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Economical Robust Mix Proportioning of Self-Compacting Concrete Mixes - A Comparative Study

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Abstract

Concrete being the second largest consumed material after water needs attention towards sustainable construction with an increase in infrastructure. The world is moving towards innovative techniques and methodologies for sustainable and durable construction of concrete structures. The selection of suitable ingredients for making concrete and determining the relative amounts with an objective of producing a concrete of required strength and durability is the need of the hour. Standard mix proportioning of concrete should satisfy the workability requirements and also meet the requirement for mechanical properties, durability, economy, and even ecology of engineering applications. The study would focus on quality control aspects in mix proportioning the concrete as per the requirements of the industry. It includes mix proportioning of self-compacting concrete as per the standards prescribed in national construction community and Indian standards, plastic viscosity, and EFNARC based mix proportioning of self-compacting concrete. The mix proportioning would focus on utilizing various industrial and agro wastes as a suitable cement replacement material, locally available fine and coarse aggregate materials along with their alternates, appropriate dosage of admixtures, etc. The outcomes of the study include the formulation of handouts and readymade mix proportions of self-compacting concrete used in the construction of buildings and pavements along with their cost estimation. The study also provides information on some of the key points to be considered in making concrete using optimization concepts which would further reduce the cost of construction. The optimized mix proportions will be handy for the ready-mix plants especially in dealing with multiple large-scale construction activities. Mix proportioning using plastic viscosity approach was proven to be economical compared to other mix design methods.

Keywords: Plastic Viscosity, GGBS, fly ash, cement, self-compacting concrete

1. Introduction

Durability was one of the major topics of interests during the early eighties of the last century in Japan. Strength and durability of concrete at its hardened state depends on the quality of concrete and quantity of vibration. Skilled workers are required to make the concrete mixes more compactable. Japan faced the scarcity of skilled labor during the early eighties, which resulted in poor quality of construction. This led to the development of Self-compacting concrete which was first coined in mid-eighties in Japan (Okamura and Ouchi, 2003). Underwater placement of concrete is also one of the primary reasons for the outcome of SCC (Gaimster and Dixon, 2003). Concrete which has the ability to flow and consolidate under its own weight is defined as Self-Compacting concrete as per European guidelines (EFNARC 2005). It is also defines as a special type of concrete which provides good filling ability, passing ability and segregation resistance (Khayat et al, 1999). The first SCC mix was proposed by Okamura in 1986 in Japan at Tokyo University. SCC was mainly introduced to reduce the noise during vibration and make the mix more reachable to congested formwork. In the end of 1990's the concept of SCC was spread to European countries (Billberg, 1999). Sweden used about 20% to 30% of SCC as an annual production of the overall concrete production in ready-mix and precast industries (Thrane et al., 2004). Later UK, France and Germany also started developing and using SCC in their construction industry (Ouchi et al., 2003).Some of the famous structures where SCC was used in construction area) Anchorages of Akashi-Kaikyo suspension bridge, Japanb) Pumping of SCC for 166 stories above the ground of Burj Khalifa, Dubaic) Sodra Lanken project, Stockholmd) 74 storied tallest Yokahoma Landmark tower in Japane) La Maladiere Football Stadium, which was made up of 60000 cum of SCC. SCC was used successfully in many of the bridge and tunneling projects of European countries (Ouchi et al. 2003).

In the recent past United States also started using SCC in the name of Self-consolidating Concrete especially in precast industries. Industry Critical Technology Committee

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on Self-Consolidating Concrete wanted all the ready mix concrete plants to adopt 15% of SCC by 2015 (ICT-SCC 2011).

