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Materials Today: Proceedings 5 (2018) 3503–3512

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ICMPC 2017

PROPERTIES of SCC in GREEN and GREY STATE

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Abstract

It is customary to use mechanical properties of concrete in application. Very few studies are having been done to determine the Mechanical properties of self-compacting concrete (SCC). The present study is aimed to obtain the mechanical properties of low and medium strength SCC and to compare with high performance concrete (HPC). The relationship between the spilt tensile strength, flexural strengths, modulus of elasticity and compressive strength of SCC can be expressed as $f_t = 0{:}48\sqrt{f_c'}$, $f_r = 0{:}79\sqrt{f_c'}$; $E=4500\sqrt{f_c'}$, respectively, where the split tensile, flexural, compressive strengths and modulus of elasticity are in MPs. It is observed that the relationship between compressive strength and other mechanical properties are almost same in SCC and HPC.

Selection and/or Peer-review under responsibility of 7th International Conference of Materials Processing and Characterization.

Keywords: Green, Grey, Self Consolidating Concrete, Mechanical Property

1. Introduction

Self- consolidating concrete (SCC) is a flowing concrete that spreads through congested reinforcement, fills every corner of the formwork and achieves consolidation under its own weight [1]. Low-density aggregates such as scoria, volcanic cinders, expanded polystyrene, tuff and diatomite are added to reduce weight of concrete [2]. Addition of air entraining ad- mixture (AEA) to concrete reduces density, water demand for a given slump, bleeding, decreases friction within the fresh concrete (Light Concrete LLC 2003) and also improves the workability (especially for lean or harsh mixes). The principal purpose and benefit of using AEA is realized in pre-stressed

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2214-7853
Selection and/or Peer-review under responsibility of 7th International Conference of Materials Processing and Characterization.

concrete [3] and light weight concrete [4,5]. AEA decreases both the flexural and compressive strengths of concrete [3,6,7]. The slump value and air content will increase with the increase in AEA [8,9,10]. The plastic viscosity and yield strength also decreases with the addition of AEA [11]The control of AEA is most important in many concrete mixes [13]. Mineral admixtures influence the workability and strength of concrete [14]. The acceptance limit for entrained air in concrete is (3.5-6.5)(%) [5]. Researchers have studied extremely the fresh properties of SCC with AEA [15,16,17] and also air- void stability of SCC [18]. However, none of the above studies investigated the effect AEA on mechanical properties of SCC. Nevertheless, the utilization effect of AEA on SCC is still necessary, as SCC is being widely used around the world. Furthermore, the effect of admixture on mechanical properties of SCC might at least lead the concrete industry to the concept of sustainable development in the near future. It is noted from literature on SCC with AEA, that experimental studies using the combination of VMA and AEA have not been reported and hence an investigation has been taken up to study its variation with respect to the mechanical properties of SCC. Accordingly, in this paper the fresh and mechanical properties of SCC with AEA, VMA and HRWR are obtained. Microstructure, density and compressive strength of SCC are also compared with those of NSCC. Any concrete other than SCC like normal concrete (NC), high performance concrete (HPC) and high strength concrete (HSC) are defined here as non- self- consolidating concrete (NSCC).

2. Materials used

- Powder: The cement used was 53 grade, with a strength of 26.50, 33.20, and 53.40 MPa at 3, 7, and 28 days respectively and specific gravity of 3.14. Class F y ash from the thermal power plant near Chennai, India was used. Unidentified micro-silica (MS)(Grade of 920 U, indicating silica content more than 92 percent) was used. The characteristics of mineral admixtures such as fly ash and micro-silica used also are given in Table1.

