EFFECT OF COARSE AGGREGATE BLENDING ON FRESH PROPERTIES OF SELF COMPACTING CONCRETE

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ABSTRACT

This paper mainly focused on finding the optimization of coarse aggregate blending or proportion in a given coarse aggregate volume of self compacting concrete (SCC). Crushed granite stones of size 20mm and 10mm are used to study the effect of coarse aggregate blending on fresh properties of SCC. All the SCC mixes had 35% replacement of cement with class F fly ash and 0.36 water/cementitious ratio (w/cm) by weight. Studies revealed that coarse aggregate blending plays a vital role in the coarse aggregate content to obtain successful SCC mixes. Slump flow, V-Funnel and L-box tests are conducted to verify the rheological properties of SCC. It is observed that both mixes with 28% and 35% coarse aggregate content did not satisfy SCC criteria for coarse aggregate blending 67:33 (20mm and 10mm). For the coarse aggregate blending 60:40, mix with 28% coarse aggregate content satisfied SCC criteria. For the coarse aggregate blending 40:60, 28% to 32% coarse aggregate content is the acceptable range for successful SCC criteria.

KEYWORDS: *Coarse aggregate blending, coarse aggregate content, self compacting concrete.*

I. INTRODUCTION

According to ACI 237R-07, self compacting concrete (SCC) is highly flowable, non segregating concrete that can spread into place, fill the formwork and encapsulate the reinforcement without any mechanical consolidation [1]. Okamura in Japan proposed first the necessity of SCC in 1986. Ozawa and Maekawa produced the first prototype of SCC at the university of Tokyo in 1988 [16] and [19].
Compared to conventional concrete (CC), SCC possess enhanced qualities with better productivity and working conditions [8] and [18]. Because vibration is eliminated, the internal segregation between solid particles and the surrounding liquid is avoided which results in less porous transition zones between paste and aggregate and there by improved strength, durability of SCC and reduced labour cost, noise pollution can be obtained [19].
The workability of SCC can be characterized by the following three fresh properties (EFNARC, 2002) [10]:
Filling ability – It is the ability of SCC to flow under its own weight and to completely fill the formwork.
Passing ability – It is the ability of SCC to flow through restricted spaces without blocking.
Segregation resistance - It is the ability of SCC to remain uniform and cohesive during and after transporting and placing.
To ensure its high filling ability, flow without blockage and to maintain homogeneity, SCC requires a reduction in coarse aggregate content, high cement content, superplasticiser (SP) and viscosity modifying agent (VMA) [14]. According to Okamura (1997), blocking depends on the size, shape and

content of coarse aggregate. A reduction in the coarse aggregate content and lowering the size are both effective in inhibiting blocking [13].

Most SCC applications have used coarse aggregate with a maximum size in the range of 16~20 mm depending on local availability and practice [9] and [10].

As SCC requires high cement content that leads to increase in cost and temperature rise during hydration, additives or mineral admixtures such as fly ash, limestone powder or slag can generally be used as partial replacement of cement to reduce the cost and heat of hydration [14].

1.1. Selection of Materials and Mix Proportions

SCC can be made from any of the constituent materials that are normally considered for structural concrete [8]. In designing the SCC mix, it is most useful to consider the relative proportions of the key components by volume rather than by mass [10].

Worldwide, there is a wide range of mix proportions that can produce successful SCC. Typical range of proportions and quantities in order to obtain SCC are given below:

- Coarse aggregate content 28 to 35% by volume of the mix [10]
- Total powder content of 400 to 600 kg/m^3 of the mix [10]
- Paste volume of 34 to 40% of the concrete volume [17]
- Water/powder ratio by volume of 0.8 to 1.10 [10] or 0.8 to 1.2 [17]
- Water content up to about 200 litre/m^3 [10]
- Fine aggregate volume of 40 to 50% of the mortar volume [17]

Limiting values of proportions by weight are given below [17]:

- Coarse aggregate : 750 to 920 kg/m^3
- Fine aggregate : 710 to 900 kg/m^3
- Powder (Binder) : 400 to 600 kg/m^3
- Water : 150 to 200 kg/m^3

In reviewing literature on the methods for proportioning SCC, numerous methods exist, most of which give only general guidelines and ranges of quantities of materials to be used in SCC proportioning. The emphasis of these methods is on the fresh properties of SCC. Ghazi and Rand proposed a new mixture proportioning method for limestone powder blended SCC with a specified compressive strength [11].

