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Effect of Water- Cement Ratio (w/c) on Mechanical Properties of Self-Compacting Concrete (Case Study)

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***Abstract*—**Nowadays, the performance required for concrete structures is more complicated and diversified. Self-compacting concrete is a fluid mixture suitable for placing in structures with congested reinforcement without vibration. Self-compacting concrete development must ensure a good balance between deformability and stability. Also, compatibility is affected by the characteristics of materials and the mix proportions; it becomes necessary to evolve a procedure for mix design of SCC.

This paper presents an experimental procedure for the design of self-compacting concrete mixes with different water-cement ratios (w/c) and other constant ratios by local materials. The test results for acceptance characteristics of self-compacting concrete such as slump flow, V-funnel and L-Box are presented. Further, compressive strength, tensile strength and modulus of elasticity of specimens were also determined and results are included here

***Keywords*—**Self-Compacting Concrete, Mix Design, Compressive Strength, Tensile Strength, Modulus of Elasticity

I. Introduction

SELF-COMPACTING CONCRETE (SCC), which flows under its own weight and does not require any external vibration for compaction, has revolutionized concrete placement. This type of concrete has proved beneficial economically because of a number of factors including faster construction, reduction in site manpower, better surface finishes, easier placing, improved durability, greater freedom in design, thinner concrete sections, reduced noise levels, absence of vibration and safer working environment.

SCC, was first introduced in the late 1980's by Japanese researchers [1], is highly workable concrete that can flow under its own weight through restricted sections without segregation and bleeding. Such concrete should have a relatively low yield value to ensure high flow ability, a moderate viscosity to resist segregation and bleeding, and must maintain its homogeneity. During transportation, placing and curing to ensure adequate structural performance and long term durability.

The Successful development of SCC must ensure a good balance between deformability and stability. Researchers have set some guidelines for mixture proportioning of SCC, which include (i) reducing the volume ratio of aggregate to cementations material [1-2]; (ii) increasing the paste volume and water-cement ratio (w/c); (iii) carefully controlling the maximum coarse aggregate particle size and total volume; and (iv) using various viscosity enhancing admixtures (VEA) [1].

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For SCC, it is generally necessary to use super plasticizers in order to obtain high mobility. Adding a large volume of powdered material or viscosity modifying admixture can eliminate segregation. The powdered materials that can be added are fly ash, silica fume, lime stone powder, glass filler and quartzite filler. Since, self-compatibility is largely affected by the characteristics of materials and the mix proportions, it becomes necessary to evolve a procedure for mix design of SCC.

Okamura and Ozawa have proposed a mix proportioning system for SCC [3]. In this system, the coarse aggregate and fine aggregate contents are fixed and self-compatibility is to be achieved by adjusting the water/powder ratio and super plasticizer dosage. The coarse aggregate content in concrete is generally fixed at 50 percent of the total solid volume, the fine aggregate content is fixed at 40 percent of the mortar volume and the water/powder ratio is assumed to be 0.9-1.0 by volume depending on the properties of the powder and the super plasticizer dosage. The required water/cement ratio is determined by conducting a number of trials. One of the limitations of SCC is that there is no established mix design procedure yet.

To find out the proper water/cement ratio (w/c), different mix designs with different water to cement ratios of 0.40, 0.45, 0.5, 0.55 and 0.60 were casted. In addition, the test results for acceptance characteristics for self-compacting concrete such as slump flow, J-ring, V-funnel and L-Box are presented. Further, the strength characteristics in terms of compressive strength, tensile strength for 3, 7, 14, 28 and 90-day specimens and modulus of elasticity for 28-days specimens are also presented.

II. Material Used

A. Cement

Ordinary type I Portland cement provided from Khazar cement factory with specific gravity of 3.15 gr/cm^3 was used. Its physical properties are given in Table I.

TABLE I
PERCENTAGE OF OXIDES OF CEMENT TYPE I

Specimen	CaO	SiO_2	Al_2O_3	Na_2O	SO_3	Fe_2O_3	MgO	K_2O
Cement type I	64.5	21	4.6	0.5	2.9	3.2	2	1.5

B. Filler (Lime Stone Powder)

Finely crushed limestone, dolomite poured onto sieve No 60 with specific gravity of 2.85 gr/cm^3 is provided from Qom lime stone factory.

C. Water

Water used in this project is drinking water of Rasht city.

D.Super plasticizer

Super plasticizer by the trade name of Viscocrete 1 complying with ASTM C-494 type F was used. The specific gravity of the super plasticizer as given by the supplier is 1.08 and the PH is 6 with chloride content of less than 0.1% [4].

E. Aggregates

Locally available natural sand (prepared from Local pipe factory) with 4.75 mm maximum size was used as fine aggregate, having specific gravity, fineness modulus and unit weight as given in Table 2 and crushed stone as coarse aggregate with 16mm maximum size having specific gravity, fineness modulus and unit weight as given in Table II was used as coarse aggregate.