TABLE1 Typical physical and chemical properties

Property	Fly ash	Microsilica
Silicon dioxide (SiO2) percent by mass	57.5	95.1
SiO2+Al2O3+Fe2O3 by mass	91	95.1
Loss on ignition percent by mass	0.57	2.79
Fineness (specitic surface)m2/gm	0.372	22

- Fine aggregate (FA): River sand passing 4.75 mm sieves with specific gravity 2.62 and the fineness modulus 2.48 was used.
- Coarse aggregate (CA): Crushed stone aggregates of 16 mm maximum size were used. The specific gravity, dry-rodded unit weight and water absorption of the coarse aggregate were 2.71, 1550 kg/m3 and 0.5 by weight of the aggregate respectively.
- High-range water-reducing (HRWR): admixture based on poly-carboxylic acid: HRWR is different from conventional super-plasticizers. Also HRWR is a high performance super-plasticizer intended for applications where in- creased early and ultimate compressive strengths is required.
- viscosity modifying admixture (VMA): The normal dosage range is from 1.0 to 4.0 liters/m3 of cementitious material, including fly ash, ground granulated blast furnace slag (GGBFS) and micro-silica. Its specific gravity is 1.06.
- High performance water reducing admixture for micro-silica concrete (HPWR) (SP500): SP500 is based on Sulphonated Naphthalene Polymers and is supplied as a brown liquid which is instantly dispersible in water. Conplast SP500 has been specially formulated to give high water reductions up to 25% without loss of workability or to produce high quality concrete of reduced permeability. Its specific gravity varies from 1.250 to 1.270, and the entrained air is approximately 1%.
- Air entraining admixture (Conplast AEA): Conplast AEA is a chloride free air entraining admixture based on neutralized vinsol resin and acts at the interface between the water and cement/aggregate particles to produce

microscopic air bubbles which are evenly distributed throughout the concrete. To start with, a dosage of 0.08 liters/100kg of cement was used to obtain an air content of 5% + 1.5% in a moderately workable concrete with cement content of 300 - 350 kg/m3.

NSCC and SCC were prepared with the same basic mixture proportion for achieving various compressive strengths, based on mix design available in literatures for no air contents [14,13,19,7,20]. Basically there are two types of mixes in present work, the one is SCC and the other is non SCC (NSCC). A total 12 mixes, 6 of SCC and 6 of NSCC with varying's of water/powder (w/p) and water/cement (w/c) ratios were prepared. Mix proportions are given in Table 2.

The total cementitious material content was 400-640 kg=m3. Different w/p ratios (0.32, 0.37, 0.43, 0.5 and 0.59) were used to examine 28 days compressive strength and other properties. Silica fume, super plasticizer and AEA were used to reduce water demand for a given slump, improve the workability (especially for lean or harsh mixes) and reduce bleeding. Micro-silica fume at dosages of 4%, 5%, 6%, 7%, 8%, 9% and y ash at dosage of 47%, 43%, 40%, 38%, 35%, 33% as replacement for ordinary Portland cement (OPC) and AEA at dosages of 0.052%, 0.055%, 0.058%, 0.060%, 0.062%, 0.063% for 0.59 respectively were used for SCC and NSCC. Micro structure of SCC is compared with that of NSCC.

TABLE2: Mix Proportions of SCC

SCC		SCC1	SCC2	SCC3	SCC4	SCC5	SCC6
Cement	Kg/m3	200	240	280	320	360	400
Water	Kg/m3	230	220	210	200	190	180
Fine Aggregate	Kg/m3	900	900	900	900	900	900
Coarse Aggregate	Kg/m3	830	830	830	830	830	830
Fly ash	Kg/m3	180	184	188	192	196	200
Silica fume	Kg/m3	8	12	17	22	29	36
HRWR (Structuro 100)	Liters	1.5	2	2.5	3	3.5	4
AEA (Conplast AEA)	Liters	0.20	0.24	0.28	0.23	0.36	0.40
VMA (Structuro 485)	Liters	0.25	0.5	0.75	1.00	1.25	1.50
Ingredient Density	Kg/m3	2350	2388	2428	2467	2509	2550

3. Preparation of test specimens and testing

3.1. Fresh concrete mixes

workability were evaluated using the slump own and the U-Box, L-Box, J-Ring, V funnel and fill box tests which were carried out as per European Standard [19]. The various equipment used are shown in Figure 1.

