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Characterization and Evaluation of Mechanical Properties Of Hybrid Self Compacting Concrete

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Abstract: Self compacting concrete (SCC) has been developed by using manufactured sand and fly ash. Various SCC mixes made up with manufactured sand and fly ash have been tested for Slump flow, V-funnel, U-Box, L-box and J-ring. It is found that the respective values are within the limits prescribed by EFNARC. Mechanical properties such as compressive strength, split tensile strength, modulus of rupture and modulus of elasticity have been evaluated as per Bureau of Indian Standards. The compressive strength and split tensile strength decreases with the increase in replacement of cement by fly ash. The modulus of rupture values are slightly decreasing with the increase of % replacement of cement by fly ash. Static modulus of elasticity has been computed for all the SCC mixes and is found to be less than the value computed by using IS: 456-2000. The reason could be due to presence of larger contents of mineral admixtures, which made the SCC mix denser, which will increase in stiffness. Paste optimization studies have been carried for cement and fly ash combination based on particle packing method through Puntke test. Fresh and mechanical properties have been evaluated. It can be concluded that SCC with manufactured sand and fly ash can be a potential candidate for the construction sector.

Keywords: Self compacting concrete; manufactured sand, fly ash; fresh properties; mechanical properties

I. INTRODUCTION

It is well known concrete has been one of the most commonly used materials in the construction sector. Concrete gives considerable flexibility to mould into desired shape or form. One of the major problems facing civil engineering community is to preserve, maintain, and retrofit of concrete structures. Cement and concrete composites are presently the most economic materials for construction. A new trend in designing complex and heavily reinforced structures showed that compaction of concrete by vibrating may be difficult in some cases and strongly depend on a human factor. It is commonly noticed many times that after the formwork is removed; the fresh concrete had not spread to all the points, uniformly and perfectly. A homogenous property of the structure has thus been adulterated. Due to these reasons, Self-Compacting Concrete (SCC) has been developed. Such concrete was applied in practice for the first time in the mid-80s during underwater concreting in Japan. Ten years later, the SCC technology began to be used also for common concreting, especially for concreting of complex heavily reinforced structures. Development of a material without vibration for compaction i.e. Self Compacting Concrete (SCC) has successfully met the challenge and is now increasingly being used in routine practice. Self-compacting concrete (SCC) is considered as a concrete with high workability that is able to flow under its own weight and completely fill the formwork, even in the presence of dense reinforcement, without vibration, whilst maintaining homogeneity (Corinaldesi and Moriconi, 2004). It is known that SCC mixes usually contain superplasticizer, high content of fines and/or viscosity modifying additive (VMA). Whilst the use of superplasticizer maintains the fluidity, the fine content provides stability of the mix resulting in resistance against bleeding and segregation. The use of fly ash, blast furnace slag and silica fume in SCC reduces the dosage of superplasticizer needed to obtain similar slump flow compared to concrete mixes made with only Portland cement (Yahia et al., 1999; Holschemacher and Klug, 2002; Okamura, Ouchi, 2003; Heba, 2011; Mucteba Uysal, 2012).

In SCC, the aggregates generally contribute approximately 2/3 of the total volume. Proper choice of aggregates has significant effect on the fresh and hardened properties of SCC concrete. Aggregate characteristics such as shape, texture and grading influence workability, finishability, bleeding, pumpability, segregation of fresh concrete and strength, stiffness, shrinkage,

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creep, density, permeability, and durability of hardened concrete. In general, it is observed that the effects of shape and texture of fine aggregate are much more important than the effects of coarse aggregate. It is in practice that river sand is being used as fine aggregate in concrete for many centuries. Most of the construction industries use river sand only as fine aggregate. Investigations are going on due to increase in demand and depletion of river sand, along with restrictions imposed on the exploitation of the river sand. It is observed from the literature (Gonçalves et al., 2007; Yüksel et al., 2011; Kou et al., 2009), that the alternative materials for river sand include manufactured sand, industrial by products (some forms of slag, bottom ash), recycled aggregates, etc. Among the above materials, manufactured sand (Msand) is relatively receiving significant attention as a replacement for river sand. The Msand is produced by impact crushing rock deposits to obtain a well graded fine aggregate (Alexander, 2005). It is known that for SCC, high powder (cement, cementitious materials and inert fillers) content is required for achieving the required fresh concrete properties (Nanthagopalan and Santhanam, 2006; Santhanam and Subramanian, 2004). Since, Msand contains large amount of fines, can be used as an alternative to river sand (Gonçalves et al., (2007). Due to high fines content in Msand, increases the yield stress of the mortar and contributes to the increase in plastic viscosity. On the other hand, the mechanical and durability properties of the concrete are reported to be considerably improved by using Msand (Gonçalves et al., 2007 and Donza et al., 2002). From the literature, it is observed that Msand is being used as fine aggregate in conventional aggregate and limited applications in SCC.

In this investigation, an attempt has been made to make SCC with manufactured sand and fly ash. Locally available sand has been used in SCC as fine aggregate. Various SCC mixes made up with manufactured sand and fly ash have been tested for Slump flow, V-funnel, U-Box, L-box and J-ring and optimisation of paste composition has been carried out. Fresh and mechanical properties of various SCC mixes have been evaluated.