1.2. Coarse Aggregate Selection

According to ACI 237R-07 [1], coarse aggregate size and volume are influential in obtaining the passing ability of SCC. As per ACI 301, particle shape of coarse aggregate is also significant in terms of affecting the workability of SCC [2]. Okamura and Ouchi (2003b) reported that the decrease in filling ability and passing ability due to an increase of the coarse aggregate content in concrete occurred regardless of its shape [15]. EFNARC [10] states that the lower the maximum aggregate size, the higher the volume of coarse aggregate.

According to ACI 237R-07, the blending of different sizes of stones can often be beneficial to improving the overall characteristics of the mixture. As a guideline to minimize blocking of SCC, if coarse aggregate size is greater than 12.5mm (1/2 in.), then coarse aggregate volume should be in the range of 28 to 32% of the volume of the mix [1].

1.3. Research Significance

As such, there is no data or specification available to specify the coarse aggregate content can be suitable to the particular coarse aggregate blending to make successful SCC. This leads to this research work to determine the suitable (optimum) coarse aggregate blending with 20mm and 10mm for the particular coarse aggregate content to obtain successful SCC.

1.4. Outline of This Paper

This paper includes the selection of materials and mix proportions for SCC from the relevant literature, the experimental program, material properties, SCC mix design and mix proportioning, tests on SCC fresh properties, results and discussion and conclusions.

II. EXPERIMENTAL STUDY

2.1. Experimental Program

Our objective was to determine the optimum blending of coarse aggregate with 20mm and 10mm for a given coarse aggregate content to make successful SCC. In this respect, 53 grade ordinary Portland cement (OPC 53), class F fly ash as an additive, crushed granite stones of size 20mm and 10mm with blending by percentage weight of total coarse aggregate as 67:33, 60:40 and 40:60, river sand, SP and VMA were used in preparing SCC mixes having w/cm 0.36 (by weight). The fresh properties that were determined are filling ability, passing ability and segregation resistance and consistence retention.

2.2. Material Properties

This section will present the chemical and physical properties of the ingredients. Bureau of Indian Standards (IS) and American Society for Testing and Materials (ASTM) procedures were followed for determining the properties of the ingredients in this investigation.

2.2.1. Cement

Ordinary Portland Cement 53 grade was used corresponding to IS-12269(1987) [7]. The physical and chemical properties of the cement as obtained by the manufacturer are presented in the Table 1.

2.2.2. Chemical Admixtures

Sika Viscocrete 10R is used as high range water reducer (HRWR) SP and Sika Stabilizer 4R is used as VMA. The properties of the chemical admixtures as obtained from the manufacturer are presented in the Table 2.

Table 1. Chemical Composition and Physical Properties of Cement

Particulars	Test Result	Requirement as per IS:12269-1987
Chemical Composition		
% Silica(SiO_2)	**19.79**	
% Alumina(Al_2O^3)	**5.67**	
% Iron Oxide(Fe_2O^3)	**4.68**	
% Lime(CaO)	**61.81**	
% Magnesia(MgO)	**0.84**	Not more Than 6.0%
% Sulphuric Anhydride (SO_3)	**2.48**	Max. 3.0% when $C_3A>5.0$ Max. 2.5% when $C_3A<5.0$
% Chloride content	**0.003**	Max. 0.1%
Lime Saturation Factor $CaO-0.7SO_3/2.8SiO_2+1.2Al_2O_3+0.65Fe_2O_3$	**0.92**	0.80 to 1.02
Ratio of Alumina/Iron Oxide	**1.21**	Min. 0.66
Physical Properties		
Specific gravity	**3.15**	
Fineness (m^2/Kg)	**311.5**	Min.225 m^2/kg
Soundness • Lechatlier Expansion(mm) • Auto clave Expansion (%)	**0.8** **0.01**	Max. 10mm Max. 0.8%
Setting time(minutes) Initial Final	 **90** **220**	 Min. 30 min Max. 600 min

Table 2. Properties of Chemical Admixtures

Chemical Admixture	Specific Gravity	Ph	Solid Content (%)	Quantity (%) by cementitious weight	Main Component
Sika Viscocrete 10R	1.10	5.0	40	0.6-2.0	Polycarboxylate Ether
Sika Stabilizer 4R	1.09	7.0	40	0.2-1.0	

2.2.3. Additive or Mineral Admixture

Class F fly ash produced from Rayalaseema Thermal Power Plant (RTPP), Muddanur, A.P is used as an additive according to ASTM C 618 [3]. As per IS-456(2000) [5], cement is replaced by 35% of fly ash by weight of cementitious material. The physical and chemical properties are presented in the Table 3.