3.2. Hardened concrete test specimens

Compressive strength, modulus of elasticity, flexural strength and tensile split- ting strength tests were conducted on all SCC mixes. Compressive strength tests were performed by crushing 150 x 150 x 150 mm cubes that were moist hardened in a water tank and loaded in compression testing machine. The tensile splitting strength test was performed in accordance to ASTM C496. For each of the SCC mixes, three 150 x 300 mm cylinders were tested. In order to avoid localized cracking and to ensure that the load is distributed uniformly, thin sheets of steel with a width of 25 mm and thickness of 5 mm were placed between the top and bottom load bearings. The modulus of elasticity test was conducted as per ASTM C597 (ASTMC597-97 2000).

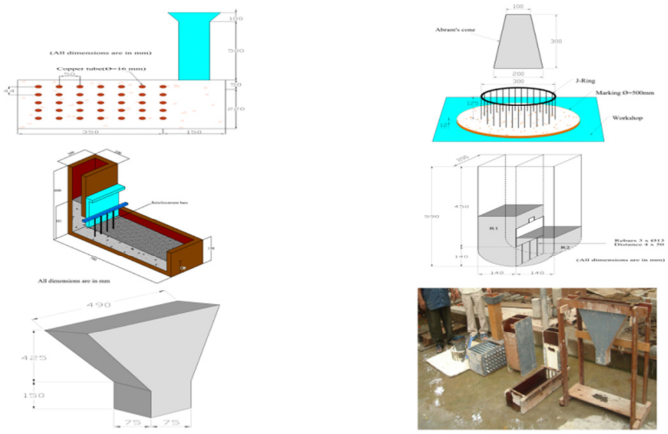


Fig. 1 Equipment details for fresh properties of test concrete

3.3. Hardened concrete test specimens

Compressive strength, modulus of elasticity, flexural strength and tensile split- ting strength tests were conducted on all SCC mixes. Compressive strength tests were performed by crushing 150 x 150 x 150 mm cubes that were moist hardened in a water tank and loaded in compression testing machine. The tensile splitting strength test was performed in accordance to ASTM C496. For each of the SCC mixes, three 150 x 300 mm cylinders were tested. In order to avoid localized cracking and to ensure that the load is distributed uniformly, thin sheets of steel with a width of 25 mm and thickness of 5 mm were placed between the top and bottom load bearings. The modulus of elasticity test was conducted as per ASTM C597 (ASTMC597-97 2000).

Table 3.

	Slump Flow	Slump T50 cm	J Ring	V Funnel	V Funnel T5 minutes	L-box (H2/H1)	U-box (H2/H1)	Fill box
	mm	sec	mm	Sec	Sec	%	mm	%
Min	650	2	0	6	0	0.8	0	90
Max	800	5	10	12	3	1.0	30	100
SCC1	680	3	4	6	3	0.95	5	95
SCC2	750	3	3.2	4	2	0.8	5	95
SCC3	700	3	3	3	2	0.9	10	95
SCC4	650	3	5	5	3	1		100
SCC5	700	4	3	6	3	1	3	95
SCC6	670	5	8	7	1	0.95	5	100