In India SCC has been widely used since 1990's. It is used mainly in the construction of bridges, buildings and tunnel construction. With the increasing use of Ready Mix Concrete (RMC) in India, use of SCC is also increasing. RMC used in 2012 was to the tune of 11 million cubic metre which is expected to increase 300% by 2022. Mumbai-Pune expressway, Mumbai sewage disposal project, J.J. Flyover, Bangalore International Airport, Vivekanada Bridge, Kolkota, Bandra-Worli bridge and Delhi Metro (Fig. 2.8, 2.9, 2.10 & 2.11) are few projects where SCC has been used successfully. (Kumar and Kaushik 2003). It is also expected that there will be an increased production of SCC considering the need for large scale construction.

1.1. Mix design of SCC with various supplementary cementitious materials

The technical advantages of SCC mainly comprised of the benefits like concreting in heavily reinforced sections, with the help of SCC, thin section precast units could be manufactured and also structures of any geometry could casted. Economically too, SCC was preferred due to its reduced construction time and reduced labour costs because of safe operations. Because SCC had a reduced level of carbon foot-printing and had a large scope for use of waste materials, it had environmental advantages as well.

The mix compositions for conventional concrete and Self compacting concrete are almost similar. Coarse aggregate content in SCC mixes are less compared to conventional concrete and fines are in larger content. A typical mix composition of SCC and conventional concrete is shown in Figure 1

Based on several researcher's contribution the mix design of SCC is classified into 3 main categories (Domone *et al*., 1999).

a) Powder method – Achieved by adding more powder content and by increasing fines. Supplementary Cementitious materials are also added to improve the viscosity of the mix.

b) Viscosity Modifying Agent (VMA) method – Use of suitable VMAs as well as High Range Water Reducing admixtures to enhance the segregation resistance.

c) Combination method – Balanced use of powder and viscosity agents based on the availability of materials, requirements of construction and limitation of concrete plants.