Table 3. Physical and Chemical Properties of Class F Fly Ash

Particulars	Class F Fly Ash	ASTM C 618 Class F Fly Ash
Chemical Composition		
% Silica(SiO_2)	**65.6**	
% Alumina(Al_2O_3)	**28.0**	
% Iron Oxide(Fe_2O_3)	**3.0**	SiO_2+ Al_2O_3+ Fe_2O_3>70
% Lime(CaO)	**1.0**	
% Magnesia(MgO)	**1.0**	
% Titanium Oxide (TiO_2)	**0.5**	
% Sulphur Trioxide (SO_3)	**0.2**	Max. 5.0
Loss on Ignition	**0.29**	Max. 6.0
Physical Properties		
Specific gravity	**2.12**	
Fineness (m^2/Kg)	**360**	Min.225 m^2/kg

2.2.4. Coarse Aggregate

Crushed granite stones of size 20mm and 10mm are used as coarse aggregate. The bulk specific gravity in oven dry condition and water absorption of the coarse aggregate are 2.6 and 0.3% respectively. The gradation of the coarse aggregate was determined by sieve analysis as per IS-383(1970) [4] and presented in the Table 4 and Table 5.

Table 4. Sieve Analysis of 20 mm Coarse Aggregate

Sieve Size	Cumulative Percent Passing	
	20 mm	**IS: 383-1970 Limits**
20 mm	100	85-100
16 mm	56.17	N/A
12.5 mm	22.32	N/A
10 mm	5.29	0-20
4.75 mm	0	0-5

Table 5. Sieve Analysis of 10 mm Coarse Aggregate

Sieve Size	Cumulative Percent Passing	
	10 mm	**IS: 383-1970 Limits**
10 mm	99.68	85-100
4.75 mm	8.76	0-20
2.36 mm	2.4	0-5

Dry-rodded unit weight (DRUW) and void ratio of coarse aggregate with relative blending by percentage weight as per IS: 2386 (Part III)-1963 [6] is shown in Table 6 and Figure 1.

Table 6. Dry-rodded unit weight and Void Ratio of a given coarse aggregate blending

Coarse Aggregate Blending by Percentage Weight (20 mm and 10 mm)	DRUW (kg/m^3)	Void Ratio
100:0	1596	0.386
80:20	1642	0.368
70:30	1647	0.366
67:33	1659	0.362
60:40	1646	0.367
40:60	1631	0.373

20:80	1559	0.4
0:100	1533	0.41

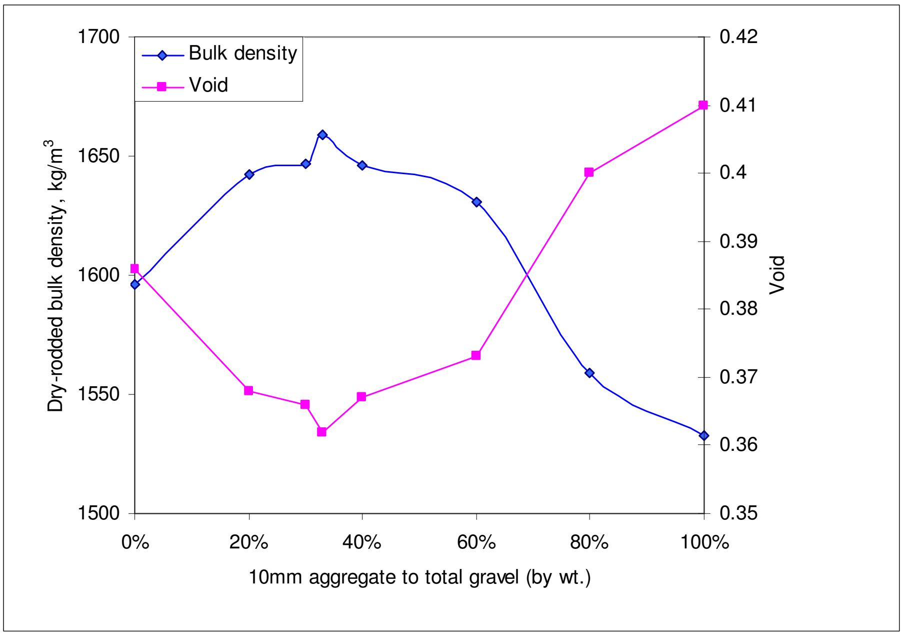


Figure 1. Dry-rodded unit weight and Void Ratio of a given coarse aggregate blending