II. Development Of Scc Mix And Evaluation Of Fresh Properties

Materials used

Ordinary Portland cement of 43 grade [IS: 12269-1987, Specifications for 43 Grade Ordinary Portland cement] has been used in the study. In the present investigation, manufactured sand (Msand) is used as fine aggregate. It is obtained by crushing of granite. The Msand is first sieved through 4.75mm sieve to remove any particles larger than 4.75mm and then is washed to remove the dust.

Properties of the fine aggregate used in the experimental work are tabulated in Table 4.3. The aggregates were sieved through a set of sieves to obtain sieve analysis and the same is presented in Table 1. The fine aggregates belonged to grading zone III. Crushed granite metal of sizes 10mm to 20 mm obtained from the locally available quarries was used as coarse aggregate in the present investigation. Water used for mixing and curing is potable water, which was free from any amounts of oils, acids, alkalis, sugar, salts and organic materials. Fly ash used in this investigation is procured from Thermal Power Station, Tamilnadu, India. It confirms with grade I of IS: 3812 – 1981. It is tested in accordance with IS: 1727 -1967. The chemical composition and physical characteristics of fly ash used in the present investigation are given in Tables 2 and 3.

In the present work, water-reducing admixture, Conplast SP 430 conforming to IS 9103: 1999, ASTM C - 494 types F, G and BS 5075 part.3 is used and Viscosity Modifying Agent used in this investigation is Glenium.

Evaluation of fresh properties

The proportioning of the quantity of cement, cementitious material like Fly ash, fine aggregate and coarse aggregate has been done by weight as per the mix design. Water, super plasticizer and VMA were measured by volume. All the measuring equipments are maintained in a clean serviceable condition with their accuracy periodically checked. The mixing process is carried out in electrically operated concrete mixer. The materials are laid in uniform layers, one on the other in the order - coarse aggregate, fine aggregate and cementitious material. Dry mixing is done to obtain a uniform colour. The fly ash is thoroughly blended with cement before mixing. Self Compacting characteristics of fresh concrete are carried out immediately after mixing of concrete using EFNARC specifications.

In order to study the effect on fresh concrete properties when fly ash is added into the concrete as cement replacement, the SCC containing different proportion of fly ash have been tested for Slump flow, V-funnel, U-Box, L-box and J-ring. The results of various fresh properties tested by slump flow test (slump flow diameter), J-ring test (flow diameter and difference in concrete height inside and outside J-ring (h2-h1)); L-box test (ratio of heights at the two edges of L-box (H2/H1)); V-funnel test (time taken by concrete to flow through V-funnel after 10 s T10s), U-box test

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(difference in height of concrete in two chambers (H2-H1)) for various mix compositions have been studied in detail (Tables 4 and 5). All the mixes in the present study conform to range given by EFNARC standards since the slump flow of SCC mixes is in the range of 610-698 mm. The J-ring diameter and difference in concrete height inside and outside J-ring are in the range of 585-640 mm and the difference in height is less than 40 mm. In addition to the slump flow test, V-funnel test is also performed to assess the flowability and stability of the SCC. V-funnel flow time is the elapsed time in seconds between the opening of the bottom outlet depending upon the time after which opened (T10s and T5min) and the time when the light becomes visible from the bottom, when observed from the top. V-funnel time, which is less than 6 s, is recommended for concrete to qualify as a SCC. As per EFNARC, time ranging from 6 to 12 s is considered adequate for a SCC. In the present study, V-funnel flow times are in the range of 8-11 s. Test results of this investigation indicated that all SCC mixes meet the requirements of allowable flow time. Maximum size of coarse aggregate is kept as 16 mm in order to avoid blocking effect in the L-box. The gap between rebars in L-box test is 35 mm.

The L-box ratio H2/H1 for the mixes is above 0.8 which is as per EFNARC standards (2002). U-box difference in height of concrete in two compartments is in the range of 5-40 mm. As a whole, it is observed that all the fresh properties of concrete values are found to be in good agreement to those of the values provided by European guidelines. Figure 1 shows typical pictures while evaluating fresh properties of various SCC mixes.

where, CM = Control Mix, w/p= Water/ Powder (cement+FA)

SCC1 = Self-compacting Concrete with 15 % FA as cement replacement.

SCC2 = Self-compacting Concrete with 25 % FA as cement replacement.

SCC3 = Self-compacting Concrete with 35 % FA as cement replacement.

SCC4 = Self-compacting Concrete with 45 % FA as cement replacement

III. Mechanical Properties Of SCC

Various hardened properties such as compressive strength, split tensile strength, modulus of rupture, modulus of elasticity have been studied for all SCC mixes.