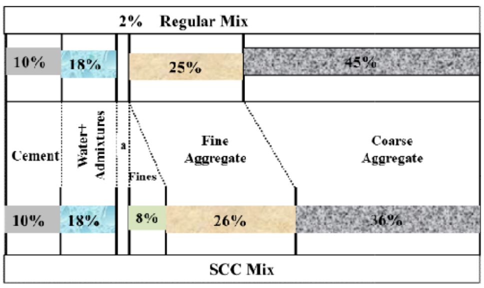


Figure 1 Conventional concrete vs SCC mix

Okamura is the first person to propose the concept of SCC in 1986, followed by Ozawa in developing a prototype at the University of Tokyo in 1988 (Ozawa, et.al, 1989). Over the last two decades, a significant growth is seen in the production of Self-Compacting Concrete. SCC has many advantages compared to conventional concrete, including a) reduction of labor cost, noise pollution and time consumption; b) capacity to fill highly congested structural members; c) increase the durability of structures; d) improve the overall performance of structures Caijun Shi (2015). There will be a release of 1 ton of Carbon dioxide to the atmosphere in the production of 1 metric ton of cement (Concrete Fact Sheet, 2008). For SCC mixes to achieve sustainability there is a need for reduction in the amount of cement consumption in the concrete mixes to ensure that there will be a significant reduction in CO2 emission. Supplementary Cementitious Materials (SCMs) like Ground Granulated Blast Slag (GGBS) and Fly Ash (FA) will reduce the impact of CO2 emission and increase the sustainability of the mix.(Sonebi, 2004) aimed at developing medium strength self-compacting concrete by partial replacement of cement with pulverized fly ash and reduced the usage of super plasticizer which reduces the cost of resulting self-compacting concrete. A mathematical model was developed based on the major five parameters in SCC like filling ability, passing ability, compressive strength & segregation. The parameters used as an input into the mathematical model were cement content & fly ash, water to powder ratio & the dosage of SP. The outputs of the mathematical model were slump flow, fluidity loss, V-funnel time, L-box, orimet time, L-box combined with orimet, compressive strength at 7, 28, 90 days, rheological parameters, segregation etc. A polynomial regression was fitted into the model. The results obtained showed that a 28-day compressive strength of 30 to 35 MPa was obtained with a cement content of 210 kg/m^3.(Khatib, 2006) studied the influence of fly ash on the properties of self-compacting concrete. Fly ash up to a replacement of 0-80% was used and water to binder ratio of 0.36 was constantly maintained. Properties of self-compacting concrete like workability, compressive strength, ultra-sonic pulse velocity, absorption and shrinkage were studied. Replacing cement with 40% fly ash resulted in maximum compressive strength of 65Mpa at 56 days. Increasing the % replacement of fly ash increased the absorption values and the same trend was observed in the case of shrinkage. Increase in admixture content, increased compressive strength up to certain content and later strength reduced. Shrinkage reduced by two-thirds at 56 days and there was a linear relationship observed between PFA content and shrinkage. Up to 1 to 2 % of absorption, strength increased and later it reduced with a slower rate.(Glesoglu *et al*., 2009) worked on the effects of binary, tertiary & quaternary blends of cementitious materials on the properties of self-compacting concrete. A durability-based study was also performed to achieve an optimal mix proportion. Water to binder ratio of 0.44 and cementitious content of 450 kg/m^3 was adopted. This cementitious is a binary, ternary, quaternary blends of Fly ash, GGBS, Silica fumes. Fresh properties of SCC like slump flow, V-funnel etc. were performed and hardened properties like sorptivity, water permeability, compressive strength etc. were performed. It was observed that the ternary blend of GGBS and silica fumes to be more durable when compared with other blends of mineral admixtures. By addition of mineral admixtures, properties of SCC moderately varied and higher compressive strength obtained in the case of ternary blend of silica fumes and GGBS. A multi objective based optimization was performed and an optimal mix was obtained which gave a certain value of the fresh properties like slump cone, V-funnel etc.(Liu, 2010) worked on different levels of fly ash on self-compacting concrete. A replacement level of up to 80% of fly ash was tested. Fresh and Hardened properties of concrete were studied. The maximum percentage replacement of fly ash observed was 80%. To improve the fresh properties of concrete by this replacement water to powder ratio is increased and SP dosage is decreased. Filling ability, passing ability and compressive strength values reduced by this replacement of cement with fly ash. Replacement of fly ash up to 20% did not show any significant effects on the properties of concrete. But it was observed that fly ash content may be restricted to 40% as after that the results obtained were not satisfactory.Hamoon Fathi and Tina Lameie (2017) studied the effect of two different types of aggregates on the behavior of self-compacting concrete subjected to varying temperatures. They found that Scoria type aggregate showed less sensitivity compared to ordinary aggregate and it has resulted in less strain too. Increasing heat produced gradual symmetric stress-strain diagram. Khan A et al (2016) developed a statistical model to proportioning the high-strength self-compacting concrete mix mixes using Response Surface Methodology. They have considered cost to be the influential parameter for the mix proportioning. They came up with optimum combinations of cement, fine aggregate, fly ash and superplasticizer using statistical model. Kalyana Rama J S et al (2017, 2018, 2019) proposed a novel mixture design procedure to proportion the Self-Compacting concrete based on the plastic viscosity of the cement paste. Brookfield Viscometer was used to calculate the plastic viscosity of cementitious pastes for various combinations involving Cement, fly ash and slag with crushed rock fines as fine aggregate. Plastic viscosity of cementitious paste was given as an input to for mixture design to get the quantities of raw materials per m^3 of concrete. It was observed that slump flow, T500, and J-ring spread increased while V-funnel time and L-box blocking ratio decreased with the increase in plastic viscosity of the mix and. Compressive strength, split tensile strength and flexural strength decreased with the increase in plastic viscosity of the mix due to the reduction of the volume of paste and increase in the volume of solids. Maximum strength is observed for SCC mix with 100% OPC for all the chosen plastic viscosities. It was also proposed that for M40 grade concrete, an assumed plastic viscosity of 9 Pa s with water to binder ratio of 0.57 and a plastic viscosity of 13 Pa s with water to binder ratio of 0.5 is found to be suitable for proportioning SCC mixes to satisfy the fresh and hardened properties in making the mixes practically feasible.