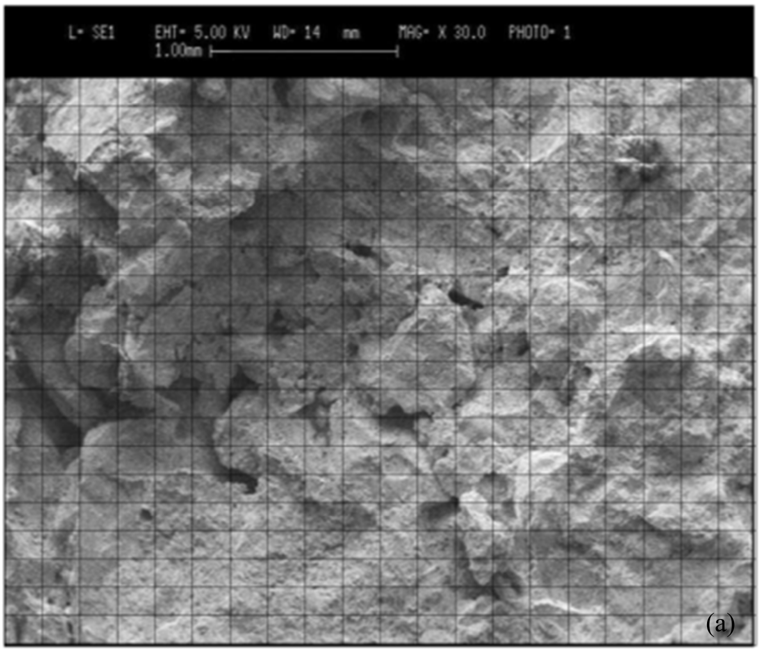
4. Test results

4.1. Properties of fresh concrete

The slump flow of SCC concrete was in the range of 650-750 mm while the time to reach 500 mm slump was in the range of 3-5 s. The values of J Ring test were in the range of 3-8 mm while the flow times from the V funnel test were in the range of 3-7 s. The funnel test flow after 5 minutes was in the range of 1-3 s. The results from L-box, U box and Fill box test were in the range of 0.8-1, 3-10 mm and 90-100 % respectively. All mixes showed a slump flow between 650 and 750 mm which is an indication of a good deformability or in other words flow ability. The slump flow seems to be more related to the dosage of super-plasticizer than to the percentage of the fly ash when the water-to-cementitious materials ratio is low. However, the dosage of the super-plasticizer in the SCC ranged from 0 to 4 liters/m3 of concrete. For all SCC mixes, the flow time increased with a decrease in the water content. The fresh properties of are SCC summarized in Table 3.

4.2. Assessment of air voids ratio

Based on density reduction the contents of air voids have been estimated from the reduction of density from fresh to hardened state of the concrete. Interestingly, the same method has been adopted by Persson[10]& further he has endorsed that the method gives better results. Image analysis is done only as a supplementary check just for two samples. The density was found to have reduced by the range of 10% to 21% in SCC and 4% to 6% in NSCC compared with ingredient densities for different mixes respectively. The reduction in density is due to the large presence of air voids in SCC as compared to NSCC. Through scanning electron microscope (SEM) The 00microscopically determination method (ASTM-C457) [22]can be used to measure dimensions, specific surface, and air/paste ratio of the air- void system in hardened concrete. By using this technique, information related to air bubble size, distribution, spacing and total air content can be assessed. In the present investigation a scanning electron microscope (SEM) has been used for the determination of air content in hardened concrete. It requires a small cubic specimen measuring 10 x 10 x 5 mm. In this procedure, a rectangular grid is placed on the surface of the samples and each grid inter section that falls within a void section is counted. The air voids can be identified by cavities in the scanned image is equal to the number of such grids coincident with voids divided by the total number of grid intersections Figure 3. The typical value of air content obtained by this method for SCC2 and NSCC4 are 14% and 7 % respectively. The scanned images are shown in Figure 4.



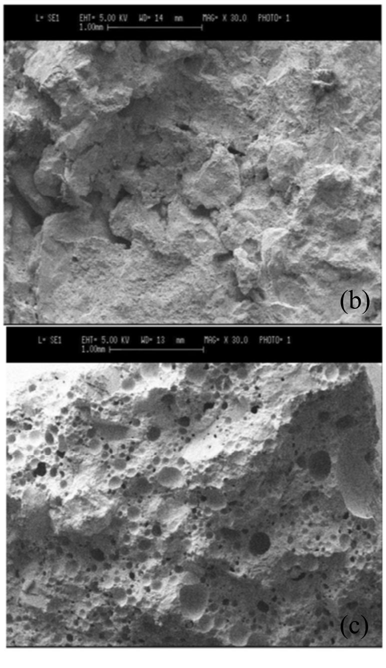


Fig .3 Typical air voids in SCC using SEM

Fig .4 Typical air voids in SCC (SCC2) and NSCC (NSCC4) using SEM

The percentage of air voids as obtained from SEM is found to be closely matching with the air voids content examined based on reduction densities from fresh to hardened states of SCC and the results are given in Table 4.

