A SIMPLE TOOL FOR SELF COMPACTING CONCRETE MIX DESIGN

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ABSTRACT
SCC can be made from any of the constituents that are generally used for structural concrete. In the mix design of SCC, the relative proportions of key components are generally considered by volume rather than by mass. On the basis of these proportions, a simple tool has been designed for self compacting concrete (SCC) mix design. In this paper, this tool has been evaluated with a SCC mix having 28% of coarse aggregate content, 35% replacement of cement with class F fly ash, 0.36 water/cementitious ratio (by weight) and 388 litre/m^3 of paste volume. Crushed granite stones of size 20mm and 10mm are used with a blending 60:40 by percentage weight of total coarse aggregate. Detailed steps used in this tool are discussed in this study. This tool can also be used for self compacting mortar (SCM) design. It is practically seen that this simple tool is very much useful for the mix design of SCC with or without blended cement and with or without coarse aggregate blending..

KEYWORDS: *Self compacting concrete, mix design, simple tool, self compacting mortar.*

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]. Professor Okamura in Japan proposed a concept for a design of concrete independent of the need for compaction in 1986. Ozawa and Maekawa produced the first prototype of SCC at the university of Tokyo in 1988 [14] and [15]. The general purpose mix design method was first developed by Okamura and Ozawa [12].

Recommendations on the design and applications of SCC in construction have been developed by many professional societies like American Concrete Institute (ACI), American Society for Testing and Materials (ASTM), European Federation of National Trade Associations (EFNARC 2002) etc. Although SCC has passed from research stage to field applications, there are no systematic standards or specifications to be followed in its mixture proportioning [9].

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 [8]. From the review of previous research on SCC, it was found that the EFNARC method for proportioning SCC have been used extensively.

SCC with low yield stress will be achieved by adding superplasticiser (SP), water, paste or some additives (fly ash or GGBS) [11]. Viscosity is controlled by changing water content, paste content or adding some additives (fly ash) or viscosity modifying agent (VMA) [10] and [11].

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 [13].

1.1 Selection of Mix Proportions

In designing the SCC mix, it is most useful to consider the relative proportions of the key components by volume rather than by mass [7]. The following key proportions for the mixes listed below [12], [7], [10] and [6]:

1. Air content (by volume)
2. Coarse aggregate content (by volume)
3. Paste content (by volume)
4. Binder (cementitious) content (by weight)
5. Replacement of mineral admixture by percentage binder weight
6. Water/ binder ratio (by weight)
7. Volume of fine aggregate/ volume of mortar
8. SP dosage by percentage cementitious (binder) weight
9. VMA dosage by percentage cementitious (binder) weight

1.2. Research Significance

A simple and user friendly tool has been developed for SCC mix design ("JGJ_SCCMixDesign.xls") on the basis of key proportions of the constituents of SCC with or without blended cement and with or without coarse aggregate blending.

1.3. Outline of This Paper

This paper includes the selection of mix proportions for SCC from the relevant literature, the experimental program, material properties, design of SCC mix design tool, calculation of key proportions for a given SCC scenario, evaluation of SCC mix design and conclusions.

II. EXPERIMENTAL STUDY

2.1. Experimental Program

Our objective was to develop a simple tool for SCC mix design with the available materials. In this study, this tool has been used to design a SCC mix having 28% of coarse aggregate content and 388 litre/m^3 of paste volume, 35% replacement of cement with class F fly ash and 0.36 water/cementitious ratio (by weight). Crushed granite stones of size 20mm and 10mm are used with the blending 60:40 by percentage weight of total coarse aggregate.

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) [5]. The specific gravity of cement is 3.15.

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. Percentage of dry material in SP and VMA is 40%.

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 [2]. As per IS-456(2000) [3], cement is replaced by 35% of fly ash by weight of cementitious material. The specific gravity of fly ash is 2.12.

2.2.4. Coarse Aggregate

Crushed granite stones of size 20mm and 10mm are used as coarse aggregate. As per IS: 2386 (Part III)-1963 [4], the bulk specific gravity in oven dry condition and water absorption of the coarse aggregate are 2.6 and 0.3% respectively. The dry-rodded unit weight (DRUW) of the coarse aggregate with the coarse aggregate blending 60:40 (20mm and 10mm) as per IS: 2386 (Part III)-1963 [4] is 1646 kg/m^3.