2.2.5. Fine Aggregate

Natural river sand is used as fine aggregate. The bulk specific gravity in oven dry condition and water absorption of the sand are 2.6 and 1% respectively. The gradation of the sand was determined by sieve analysis as per IS-383(1970) [4] and presented in the Table 7. Fineness modulus of sand is 2.26.

Table 7. Sieve Analysis of Fine Aggregate

Sieve No.	Cumulative Percent Passing	
	Fine Aggregate	IS: 383-1970 – Zone III Requirement
3/8” (10mm)	100	100
No.4 (4.75mm)	100	90-100
No.8 (2.36mm)	100	85-100
No.16 (1.18mm)	99.25	75-100
No.30 (600µm)	65.08	60-79
No.50 (300µm)	7.4	12-40
No.100 (150µm)	1.9	0-10

2.2.6. Water

Ordinary tap water is used.

III. EXPERIMENTAL PROCEDURE

3.1. SCC Mix Design

Several methods exist for the mix design of SCC. The general purpose mix design method was first developed by Okamura and Ozawa (1995) [12]. In this study, the key proportions for the mixes are done by volume. The detailed steps for mix design are described as follows:

1. Assume air content as 2% (20 litres) of concrete volume.
2. Determine the dry-rodded unit weight (DRUW) of coarse aggregate for a given coarse aggregate blending.
3. Using DRUW, calculate the coarse aggregate content by volume (28 – 35%) of mix volume.
4. Adopt fine aggregate volume of 40 to 50% of the mortar volume.
5. Maintain paste volume of 388 litre/m^3 of the concrete volume.

6. Keep water/ cementitious ratio by weight (w/cm) as 0.36.
7. Calculate the binder (cementitious material) content by weight.
8. Replace cement with 35% Class fly ash by weight of cementitious material.
9. Optimize the dosages of super plasticizer (SP) and viscosity modifying agent for the given w/cm (0.36) using mortar tests by mini slump cone test.
10. Perform SCC tests.

3.2. SCC Mix Target

Typical acceptance criteria and target for SCC are shown in Table 8.

Table 8. Typical Acceptance Criteria and Target for SCC

Property	Test Method	Unit	SCC Mix Target	
			Minimum	Maximum
Filling ability	Slump Flow	Mm	650	750
	T_{50cm}	Sec	2	5
	V-Funnel	Sec	6	12
Passing ability	L-Box	h2/h1 (mm/mm)	0.8	1.0
Segregation resistance	V-Funnel at T_{5min}	Sec	6	15

3.3. Mixing procedure for SCC

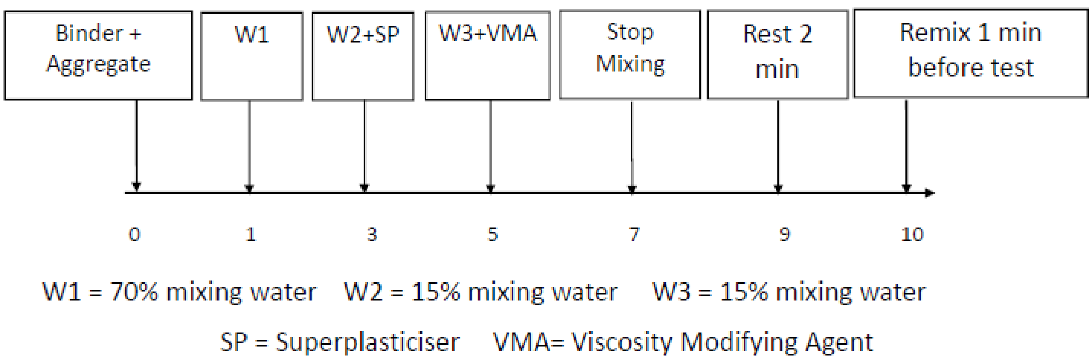


Figure 2. Mixing procedure for SCC with SP and VMA

Mixing procedure for SCC shown in Figure 2 is described as follows:

1. Binder and aggregate are mixed for one minute.
2. The 1st part (70%) of water was added and mixed for two minutes.
3. SP along with the 2nd part (15%) of water was added and mixed for two minutes.
4. VMA along with the 3rd part (15%) of water was added and mixed for two minutes.
5. The mix was stopped and kept rest for 2 minutes.
6. The mix was remixed for one minute and discharged for SCC tests.