2. Mix Proportioning of Self Compacting Concrete

There are various methods to proportion Self Compacting Concrete as shown in Figure 2.

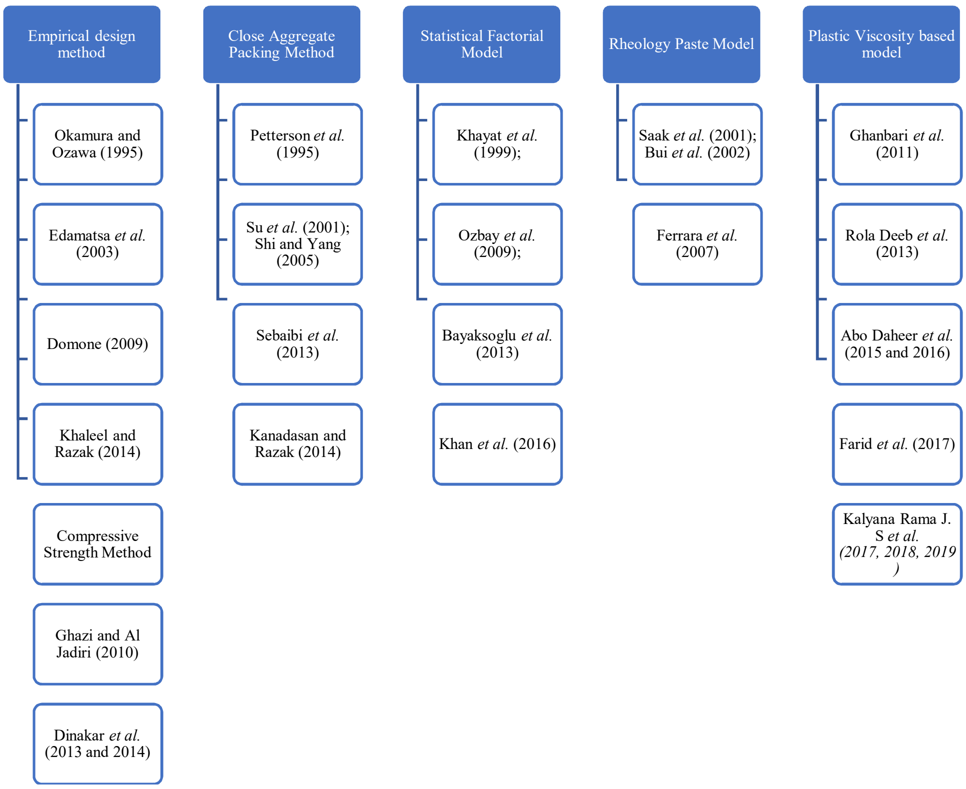


Figure 2 Various Methods to proportion Self Compacting Concrete

2.1. Mix proportioning using IS 10262:2019

Bureau of Indian Standards had introduced mix proportioning of SCC mixes in the revised version of IS 10262:2019. The following is the step by step process of proportioning SCC mixes.

1. Target strength for mix proportioning
2. Choose an approximate Air content
3. Selection of an appropriate water to cement ratio
4. Selection of water content and cementitious content
5. Selection of admixture content
6. Selection of Powder Content and Fine Aggregate Content
7. Selection of Coarse Aggregate Content
8. Calculation of Volume of Powder Content

The above-mentioned procedure confirms to EFNARC guidelines for a satisfactory performance of SCC.