4.3. Compressive strength of SCC and NSCC

The effect of AEA is more on compressive strength. When there is reduction in compressive strength other mechanical properties also decrease. The compressive strengths of the mixes were determined at 28 days for NSCC and SCC.

TABLE:4. Comparison of SCC and NSCC and compressive strength reduction

Notation	ρ	ρ′	a	Actual $f_c(28)$	Design f_c	di□□. f_c	di□□.1. f_c
	Kg/m3	Kg/m3	%	Mpa	Mpa	%	%
NSCC1	2350	2300	2.1	30.2	30	-	9
SCC2	2388	2100	12.1	12.4	40	69	48
NSCC2	2388	2310	3.3	33.3	40	17	13
SCC3	2428	2070	14.7	14.2	50	72	59
NSCC3	2428	2340	3.6	38.2	50	24	14
SCC4	2467	2060	16.5	18.1	55	67	66
NSCC4	2467	2360	4.3	45.1	55	18	17
SCC5	2509	2020	19.5	22.8	65	65	78
NSCC5	2509	2330	7.1	50.3	65	23	29
SCC6	2550	1980	22.4	26.5	75	65	89
NSCC6	2550	2360	7.5	60.1	75	20	30

Fresh Density = ρ, hardened density at 28 days =ρ′, air content = α, diff.f_c =$\frac{\text{design}-\text{actual}}{\text{design}} * 100$, Reduction in f_c from Eq. 1 =dff.1f_c.

Figure 5 shows the effect of w/p ratio and compressive strength of both NSCC and SCC. The compressive strength of NSCC and SCC as mentioned were deter- mined at 28 day. The compressive strengths of NSCC at 28 days shows a steep reduction with increasing w/p ratio. while reduction of 28 day compressive strength of SCC is seen to be less steeper as w/p ratio increases. Therefore it may be concluded that the compressive strength of SCC is less sensitive to the w/p ratio. Aitcin and Lessard[23] have shown that in HPC the concrete compressive strength is influenced by the air content. The relationship is:

$\frac{(f_c)_{\text{no air}}-(f_c)_{\text{air}}}{(f_c)_{\text{no air}}}$=(4 or 4.5) * a (1) Where "a" is the air content in percentage

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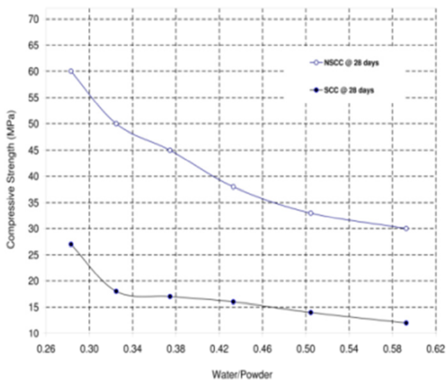


Fig. 5 Compressive strength of NSCC and SCC versus water/powder ratio

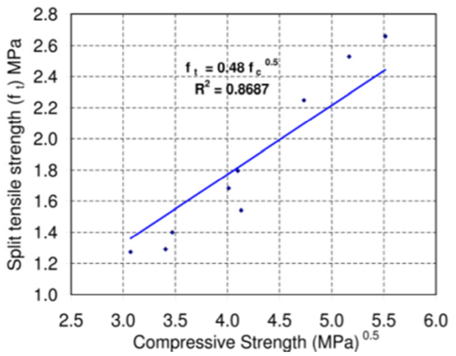


Fig .6 Split tensile versus compressive strength of SCC

The achieved compressive strengths in both NSCC and SCC were certainly lower than the design strengths because of air voids. The air void content in NSCC for different mixes varies from 2-10% and the reduction in compressive strength varies from 8-40% compared to the design strength. In SCC the air void content varies from 10 to 22% but the strength reduction varies from 40% to 96% which shows that for large air voids content the reduction in strengths still closely follows the Eq.1 as given in Table4. It is conjunctured that the presence of incompatibility of AEA on SCC has caused the dramatic reduction in strength in SCC, an observation not reported till now in literature.