3.4. Testing Fresh Properties of SCC [10]

3.4.1. Slump Flow Test

Slump flow test apparatus is shown in Figure 3(a). Slump cone has 20 cm bottom diameter, 10 cm top diameter and 30 cm in height. In this test, the slump cone mould is placed exactly on the 20 cm diameter graduated circle marked on the glass plate, filled with concrete and lifted upwards. The subsequent diameter of the concrete spread is measured in two perpendicular directions and the average of the diameters is reported as the spread of the concrete.

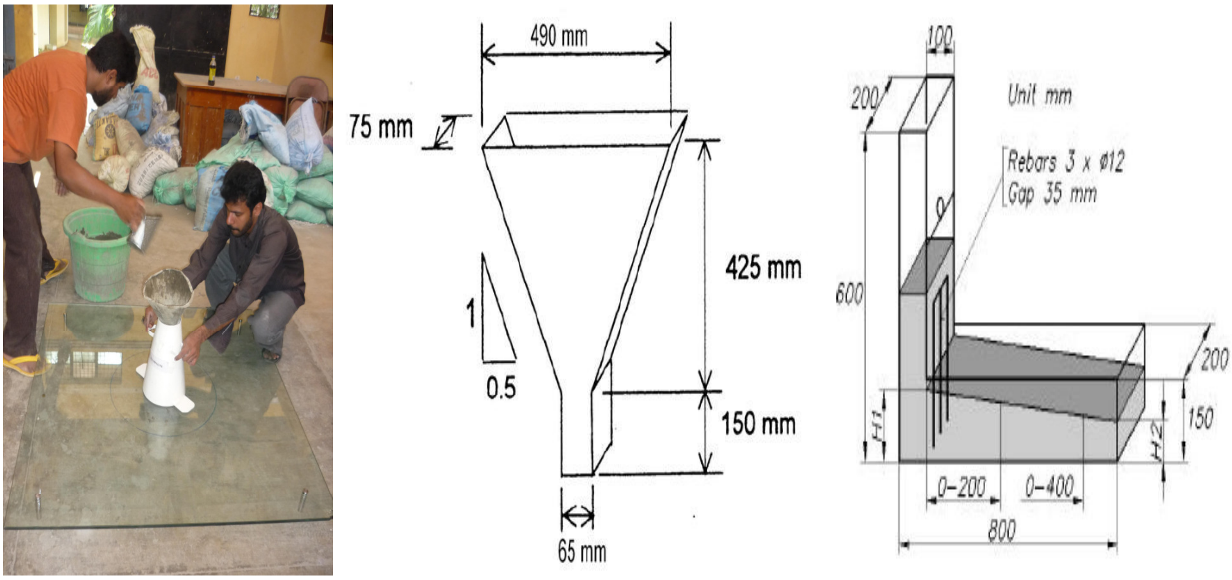
T_{50cm} is the time measured from lifting the cone to the concrete reaching a diameter of 50 cm. The measured T_{50cm} indicates the deformation rate or viscosity of the concrete.

3.4.2. V-Funnel Test

V-Funnel test apparatus dimensions are shown in Figure 3(b). In this test, trap door is closed at the bottom of V-Funnel and V-Funnel is completely filled with fresh concrete. V-Funnel time is the time measured from opening the trap door and complete emptying the funnel. Again, the V-Funnel is filled with concrete, kept for 5 minutes and trap door is opened. V-Funnel time is measured again and this indicates V-Funnel time at T_{5min}.

3.4.3 L-Box Test

L-Box test apparatus dimensions are shown in Figure 3(c). In this test, fresh concrete is filled in the vertical section of L-Box and the gate is lifted to let the concrete to flow into the horizontal section. The height of the concrete at the end of horizontal section represents h2 (mm) and at the vertical section represents h1 (mm). The ratio h2/h1 represents blocking ratio.