2.2. Plastic Viscosity based Mix proportioning

To describe the flow behavior of concrete, a rheological parameter plastic viscosity is much better than workability which is calculated by conducting slump flow test, compaction factor tests etc. Rheological studies can be carried out using Brookfield Viscometer to measure the yield stress and most importantly plastic viscosity of cement paste with different compositions. Following procedure is followed for proportioning SCC mixes based on the plastic viscosity of the paste

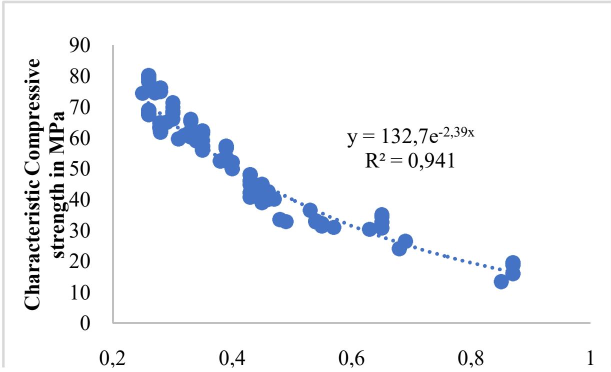
According to Abram's law of water to cement ratio, the compressive strength of concrete depends on the water-cement ratio adopted and the strength is inversely proportional to water to cement ratio (in terms of mass). Based on this law it is clear that the strength of SCC also depends on the water to binder ratio. In order to establish a relation between the strength of concrete and the water to cement ratio, a set of values for water to cement ratio and the resulting 28 day-compressive strength using various mineral admixtures are adopted from (Boukendakdji *et al.*, 2012; Douma *et al.*, 2016, 2014; Uysal *et al.*, 2012; Uysal and Tanyildizi, 2012; Uysal and Sumer, 2011; Gesoglu *et al.*, 2009; Siddique *et al.*, 2011; Alqadi *et al.*, 2013; Raheman and Modani, 2013; Aggarwal and Aggarwal, 2011; Pathak *et al.*, 2012; Guneyisi *et al.*, 2010; Beycioğlu *et al.*, 2014) Using this data, regression analysis is performed to obtain the best fit curve as shown in which is Abram's type power curve with $R^2 = 0.941$. The expression for compressive strength in terms of w/b ratio is given by

$$f_{cu} = \frac{132.77}{11^{(w/cm)}} \qquad (1)$$

Where,

f_{cu} is the 28-day cube compressive strength of concrete in MPa.

$\frac{w}{cm}$ represents the adopted water to cement ratio of the concrete mixture.



SCC mix is considered as a suspension of particles in which the rigid solid spheres (aggregates) are suspended in a viscous fluid (cement paste). Firstly, to the suspension of cement paste, fine aggregate is added and then to this mixture coarse aggregate is added and then the process continues. Now, following this procedure, a standard expression is developed as

$$\eta_{mix} = \eta_{paste} * f_1(\phi_1) * f_2(\phi_2) \ldots * f_n(\phi_n) (2)$$

Where,

η_{paste} represents the plastic viscosity of cement paste.

$\phi_1, \phi_2 \ldots\ldots\ldots \phi_n$, are the volume fractions of the particles (phases) to be added to the suspension of cement paste.

Applying the Krieger and Dougherty theory to calculate the contribution of individual particle to the plastic viscosity of the mix is given as

$$f_i(\phi_i) = \left(1 - \frac{\phi_i}{\phi_m}\right)^{-[\eta]\phi_m} \qquad (3)$$

From the Eq.s (2, 3), the plastic viscosity of the SCC mix is given as

$$\eta_{mix} = \eta_{paste} * \left(1 - \frac{\phi_{FA}}{\phi_m}\right)^{-1.9} * \left(1 - \frac{\phi_{CA}}{\phi_m}\right)^{-1.9} \qquad (4)$$

By adding fine aggregate to the suspension of cement paste, first the packing fraction of the suspension or the mixture is assumed to be random hexagonal packing and then after the addition of coarse aggregate the packing becomes dense and then the packing is assumed to be hexagonal packing. Based on these assumptions, the plastic viscosity of SCC mix is given as

$$\eta_{mix} = \eta_{paste} * \left(1 - \frac{\phi_{FA}}{0.63}\right)^{-1.9} * \left(1 - \frac{\phi_{CA}}{0.74}\right)^{-1.9} (5)$$