TABLE II
PHYSICAL PROPERTIES OF COARSE AND FINE AGGREGATES

Physical tests	Coarse aggregate	Sand
Specific gravity	2.56	2.63
Fineness modulus	6.86	2.64
Bulk density (Kg/m^3)	1580	1720

Both fine and coarse aggregate grading curves and also ASTM C33 [5] limitations for appropriate aggregates are shown in Figures 1 & 2.

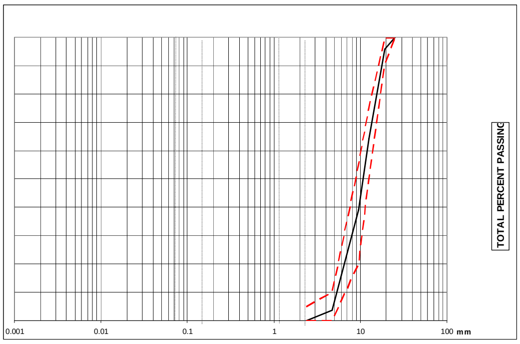

Fig. 1 Curve of coarse aggregates grading

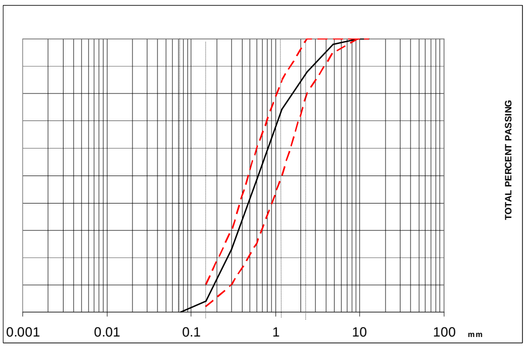

Fig. 2 Curve of fine aggregate grading

III. EXPERIMENTAL PROGRAM

A. Composition of Trial Mixes

For selecting a suitable mix using local aggregates, trial mixes were considered by varying the mix parameters, such as quantity of filler, super plasticizer and water/cement ratio while keeping the cement weight and fine aggregate/coarse aggregate ratio constant.

Five trial mixes were prepared by using a fixed amount of cement (375 kg/m³) and varying the water to cement ratio to select a suitable mix. For each trial mix, a constant fine aggregate/coarse aggregate ratio of 1.13 was taken. Proportioning of the trial mixes was carried out using the absolute volume method [6]

Quantities of the ingredients calculated for all five trial mixes of SCC (I through V) are presented in Table III.

TABLE III
WEIGHTS OF CONSTITUENTS IN TRIAL MIXES

Trial Mix	Quantities of Mix Ingredients (kg/m³)								
	Coarse Aggregates	Fine Aggregates	fine aggregate/coarse aggregate ratio	Powder		Water	Super plasticizer	w/c	Density
				Cement	Filler				
I	680	772	1.13	375	245	225	3.55	0.6	2300
II	700	797	1.13	375	245	206.2	5.2	0.55	2328
III	719	815	1.13	375	250	187.5	6.8	0.50	2354
IV	737	834	1.13	375	258	168.8	8.4	0.45	2381
V	751	849	1.13	375	265	150	10.3	0.40	2400

B. Fresh Concrete Test Methods

Self Compacting Concrete is characterized by filling ability, passing ability and resistance to segregation. Many different methods have been developed to characterize the properties of SCC. No single method has been found until date, which characterizes all the relevant workability aspects, and hence, each mix has been tested three test methods for the different workability parameters.

C. Slump flow Test

The slump flow test [7] is used to assess the horizontal free flow of SCC in the absence of obstructions. On lifting the slump cone, filled with concrete, the concrete flows. The average diameter of the concrete circle is a measure for the filling ability of the concrete. The time is a secondary indication of flow. It measures the time taken in seconds from the instant 50cm the cone is lifted to the instant when horizontal flow reaches diameter of 500mm. (T_{50cm})

D.Funnel Test

The flow ability of the fresh concrete can be tested with the V-funnel test [7], where by the flow time is measured. The funnel is filled with about 12 liters of concrete and the taken for it to flow through the apparatus is measured. Further, $T_{5\min}$ is also measured with V-funnel, which indicates the tendency for segregation, wherein the funnel can be refilled with concrete and left for 5 minutes to settle. If the concrete shows segregation, the flow time will increase significantly.

E. Figures and Tables box Test

The passing ability is determined using the L- box test [7] the vertical section of the L-Box is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. The height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H2/H1). This is an indication of passing ability. The specified requisite is the ratio between the heights of the concrete at each end or blocking ratio to be 0.8.