(a) Slump Flow Test (b) V-Funnel Test (c) L-Box Test

Figure 3. Schematic of SCC Tests

3.4.4. Determination of Consistence Retention

Consistence retention is also an important fresh property of SCC in view of workability. It refers to the period of duration during which SCC retains its properties, which is important for transportation and placing. Consistence retention was evaluated by measuring the slump flow spread and T_{50cm} of successful SCC mixes at 60 minutes after adding water. The SCC mix was remixed for one minute before each test.

3.5. Mix Proportions

Mix types with percentage relative proportions and mix proportions of constituent materials are shown in Table 9 and Table 10.

Table 9. Percentage Relative Proportions of mixes

Cementitious Material – OPC+35%Fly Ash					w/cm – 0.36	
Mix Type	Coarse Aggregate Blending Percentage By Weight (20 mm and 10 mm)		Percentage of Coarse aggregate	Percentage of Mortar	Percentage of Sand in Mortar	Percentage of Paste
			By Volume			
35_67:33	67	33	35.03	64.97	40.3	38.8
28_67:33	67	33	28.08	71.92	46.1	38.8
28_60:40	60	40	28.05	71.95	46.1	38.8
30_60:40	60	40	30.01	69.99	44.6	38.8
28_40:60	40	60	28.04	71.96	46.1	38.8
32_40:60	40	60	31.99	68.01	43.0	38.8
34_40:60	40	60	34.00	66.00	41.2	38.8

Table 10. Mix Proportions of Constituent Materials

Mix Type	Binder kg/m^3	Cement Kg/m^3	Fly Ash Kg/m^3	Water l/m^3	20mm kg/m^3	10mm kg/m^3	Sand kg/m^3	SP l/m^3	VMA l/m^3
35_67:33	495	321.75	173.25	178.2	610.23	300.56	680.75	4.46	0.99
28_67:33	495	321.75	173.25	178.2	489.07	240.89	862.09	4.46	0.99
28_60:40	495	321.75	173.25	178.2	437.51	291.67	862.45	4.46	0.99
30_60:40	495	321.75	173.25	178.2	468.12	312.08	811.63	4.46	0.99
28_40:60	495	321.75	173.25	178.2	291.62	437.43	862.50	4.46	0.99
32_40:60	495	321.75	173.25	178.2	332.72	499.09	760.32	4.46	0.99
34_40:60	495	321.75	173.25	178.2	353.60	530.40	706.99	4.46	0.99

IV. RESULTS AND DISCUSSION

4.1. SCC Fresh Properties

SCC fresh properties i.e., slump flow, T_{50cm} at initial and at 60 minutes, V-Funnel time, V-Funnel time at 5 minutes (T_{5min}) and L-Box ratio (h2/h1) are presented in the Table11 for all the mixes.

Table 11. Fresh Properties of SCC

Mix Type	Slump Flow (mm)		T_{50cm} (sec)		V-Funnel Time (sec)		L-Box Ratio (h2/h1)
	Initial	At 60 min	Initial	At 60 min	Initial	T_{5min}	
35_67:33[a]	640	ND[b]	8.2	ND	Blocked	Blocked	Blocked
28_67:33	685	ND	4.51	ND	10.21	13.23	Blocked
28_60:40	696	657	3.12	4.28	6.23	7.59	0.81
30_60:40	687	ND	4.06	ND	11.13	14.41	Blocked
28_40:60	710	651	2.76	3.76	4.32	6.41	1.0
32_40:60	695	649	3.24	4.34	6.35	8.12	0.82
34_40:60	688	ND	5.06	ND	11.69	14.31	Blocked

[a]35_67:33: where 35 is the percentage of coarse aggregate volume in a concrete mix
67:33 is the coarse aggregate blending by percentage weight of 20mm and 10mm resp.
[b]ND: Not done

From the above Table 11, it is seen that though the mix 35_67:33 got the slump flow spread of 640mm in 8.2sec as shown in Figure 4, this mix was failed in V-Funnel and L-Box tests. The blocking was due to 67% of 20mm aggregate in 35% of coarse aggregate volume in the mix that leads to more collision and internal friction within the coarse aggregate particles. It is clearly observed that both coarse aggregate maximum size and coarse aggregate volume are influential in obtaining the passing ability of SCC and the same is confirming to ACI 237R-07 [1].