2.2.5. Fine Aggregate

Natural river sand is used as fine aggregate. As per IS: 2386 (Part III)-1963 [4], the bulk specific gravity in oven dry condition and water absorption of the sand are 2.6 and 1% respectively.

2.2.6. Water

Ordinary tap water is used.

III. DESIGN OF SELF COMPACTING CONCRETE MIX DESIGN TOOL

3.1. Material Properties for SCC Mix Design Tool

The following material properties for the SCC mix design tool are to be determined as shown in Table 1.

1. Specific gravity of cement, fly ash, coarse aggregate and fine aggregate.
2. Percentage of water absorption of coarse and fine aggregates.
3. Percentage of moisture content in coarse and fine aggregates.
4. Dry-rodded unit weight (DRUW) of coarse aggregate for the particular coarse aggregate blending.
5. Percentage of dry material in SP and VMA.

Table 1. Material Properties

Material Data			
Material	**Specific Gravity**	**% Absorption**	**% Moisture**
Cement	3.15	N/A	N/A
Additive – Fly Ash	2.12	N/A	N/A
Coarse aggregate (CA1 20mm)	2.6	0.3	0
Coarse aggregate (CA2 10mm)	2.6	0.3	0
Fine aggregate (Sand)	2.6	1.0	0

3.2. Detailed Steps for SCC Mix Design Tool

The detailed steps for mix design are described as follows:

1. Assume air content by percentage of concrete volume.
2. Input the coarse aggregate blending by percentage weight of total coarse aggregate.
3. Input the percentage of coarse aggregate in DRUW to calculate the coarse aggregate volume in the concrete volume.
4. Adjust the percentage of fine aggregate volume in mortar volume.
5. Obtain the required paste volume.
6. Adopt suitable water/ binder ratio by weight.
7. Input the percentage replacement of fly ash by weight of cementitious material.
8. Input the dosage of SP and VMA (if required) by percentage weight of binder.
9. Adjust the binder (cementitious material) content by weight to obtain the required paste.

The coarse aggregate optimization is shown in Table 2. The input parameters section is shown in Table 3.

Table 2. Coarse Aggregate Optimization or Blending

Coarse aggregate optimization	
Material	**% by weight**
CA1 20mm	60
CA2 10mm	40

Table 3. Input Parameters Section

Input parameters	
Dry Rodded Unit Weight(kg/cum)	1646
% of CA in DRUW	44.3
% of Sand in Mortar	46.1
% of Fly ash	35
Wt. Water/Binder	0.36
Binder (kg/cum)	495
SP (% wt.of binder)	0.9

VMA (% wt. of binder)	0.2
% of Air	2
% of dry material in SP	40
% of dry material in VMA	40

3.3. Output Constituent Materials for SCC

After giving all the necessary data, the tool automatically calculates and shows the required out put. Concrete mix proportions by volume and total aggregate by weight are shown in Table 4.

Table 4. Concrete Mix Proportions by Volume

Coarse aggregate (kg/cum)			**729.178**
% of CA in concrete volume			**28.04530769**
Concrete Mix proprtions by volume (lit/cum)			
CA	**Mortar**	**Sand**	**Paste**
280.4531	**719.5469**	**331.7111**	**387.8357915**
Sand (kg/cum)			**862.448942**
Total aggregates (kg/cum)			**1591.626942**

Paste composition is shown in Table 5. Constituent materials for SCC are shown in Table 6. Constituent materials for SCM are shown in Table 7. This tool also displays the constituent materials for the required volume of SCC or SCM as shown in Table 6 and Table 7. Aggregate proportions by volume and by weight are shown in Table 8.

Table 5. Paste Composition

Vol. Water/Powder				**0.969191695**	
Paste composition					
Kg/cum					**lit/cum**
Cement	**Fly ash**	**Water**	**SP**	**VMA**	**Paste**
321.75	**173.25**	**178.2**	**4.455**	**0.99**	**387.5096**

Table 6. Constituent Materials for SCC

Constituent Materials for Concrete				
Material (kg/cum)	**Initial**	**Adjusted**	**Required (cum)** **0.0062**	**g/ml**
Cement	**321.75**	**321.75**	**1.99485**	**1994.85**
Fly Ash	**173.25**	**173.25**	**1.07415**	**1074.15**
Water	**178.2**	**185.745**	**1.151619145**	**1151.619**
CA1 20mm	**437.5068**	**437.5068**	**2.71254216**	**2712.542**
CA2 10mm	**291.6712**	**291.6712**	**1.80836144**	**1808.361**
Sand	**862.4489**	**862.4489**	**5.34718344**	**5347.183**
SP (lit)	**4.455**	**4.455**	**0.027621**	**27.621**
VMA (lit)	**0.99**	**0.99**	**0.006138**	**6.138**
Unit Weight	**2270.272**	**Total (kg)**	**14.12246519**	**14122.47**
		Litres	**6.12075648**	