TABLE IV
THE TEST RESULTS FOR MIXES AND ACCEPTANCE CRITERIA FOR SELF-COMPACTING CONCRETE BY EFNARC[7]

Test Method	Trial Mixes					Unit	Typical range of values[7]	
	I	II	III	IV	V		Min	Max
Slump flow by Abrams cone	**705**	**690**	**685**	**700**	**675**	**mm**	**650**	**800**
Slump flow T_{50cm}	**<1**	**2.1**	**4.2**	**5.4**	**9**	**sec**	**2**	**5**
V-funnel	**2.7**	**5.5**	**8.8**	**12.7**	**32**	**sec**	**6**	**12**
V-funnel ($T_{5\min}$)	**5.1**	**7.5**	**10.5**	**13.9**	**34**	**sec**	**0**	**+3**
L-box	**0.97**	**0.91**	**0.86**	**0.76**	**0.54**	**(h2/h1)**	**0.8**	**1.0**
Acceptable (yes) or not acceptable (no) by EFNARC	**no**	**yes**	**yes**	**yes**	**no**			
Class of SCC by EFNARC	**-**	**SF2**	**SF2**	**SF2**	**-**			

IV. RESULTS AND DISCUSSION

Several experiments were conducted in each mixture to assess the most important features of fresh properties of SCC. The test results for mixes and acceptance criteria for self-compacting concrete by EFNARC [7] are shown in Table III.Mixes I and V were considered as trial mixes, as these mixes do not fulfill all the requirements of the SCC according to EFNARC [7] limitations, Mixes. No II to IV are the SCC mixes that satisfy all the properties of SCC mixes (Table IV).

A. Compressive Strengths

Based on ASTM C192/C192M-98 [8] concrete cube specimens (100mm) of mixes II, III and IV were casted and kept in ordinary water and tested at 3, 7,14, 28 and 90-day (two specimens at each age). The results are shown in Figure 3. This figure shows that by decreasing the water/cement ratio in SCC mixes up to 0.45, compressive strength will improve.

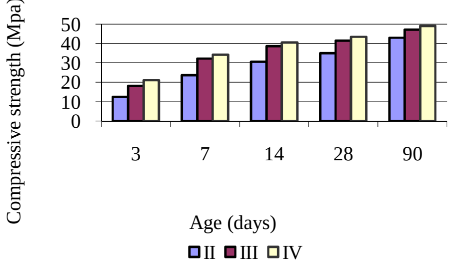

Fig. 3 Compressive strength of concrete specimens of different mixes

B. Modulus of Elasticity Tests

This type of tests were carried with a Universal Testing Machine which was able to draw the Load-Deflection curves for finding the modulus of elasticity based on ASTM C496-96. [9]. the results of specimens of 28-days are shown in table V.

TABLE V
THE RESULTS OF SPECIMENS OF 28-DAYS

Mix	$\frac{W}{C}$	Compressive Strengths of Cube specimens(Mpa)	E_C = 15100$\sqrt{f'_C}$ (Gpa)	Experimental Modulus of Elasticity(Gpa)	Ratio of Experimental Modulus of Elasticity to E_C
II	0.55	35	25.5	23.8	0.93
III	0.50	42	27.8	29.08	1.05
IV	0.45	42.5	28	29.9	1.07

Modulus of elasticity that calculated from compressive strength of the specimens based on ACI 318-05 [10] are shown in table V. Comparing these two methods shows that experimental. Modulus of elasticity can be estimated by ACI 318 method to calculate modulus of elasticity for normal concretes.Also the results of this table show that the ability of mix IV in gaining the modulus of elasticity is more than other mixes.

C. Tensile Strengths

The cylindrical specimens based on ASTM CC31/C31M-00 [10] (two specimens at each age) were made and the average values of the test results based on ASTM C496–96 [11] are shown in Figure 4. Results show that mix No IV that has the lowest water- cement ratio has the best 90- day's tensile strength.

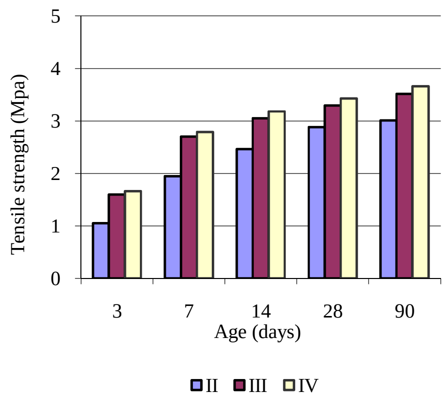

Fig. 4 Tensile strength of concrete specimens of different mixes

V. CONCLUSIONS

1. At the fine aggregate/coarse aggregate ratio of 1.13, slump flow test, V-funnel test and L-box test results were found to be satisfactory, i.e. passing ability; filling ability and segregation resistance are well within the limits.
2. SCC could be developed without using Viscosity Modifying Agents (VMA), as was done in this study.

3. The mixes No II to IV can be easily used to make SCC for strength of 33 MPa to 43 MPa at 28-days, which are useful for most of the constructions. The proportions for mix No IV satisfying all the properties of Self-Compacting Concrete can be easily used for the development of medium strength self-compacting and for further study will be require.
4. By decreasing the water/cement ratio in SCC mixes up to 0.45, compressive strength, tensile strength and modulus of elasticity will improve.
5. The results show that water/cement ratios more than 0.55 and less than 0.45 are not useful for SCC mix designs.
6. As SCC technology is now being adopted in many countries throughout the world, in absence of suitable standardized test methods it is necessary to examine the existing test methods and identify or, when necessary to develop test methods suitable for acceptance as International Standards. Such test methods have to be capable of a rapid and reliable assessment of key properties of fresh SCC on a construction site.

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