Specific gravities of materials used for proportioning the materials required for SCC mix is given in Table 1

Table 1Specific Gravity of raw materials

Raw Material	Specific Gravity
OPC	3.15
Fly Ash	2.16
GGBS	2.85
Rice Husk Ash	2.1
Crushed Sand	2.61
Coarse Aggregate	2.71
Superplasticizer	1.07

Table 2 Plastic Viscosity of cementitious pastes

Cementitious material combinations	Paste plastic viscosity (Pa-s)
100 % - OPC	0.24
75 % - OPC + 25 % - GGBS	0.25
80 % - OPC + 20 % - Fly ash	0.22
50 % - OPC + 25 % - GGBS + 25 % - Fly ash	0.26

Another input required for the proposed mix design methodology is the plastic viscosity of the cement paste. So, for the given grade of SCC to be proportioned, the water to cement ratio adopted is 0.5 as per Eq. 1. Corresponding to 0.5 water to cement ratio, the plastic viscosity of cement pastes for different cementitious materials are measured using Brookfield viscometer. The plastic viscosities of pastes with different cementitious materials are given in

Table 2

Based on these plastic viscosities and considering the target plastic viscosity of the SCC to be proportioned as 7, 9 and 11 Pa-s for water to binder ratio of 0.57 and 9 and 13 for water to binder ratio of 0.5. The proportions of different materials used to prepare an SCC mix with a grade equal to M 40 are calculated with the help of a computer program. Different values of parameters t_1& t_2 are considered as an input starting from 0 to the maximum value with a condition that the volume fractions of coarse and fine aggregates do not exceed 1. The output of this code generated several combinations of SCC mix proportions and some of the best mixes from many combinations generated are chosen based on the satisfactory requirements of EFNARC guidelines.

Case I: Influence of plastic viscosities 9 Pa s and 13 Pa s on the fresh and hardened properties for water to binder ratio of 0.5.

The following is the step-by-step process for proportioning the SCC mixes:

1. The first step is to choose a corresponding grade of concrete and accordingly water to cement ratio is calculated from Eq. 1.
2. Plastic viscosity of the paste is to be adopted based on the water to cement ratio obtained from step (1). The values of plastic viscosity of the paste are obtained either by measuring using Brookfield Viscometer or from standard literature available. For the current study, these values are obtained using Brookfield Viscometer.
3. Based on the required workability of the mix, a trial plastic viscosity of the mix has to be chosen. With the increase in plastic viscosity of the mix, T50 time increases accordingly. With the addition of fibres, the plastic viscosity of the mix will be on the higher side.
4. Adopt suitable water content as per the standard EFNARC guidelines ranging from 150 to 210 kg/m^3 based on the overall workability of the mix.
5. With the known water to cement ratio and water content, total cementitious content is to be calculated. Total cementitious content is a combination of OPC, fly ash and GGBS depending on the type of additions i.e. binary or ternary.
6. The % replacement of OPC with GGBS and Fly ash with OPC for binary blends is suggested as 25 % for GGBS and 20 % for Fly ash for good strength gain properties by ACC limited. By consulting the industry experts, a replacement of 25% of GGBS and 25% of Fly ash is suggested for ternary mixes (Abhijeet et al).
7. A trial super-plasticizer dosage as a % of the cementitious material is adopted which satisfies the required workability of the SCC mix.
8. Individual quantities of ingredients i.e. amount of coarse and fine aggregate to be added can be found from the volume fractions of materials obtained from Eq. (6 and 7). t1 and t2 are arbitrarily chosen such that t1 x t2 = 1. Each of them corresponding to the factor representing the volume fraction of fine and coarse aggregate.