4.4. Compressive strength vs. split tensile

Split tensile strength test is often used to obtain the tensile strength of concrete rather than by a direct tensile strength test. The split tensile strength of SCC obtained by experimental test as a function of the compressive strength is Shown in Figure 6 the tensile strengths are estimated from the compressive strength by using empirical correlation equations.

The value of the R2 has been obtained as 0.85. The values from the formula proposed by the authors viz Eq. 2 is compared with the values from the various other formulas like ACI-318 [25], ACI-363 and Bharatkumar et al. [24]given below:

$f_t = 0.55\sqrt{f_c'}$ (MPa) ACI-318(NC) (3)

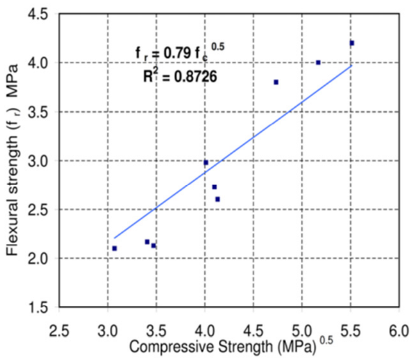
$f_t = 0.59\sqrt{f_c'}$ (MPa) ACI-363(NC) (4)

$f_t = 0.47\sqrt{f_c'}$ (MPa) Bharatkumar (HPC) (5)

The values from the proposed formula are about 13%, 19% less than the expressions given by ACI 318, ACI-363 respectively. The values are 2% more than the expression given by Bharatkumar[24]. The formula suggested by ACI is for normal mix proportion where the volume of coarse aggregate is generally more than the volume of _ne aggregate. The formula suggested by Bharatkumar[24] is for HPC, where the volume of CA is almost the same as that of FA. Therefore, the coefficient value in the Eq. 5 which is for HPC is closer to the formula viz Eq. 2 for SCC suggested by the authors.

4.5. Flexural Strength

Mechanical property of concrete such as flexural strength is often used to calculate the tensile strength of concrete. The test results from the flexural strength test of SCC with AEA and VMA under four point bending was obtained by the standard test for flexural strength, ASTM C78, conducted using 100 x 100 x 400 mm model beams. Three specimens per mix were tested at 28 days and the average modulus of rupture is reported in Figure 7.



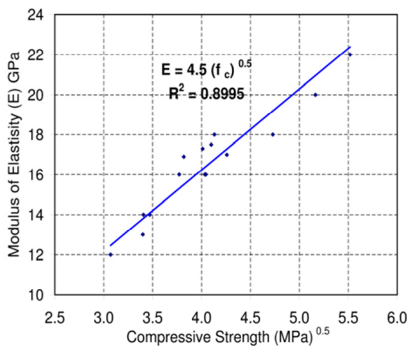


Fig .7 Flexural strength versus compressive strength of SCCFig . 8 Relation between E (GPa) and f_c' (MPa).

The flexural strength range is from 1.8-6.2 MPs. Analyzing the present test results statistically, the relationship between the 28-day flexural and compressive strengths has been obtained as

$$f_r = 0.47\sqrt{f'_c} \text{ (MPa)} \quad (6)$$

Where f_r and f'_c denote the textural and compressive strengths of concrete expressed, in MPa, respectively. The value of the R2 has been obtained as 0.87. The above formula has been compared with the following expressions in literature given by ACI-318 [25] as

$$f_r = 0.81\sqrt{f'_c} \text{ (MPa)} \quad (7)$$

Similarly there are expressions for SCC and HPC [25,24]

$$f_r = 0.91\sqrt{f'_c} \text{ (MPa)} \quad (8)$$

The Eq. 8 is for SCC and NSCC. The values from the proposed formula Eq. 6 are about 2% and 13% less than the expressions given by ACI 318 and Bharatkumar[24] respectively.