Table 7. Constituent Materials for SCM

Constituent Materials for Mortar				
Material (kg/cum)	**Initial**	**Adjusted**	**Required (cum)** **0.0008**	**g/ml**
Cement	**321.75**	**321.75**	**0.2574**	**257.4**
Fly Ash	**173.25**	**173.25**	**0.1386**	**138.6**
Water	**178.2**	**183.5575**	**0.146845992**	**146.846**
Sand	**862.4489**	**862.4489**	**0.689959154**	**689.9592**
SP (lit)	**4.455**	**4.455**	**0.003564**	**3.564**

VMA (lit)	**0.99**	**0.99**	**0.000792**	**0.792**
Unit Weight	**1541.094**	**Total (kg)**	**1.237161145**	**1237.161**
		Litres	**0.563662541**	

Table 8. Aggregate Proportions by Volume and by Weight

Aggregate Proportions		
Material	**% by Vol**	**% by Weight**
CA1 20mm	**27.48802**	**27.48802426**
CA2 10mm	**18.32535**	**18.32534951**
Sand	**54.18663**	**54.18662623**
Total	**100**	**100**

IV. CALCULATION OF KEY PROPORTIONS

The detailed steps for calculation of key proportions are presented below with an example. The interface of SCC mix design tool for the mix 28_60:40 is shown in Figure 1.

SCC Mix Scenario: A SCC mix with 28% coarse aggregate content of concrete volume with a paste volume of 388 litre/m^3 have been designed for water/ binder ratio 0.36 (by weight). Cement has been replaced with 35% of Class F fly ash by percentage weight of cementitious material. Coarse aggregate of sizes 20mm and 10mm with coarse aggregate blending 60:40 by percentage weight of total aggregate are used in this mix. SP and VMA are used. All the material properties and input parameters are shown in Table 1 and Table 3. Air content assumed as 2% of concrete volume.

4.1. Calculation of Coarse Aggregate Content in Concrete Volume

Coarse aggregate blending	:	60:40
Specific gravity of 20mm & 10mm	:	2.6
DRUW of coarse aggregate	:	1646 kg/m^3
% of Coarse aggregate in DRUW	:	44.3
Coarse aggregate weight	:	1646*(44.3/100) = 729.18 kg/m^3
Coarse aggregate volume	:	[(729.18*(60/100))/2.6] + [(729.18*(60/100))/2.6] =280.45 litre/m^3 or 28.05%

4.2. Calculation of Mortar Volume

Mortar Volume	:	Concrete volume-coarse aggregate volume
	:	1000-280.45 = 719.55 litre/m^3

4.3. Calculation of Sand Volume

% of sand in Mortar volume	:	46.1
Sand Volume	:	719.55*(46.1/100) = 331.71 litre/m^3

4.4. Calculation of Paste Volume

Paste Volume	:	Mortar volume-sand volume
	:	719.55-331.71 = 387.84 litre/m^3

4.5. Calculation of Paste Composition

Specific gravity of cement	:	3.15
Specific gravity of fly ash	:	2.12
Air content	:	2% = 20 litre/m^3
Water/ binder ratio (by weight)	:	0.36
% of fly ash by weight of binder	:	35
% of SP by weight of binder	:	0.9
% of VMA by weight of binder	:	0.2
Binder	:	495 kg/m^3
Fly ash	:	495*(35/100) = 173.25 kg/m^3
Cement	:	495-173.25 = 321.75 kg/m^3
Water	:	495*0.36 = 178.2 litre/m^3

Volume of cement : 321.75/3.15 = 102.14 litre/m^3
Volume of fly ash : 173.25/2.12 = 81.72 litre/m^3
SP : 495*(0.9/100) = 4.46 litre/m^3
VMA : 495*(0.2/100) = 0.99 litre/m^3
Total Paste volume : Volume of (cement+fly ash+Water+SP+VMA+Air)
102.14+81.72+178.2+4.46+0.99+20=387.51 litre/m^3

In the tool, the binder has been adjusted to 495 kg/m^3 in order to obtain the required paste volume of about 387.51 litre/m^3 (say 388 litre/m^3).

