.92	269.7	107.88
Coarse Aggregate	Rs. 1075/ 1410 kg (cum)	0.76	1170	889.2	735	558.6	735	558.6	735	558.6	735	558.6
Admixture	56.92	56.92	2.22	126.36	-	-	-	-	-	-	-	-
Fosroc Auramix400	136.8	136.8	-	-	3.5	478.8	3.5	478.8	3.5	478.8	3.5	478.8
Major ingredient cost			2876.96		3476.8		3458.82		3440.84		3422.86	
Cost Difference (in Rs.)			-555.12		-743.4		-761.38		-779.36		-797.34	
Cost Difference (in %age of Normal concrete cost)			**-16.17%**		**1.3%**		**0.78%**		**0.26%**		**-0.27%**	

Figure 7 shows the variation of cost and 28-day compressive strength of SCC mix having different bottom ash percentage (with 50% fly ash) with respect to cost & strength of normal concrete. The cost of SCC having 50% fly ash is almost at par with the cost of normal concrete.



	NCF50B0	SCCF50B0	SCCF50B10	SCCF50B20	SCCF50B30
Cost Difference	-16.17	1.3	0.78	0.26	-0.27
28 DAYS Strength Difference	-18.73	-21.93	-27.49	-37.44	-47.96

Figure 7 Variation of Cost and 28 days Compressive Strength of Concrete Mix With Varying Percentage of Bottom Ash (50% Fly Ash)

CONCLUDING REMARKS

On the basis of present study, the following conclusions are drawn:

- The water requirement increases with increase in bottom ash.
- The fresh properties of the mix with 50% fly ash contents are less affected with the use of bottom ash as compared to mix with 25% fly ash.
- It was observed from this study that with the increase in age, the loss of strength due to use of bottom ash & fly ash decreases significantly.
- With the 50% fly ash as replacement of cement & 10% bottom ash as replacement of sand resulted in saving of 125 kg of cement and 89.9kg of natural sand without compromising the grade of concrete and bringing the major material cost of SCC almost at par with normal concrete, thereby resulting in net saving towards labour & energy requirement in placement, compaction, and finishing of SCC as compared to normal concrete.
- Based on the materials used in this study, the results suggested that it is technically feasible to utilize bottom ash as a part of fine aggregate & increase the fly ash percentage in total powder contents in the production of SCC. Besides environmental benefits, there could be some technical and financial advantages as well.

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