The mix 28_67:33 was succeeded in slump flow and V-Funnel tests, but the mix was failed in L-Box test. Though the coarse aggregate volume was 28%, but the influence of 67% of 20mm aggregate in the coarse aggregate content caused the blocking. As the minimum coarse aggregate content was 28% in this study, effect of the blending 67:33 was not tried for the coarse aggregate content less than 28%. So, for the coarse aggregate blending 67:33, both mixes 35_67:33 and 28_67:33 have not met the SCC acceptance criteria.

It is observed that the mix 28_60:40 was success and met the SCC acceptance criteria as shown in Figure 5(a). As compared to the mix 28_67:33, when the blending changed from 67:33 to 60:40, blocking of coarse aggregate was not observed in L-Box test as shown in Figure 5(b). The 60:40 blending reduced the yield stress or internal friction and increased the deformation rate.

The mix 30_60:40 was also failed in L-Box test as shown in Figure 6, though it was succeeded in slump flow and V-Funnel tests. The reason was that for the blending 60:40, the increase of coarse aggregate content from 28% to 30% increased the volume of 20mm aggregate and leads to blocking of the aggregates. This is inline with the statement that the filling ability and passing ability decreases with an increase in the coarse aggregate content in concrete [15].

So, for the coarse aggregate blending 60:40, only the mix 28_60:40 was met the SCC acceptance criteria.

It is noted that for coarse aggregate blending 40:60, both mixes 28_40:60 and 32_40:60 were met the SCC acceptance criteria. It is practically seen that though the volume of coarse aggregate was increased from 28% to 32%, the influence of 40:60 (20mm and 10mm) blending didn't affect the fresh properties of the mix 32_40:60. It can be stated that lower volume of maximum size aggregate (i.e., 20mm) let the coarse aggregate content to increase to some reasonable extent.
But the increase of coarse aggregate content from 32% to 34% for the same blending 40:60 caused the mix 34_40:60 blocking in L-Box test. This is due to more coarse aggregate content as compared to that of the mix 32_40:60.
Interestingly it is seen that both mixes 28_60:40 and 32_40:60 were almost similarly performed the fresh properties. So, it is to be mentioned that if higher volume of maximum size (20mm) aggregate has to be used, the coarse aggregate content has to be adjusted. Similarly, if the coarse aggregate content has to be increased, the volume of maximum size (20mm) aggregate has to be adjusted. So, either volume of maximum size (20mm) aggregate or coarse aggregate volume has to be adjusted for a particular coarse aggregate blending.
For the failure mixes 34_67:33, 28_67:33, 30_60:40 and 34_40:60, the consistence retention measurements i.e., slump flow and T_{50cm} at 60 minutes were not performed.
The typical range of coarse aggregate content suitable for a particular coarse aggregate blending is represented as shown in Table 12.

Table 12. Coarse aggregate content for a particular coarse aggregate blending

Coarse aggregate blending (20mm & 10mm)	Coarse aggregate content
67:33	<28%
60:40	28%
40:60	28% to 32%

Figure 4. Slump Flow of 35_67:33 Mix

(a) Slump Flow of 28_60:40 Mix (b) L-Box Test of 28_60:40 Mix

Figure 5. Fresh Properties of 28_60:40 Mix

Figure 6. L-Box Test of 30_60:40 Mix

V. CONCLUSIONS

The following conclusions have been drawn based on the investigation studied on the effect of coarse aggregate blending on SCC:

1. Both coarse aggregate maximum size and coarse aggregate volume are influential in obtaining the successful SCC mixes.
2. A change in coarse aggregate blending for a particular coarse aggregate content influences the fresh properties of SCC.
3. Though some mixes are successful in slump flow test, they are failed in L-Box test due to coarse aggregate blocking for a given coarse aggregate blending in a particular coarse aggregate content.
4. If the coarse aggregate content has to be increased, the volume of maximum size aggregate has to be reduced in a particular coarse aggregate blending. If the volume of maximum size aggregate has to be increased, the coarse aggregate content has to be reduced. In other words, a change in coarse aggregate blending plays a vital role and reflects the fresh properties of SCC for a particular coarse aggregate content.
5. Choosing a coarse aggregate content for a particular coarse aggregate blending is critical and challenging one. This study concludes the range of coarse aggregate content suitable for a particular coarse aggregate blending as given in Table 12.
6. It is observed that both mixes 28_60:40 and 32_40:60 performed SCC fresh properties almost similarly.

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