4.6. Calculation of Constituent Materials for Concrete

Specific gravity of sand : 2.6
% of absorption of 20mm : 0.3
% of absorption of 10mm : 0.3
% of absorption of sand : 1.0
% of moisture in 20mm : 0.0
% of moisture in 10mm : 0.0
% of moisture in sand : 0.0
% of dry material in SP : 40
% of dry material in VMA : 40
Cement : 321.75 kg/m^3
Fly ash : 173.25 kg/m^3
Initial water content : 178.2 litre/m^3
Coarse aggregate : 729.18 kg/m^3
20mm coarse aggregate (CA1) : 729.18*(60/100) = 437.51 kg/m^3
10mm coarse aggregate (CA2) : 729.18*(40/100) = 291.67 kg/m^3
Sand : 331.71*2.6 = 862.46 kg/m^3

Adjusted water content = Initial water - [CA1*(% of moisture - % of absorption)/100]
- [CA2*(% of moisture - % of absorption)/100]
- [sand*(% of moisture - % of absorption)/100]
- [SP*(100-%of dry material in SP)/100]
- [VMA*(100-%of dry material in VMA)/100]
= 178.2 - [437.51*(0-0.3)/100]-[291.67*(0-0.3)/100]
- [862.46*(0-1)/100]-[4.46*(100-40)/100]-[0.99*(100-40)/100]
= 185.75 litre/m^3

Adjusted 20mm coarse aggregate : CA1*[1+(% of moisture/100)]
437.51*[1+(0/100)] = 437.51 kg/m^3

Adjusted 10mm coarse aggregate : CA2*[1+(% of moisture/100)]
291.67*[1+(0/100)] = 291.67 kg/m^3
Adjusted sand : sand*[1+(% of moisture/100)]
862.46*[1+(0/100)] = 862.46 kg/m^3

4.7. Calculation of Constituent Materials for Mortar

Coarse aggregate contribution should not be considered in the adjustment of water. The remaining constituents are already discussed in the section 4.6.

Initial water content : 178.2 litre/m^3

Adjusted water content = Initial water - [sand*(% of moisture - % of absorption)/100]
- [SP*(100-%of dry material in SP)/100]
- [VMA*(100-%of dry material in VMA)/100]
= 178.2 - [862.46*(0-1)/100]-[4.46*(100-40)/100]-[0.99*(100-40)/100]
= 183.56 litre/m^3

4.8. 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 SCC Mix

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			
28_60:40 [a]	60	40	28.05	71.95	46.1	38.8

[a]28_60:40: where 28 is the percentage of coarse aggregate volume in a concrete mix
60:40 is the coarse aggregate blending by percentage weight of 20mm and 10mm resp.

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
28_60:40	495	321.75	173.25	178.2	437.51	291.67	862.46	4.46	0.99

V. EVALUATION OF SCC MIX DESIGN

The SCC mix designed by the SCC mix design tool has been evaluated by conducting the SCC fresh properties tests on the 28_60:40 SCC mix.

5.1. 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 the SCC mix 28_60:40.