$$\phi_{FA} = \frac{\frac{FA}{\rho_{FA}}}{\left(\frac{cem}{\rho_{cem}} + \frac{w}{\rho_w} + \frac{SP}{\rho_{SP}} + 0.02\right) + \frac{FA}{\rho_{FA}}} \tag{6}$$

$$\phi_{CA} = \frac{\frac{CA}{\rho_{CA}}}{\left(\frac{cem}{\rho_{cem}}+\frac{w}{\rho_w}+\frac{SP}{\rho_{SP}}+\frac{FA}{\rho_{FA}}+0.02\right)+\frac{CA}{\rho_{CA}}} \tag{7}$$

Where,

Cem	=	Cementitious material
FA	=	Fine Aggregate
CA	=	Coarse Aggregate
SP	=	Superplasticizer
w	=	Water
η_{mix}	=	Plastic Viscosity of the Mix
η_{paste}	=	Plastic Viscosity of the Paste
η_r	=	Plastic Viscosity of the Suspension of Particles
ρ_{CA}	=	Density of Coarse Aggregate
ρ_{cem}	=	Density of Cement
ρ_{FA}	=	Density of Fine Aggregate
ρ_{sp}	=	Density of Superplasticizer
ρ_w	=	Density of Water
ϕ_{CA}, ϕ_{FA}	=	Volume Fraction of Coarse Aggregate and Fine Aggregate

9. The total volume of the mix should be equal to 1 m^3. Suitable adjustments have to be made to ensure that the total volume equals 1 m^3.
10. Eq. (5) is being used to estimate the plastic viscosity of the mix with the obtained proportions of raw materials. The percentage difference between the assumed plastic viscosity from step (3) and the estimated plastic viscosity should be within 5%. If the difference is more, then different sets of volume fractions for solid phase ingredients i.e. fine and coarse aggregates are to be chosen and steps 9 and 10 are to be repeated.

3. Raw Materials for Cubic Meter and Cost Comparison

The proportions for different combinations of SCC mixes for a chosen M40 grade designed as per IS 10262:2019 and plastic viscosity are shown in tables 1 to 6. The tables also included a detailed break up of cost of each of the mixes.

Table 3 Raw Materials for SCC designed as per IS 10262:2019 with industrial waste

Materials (kg/m^3)	**Raw Material Cost per kg**	***OPC***	***20% Fly ash***	***25% GGBS***	***25% FA-GGBS***
Cement	7	440	352	330	220
Fly Ash	0.9	0	88	0	110
GGBS	3	0	0	110	110
Water	0.1	170	170	170	170
Crushed Sand	0.6	894	877	890	868
Coarse Aggregate	0.6	715	701	712	694
Superplasticizer	70	4.8	4.8	4.8	4.8
Total Cost in Rs		**4230**	**4036**	**3786**	**3542**

Table 4 Raw Materials for SCC designed as per IS 10262:2019 with industrial and agro waste

Materials (kg/m^3)	**Raw Material Cost per kg**	***OPC***	***15% RHA***	***15% GGBS***	***15% RHA-GGBS***
Cement	7	440	374	374	308
Rice Husk Ash (RHA)	0.9	0	66	0	66
GGBS	3	0	0	66	66
Water	0.1	170	170	170	170
Crushed Sand	0.6	894	877	890	868
Coarse Aggregate	0.6	715	701	712	694
Superplasticizer	70	4.8	4.8	4.8	4.8
Total Cost in Rs		**4230**	**4079**	**3962**	**3806**

Table 5 Raw Materials for SCC designed for Plastic Viscosity of 13 Pa.s industrial waste

Materials (kg/m^3)	**Raw Material Cost per kg**	***OPC***	***20% Fly ash***	***25% GGBS***	***25% FA-GGBS***
Cement	7	400	309	300	194
Fly Ash	0.9	0	77	0	97
GGBS	3	0	0	100	97
Water	0.1	200	193	200	194
Crushed Sand	0.6	937	964	937	943
Coarse Aggregate	0.6	772	754	772	756
Superplasticizer	70	5	4.83	5	4.85
Total Cost in Rs		**4195**	**3621**	**3795**	**3115**