5.6 Modulus of Elasticity

The relationship between the modulus of elasticity and compressive strength is very important which reects their linear elastic stress-strain relation. The following equations have been obtained for SCC, in the current investigation.

$$E = 4.5\sqrt{f'_c} \text{ (GPa)} \quad (9)$$

Where E is the modulus of elasticity in GPa and f'_c is the cylinder compressive strength in MPa. The value of the R2 has been obtained as 0.90. Results obtained from the experiments are plotted in Figure 8 and regression analysis was performed based on the experimental data. In the past, various investigators obtained expression for describing the relationship between the modulus of elasticity and compressive strength (both in MPs) and some of them such as ACI-318 (ACI Committee 318 2002) for normal concrete:

$$E = 4.73\sqrt{f'_c} \text{ (GPa)} \quad \text{ACI - 318(NC)} \quad (10)$$

The coefficient in the current proposed is 4 %lower than that proposed by ACI-318. That is again attributed to presence of AEA and VMA in the SCC of the current investigation.

5. Discussion

There are several variables like cement, coarse and fine aggregate, silica fume, fly ash, HRWR, AEA and VMA. However the role of each of the variable is very distinct and clear. The influence of each of them on the fresh properties is so very different and independent, because they are very apparent in the fresh properties. To make it more specific, cement, coarse and fine aggregate and silica fume have influence only on the 28 day strength and not so much on the fresh properties. Fly ash has some influence on workability but contains not as much a w=c ratio and the dosage of HRWR. Similarly AEA and VMA have no influence on workability VMA also has distinct influence on reducing segregation. In the past, various investigators compared mechanical properties of SCC with normal concrete (NC). But the authors felt that the mechanical properties of SCC with AEA and without AEA are almost similar to high performance concrete "(in view of, the basic materials being same)" and not that of NC. It is also obvious that the mechanical properties are controlled by the proportions in the basic combinations such as cement content, water/cement, water/binder, water/powder, fine aggregate /powder and coarse aggregate/powder.

6. Conclusions

Experiments were conducted to determine mechanical properties of SCC with AEA and VMA. To compare the effect of AEA in SCC as well as in NSCC, specimens of NSCC with AEA were also tested for microstructure, compressive strength and density.

A regression analysis of the experimental results is performed to relate various properties of SCC. The results are compared with those available in literature and in certain codes of practices. The conclusions are:

- The fresh properties of SCC with AEA and VMA such as values from slump flow test, J-Ring, V-funnel, L-Box, U-Box, Fill Box tests satisfy the requirements of the European Standard [19].
- SCC and NSCC with the same mix proportions of cement, sand, coarse aggregate, w/p ratio are compared. There were HRWR and VMA in SCC and Conplast SP500 was present in NSCC. The reduction in strength from the design strength is in the range of 40% to 90% in SCC while in NSCC it is about 8% to 40%. The apparent reason could be that the combination of HRWR, AEA and VMA causes a larger content of air voids in SCC.
- It is observed that 28 day hardened density was less compared with fresh density in both SCC and NSCC. It is noted that the reduction in density was 2 to 10% in NSCC while in SCC it was 10 to 22% for the various mixes in the study.
- The relationship between the spilt tensile strength and compressive strength of SCC can be expressed as

$$f_t = 0.48\sqrt{f'_c} \text{ (MPa)} \quad (11)$$

- The relationship between the flexural strength and compressive strength of SCC is given as.

$$f_r = 0.79\sqrt{f'_c} \text{ (MPa)} \quad (12)$$

- The relationship between the modulus of elasticity and compressive strength of SCC is of the form.

$$E=4500\sqrt{f'_c} \quad (13)$$

The split tensile flexural, compressive strengths and modulus of elasticity are in MPa.

Acknowledgement

The authors are thankful to Mr. G.B. Vamadev, Business Manager of Fosroc Chemicals (India) Pvt.Ltd. for supplying materials.

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