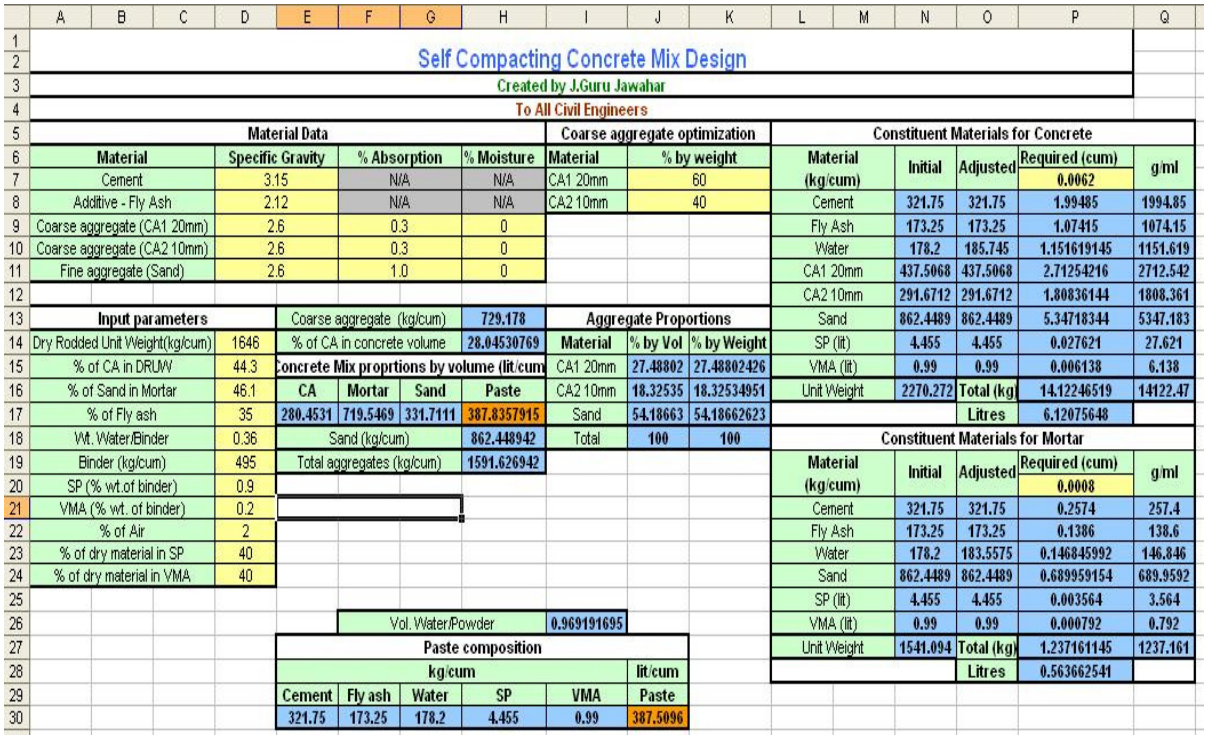
Table 11. Fresh Properties of SCC

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}	
28_60:40	696	657	3.12	4.28	6.23	7.59	0.81

As it can be seen from the above results, the mix 28_60:40 has met the SCC acceptance criteria mentioned by EFNARC [7]. Hence, it is practically seen that SCC mix design tool is very much useful in designing any SCC mix. The only challenge in getting successful SCC mix is the adjusting the key proportions of the constituents.

VI. CONCLUSIONS

The following conclusions can be drawn on the basis of SCC mix design tool:
Self compacting concrete mix design tool is developed based on the key proportions of the constituents. This tool is very simple and user friendly for the self compacting concrete mix design.
This tool can be used for the SCC mix with or without blended cement and coarse aggregate with or without coarse aggregate blending. This tool can also be enhanced for multi blended cements with more additives.
This tool is also useful for Self compacting mortar design. It displays all necessary data for SCC mix design and also displays constituent materials for SCC or SCM for the required volume.



Self Compacting Concrete Mix Design

Created by J.Guru Jawahar

To All Civil Engineers

Material Data

Material	Specific Gravity	% Absorption	% Moisture
Cement	3.15	N/A	N/A
Additive - Fly Ash	2.12	N/A	N/A
Coarse aggregate (CA1 20mm)	2.6	0.3	0
Coarse aggregate (CA2 10mm)	2.6	0.3	0
Fine aggregate (Sand)	2.6	1.0	0

Coarse aggregate optimization

Material	% by weight
CA1 20mm	60
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Input parameters

Dry Rodded Unit Weight(kg/cum)	1646
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% of Fly ash	35
Wt. Water/Binder	0.36
Binder (kg/cum)	495
SP (% wt.of binder)	0.9
VMA (% wt. of binder)	0.2
% of Air	2
% of dry material in SP	40
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Coarse aggregate (kg/cum)	729.178
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Total aggregates (kg/cum)	1591.626942

Concrete Mix proprtions by volume (lit/cum)

CA	Mortar	Sand	Paste
280.4531	719.5469	331.7111	387.8357915

Aggregate Proportions

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Vol. Water/Powder 0.969191695

Paste composition

kg/cum					lit/cum
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Constituent Materials for Concrete

Material (kg/cum)	Initial	Adjusted	Required (cum) 0.0062	g/ml
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VMA (lit)	0.99	0.99	0.000792	0.792
Unit Weight	1541.094	Total (kg)	1.237161145	1237.161
		Litres	0.563662541	

Figure 1. SCC Mix Design Tool Interface

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