Table 6 Raw Materials for SCC designed for Plastic Viscosity of 13 Pa.s industrial and agro waste

Materials (kg/m^3)	**Raw Material Cost per kg**	***OPC***	***15% RHA***	***15% GGBS***	***15% RHA-GGBS***
Cement	7	*400*	*340*	*300*	*280*
Rice Husk Ash (RHA)	0.9	0	60	0	60
GGBS	3	0	0	100	60
Water	0.1	200	193	200	194
Crushed Sand	0.6	937	964	937	943
Coarse Aggregate	0.6	772	754	772	756
Superplasticizer	70	5	4.83	5	4.85
Total Cost in Rs		**4195**	**4068**	**3795**	**3818**

Table 7 Raw Materials for SCC designed for Plastic Viscosity of 9 Pa.s industrial waste

Materials (kg/m^3)	**Raw Material Cost per kg**	***OPC***	***20% Fly Ash***	***25% GGBS***	***25% RHA-GGBS***
Cement	7	426	326	319	206
Fly Ash	0.9	0	82	0	103
GGBS	3	0	0	106	103
Water	0.1	213	204	213	206
Crushed Sand	0.6	904	918	900	894
Coarse Aggregate	0.6	755	753	753	752
Superplasticizer	70	4.27	4.08	4.25	4.11
Total Cost in Rs		**4298**	**3664**	**3862**	**3140**

Table 8 Raw Materials for SCC designed for Plastic Viscosity of 9 Pa.s industrial and agro waste

Materials (kg/m^3)	**Raw Material Cost per kg**	***OPC***	***15% RHA***	***15% GGBS***	***15% RHA-GGBS***
Cement	7	*426*	*362*	*362*	*298*
Rice Husk Ash (RHA)	0.9	0	64	0	64
GGBS	3	0	0	64	64
Water	0.1	213	204	213	206
Crushed Sand	0.6	904	918	900	894
Coarse Aggregate	0.6	755	753	753	752
Superplasticizer	70	4.27	4.08	4.25	4.11
Total Cost in Rs		**4298**	**4163**	**4037**	**3895**

Table 3 and Table 4shows the quantities of raw materials of Self-Compacting Concrete designed as per IS 10262:2019 with industrial and agro wastes. Overall quantities of raw materials along with individual costs and total cost per cubic metre of concrete are shown. Table 5and Table 6, Table 7and Table 8 shows the quantities of raw materials of Self-Compacting Concrete designed based on the plastic viscosity of the mix with industrial and agro wastes. Two plastic viscosities 9 and 13 are chosen for the present study. For the given grade of concrete a user can adopt to varying plastic viscosities depending on the desired quantities of raw materials. The percentage replacement of supplementary cementitious materials is as per the suggestions given by technical experts from various ready-mix concrete plants and cement industries.

From the tables 3 to 8 it can be observed that the plastic viscosity of the mix plays an important role in making economical mixes. As there is a flexibility of varying the plastic viscosities of the mix for a given grade of concrete, a database can be prepared with combinations of raw materials for different grades of concrete. The cost of mix with pure cement is less for SCC proportioned based on plastic viscosity of 13 Pas. Increase in plastic viscosity of the mix will increase the quantities of raw materials which will give a range of quantities for a given grade of concrete.

4. Conclusions

Mix proportioning of Self-Compacting concrete was carried out as per IS 10262:2019 and plastic viscosity of the mix. The following are the observations from the study

- Plastic viscosity of the paste has been successfully used to proportion the self-compacting concrete mixes
- Cost of the mix increases with decrease in plastic viscosity of the mix
- Plastic viscosity based mix proportioning of SCC is economical compared to IS 10262:2019
- Ternary mixes at an acceptable replacement levels of fly ash upto 25% and GGBS upto 25% is found to be acceptable and economical
- Mixes with agro waste like Rice Husk Ash are uneconomical compared to mixes with industrial waste

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Disclosures

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