Compressive strength studies have been carried out on cube specimens of size 150mm× 150mm×150mm. All the cubes have been tested as per IS: 516-1959, for 7, 28 and 56 days. Table 7 presents the compressive strength values of a cube for all SCC mixes. The average compressive strength of a cube in the case of control mix at 56 days is obtained as 34.63 MPa and is higher than the strength of 7 days and 28 days. This could be due to continuous hydration of cement with concrete. Same trend has been observed for all SCC mixes. Further, it is noted that the compressive strength decreases with the increase in replacement of cement by fly ash (Figure 2). It has been noted that the values are comparable with the values reported in the literature (Xie et al., 2002).

Split tensile strength studies are carried out on 100mm diameter and 200 mm long cylinder at 28 days as per IS: 516. Various SCC mixes with replacement of cement by fly ash have been considered for the studies. From the studies, it is observed that the split tensile strength for 7 days in the case of control mix is 1.13 MPa and it gradually increases till 56 days. The value of split tensile strength at 56 days is 1.584 MPa. Similar trend is observed for all SCC mixes with various replacement of cement by fly ash. Further, it can be noted that split tensile strength decreases with increase of addition of fly ash compared to control mix. Figure 3 shows the variation of split tensile strength with age.

Flexural studies have been carried out on concrete prisms of size 100mm×100mm×500mm at 28 days as per IS: 516. Table 8 shows the values of modulus of rupture.

From the studies, it is observed that modulus of rupture values are slightly decreasing with the increase of % replacement of cement by fly ash. Further, it can be noted that IS: 456 underestimates the flexural strength compared to corresponding experimental observations. Modulus of elasticity has been computed for all the SCC mixes. Cylinders of size 150mm ×300mm have been tested in uniaxial Universal testing machine as per IS:516. The static modulus of elasticity is determined as the slope of the tangent to the stress-strain curve. The average modulus of elasticity for all the mixes is obtained as 28084 MPa which is slightly less than the value computed by using IS: 456-2000 ($5000\sqrt{f_{ck}}$). The reason for the same modulus of elasticity for all SCC mixes may be attributed to presence of large contents of mineral admixtures, make the SCC mix denser, which will increase in stiffness.

IV. Optimisation Of Paste Composition

Cement and fly ash combination was selected based on particle packing method through Puntke test (Puntke et al., 2000).

It works on the principle that the water which is added to the dry materials fills the voids in between the particles and acts as a lubricant to

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make the materials compact efficiently. The water, which is in excess after completely filling the voids, appears at the surface of the mixture, indicating the saturation limit. A typical combination of cement:fly ash by volume, resulting in maximum packing density, has been selected for further investigations. With optimum combination of powder, the cementitious paste is prepared for different w/p ratio and superplasticiser dosage by using a planetary motion high shear (Hobart) mixer. The superplasticiser dosage has been optimised in cementitious paste by using mini-slump cone test (Kantro, 1980, Nanthagopalan and Santhanam, 2008) and The VMA dosage was optimised by using the Marble test (Nanthagopala and Santhanam. 2010) in the cementitious pastes. The optimum dosages selected from paste studies have been evaluated in SCC by using the sieve segregation test (EFNARC, 2005). The optimised dosages thus determined are given in Table 9. Tables 10 to 12 show the fresh properties, mechanical properties and modulus of rupture respectively for various mixes. It can be observed from Table 10 that all the mixes conform to range given by EFNARC standards. Table 11 presents the average compressive strength values, which are slightly higher than the values obtained without paste optimization. Similarly modulus of rupture values are also marginally higher compared to those values obtained with out paste optimization.

V. Summary And Concluding Remarks

Self compacting concrete mix has been developed by using fly ash and manufactured sand. Characterization studies of all the ingredients of SCC have been carried out. SCC containing different proportion of fly ash have been tested for Slump flow, V-funnel, U-Box, L-box and J-ring and found that the values are within the limits prescribed by EFNARC. The average compressive strength of a cube in the case of control mix at 56 days is obtained as 34.63 MPa and is higher than the strength of 7 days and 28 days. This could be due to continuous hydration of cement with concrete. Same trend has been observed for all SCC mixes. Further, it is noted that the compressive strength decreases with the increase in replacement of cement by fly ash. From split tensile strength studies, it is observed that the split tensile strength for 7 days in the case of control mix is 1.13 MPa and it gradually increases till 56 days. The value of split tensile strength at 56 days is 1.584 MPa. Similar trend is observed for all SCC mixes with various replacement of cement by fly ash. Further, it can be noted that split tensile strength decreases with increase of addition of fly ash compared to control mix. The modulus of rupture values are slightly decreasing with the increase of % replacement of cement by fly ash. Further, it is noted that IS: 456 underestimates the flexural strength compared to corresponding experimental observations. Static modulus of elasticity has been computed for all the SCC mixes and is found to be less than the value computed by using IS: 456-2000. The reason for the same modulus of elasticity for all SCC mixes may be attributed to presence of large contents of mineral admixtures, make the SCC mix denser, which will increase in stiffness. Paste optimization studies have been carried for cement and fly ash combination based on particle packing method through Puntke test. Fresh and mechanical properties have been evaluated. It can be concluded that SCC with manufactured sand and fly ash can be used for all applications in the construction sector.

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(a) Slump flow test

(b) L-Box test

c) V - funnel test

(d) J-ring test

Figure 1 Evaluation of SCC fresh properties

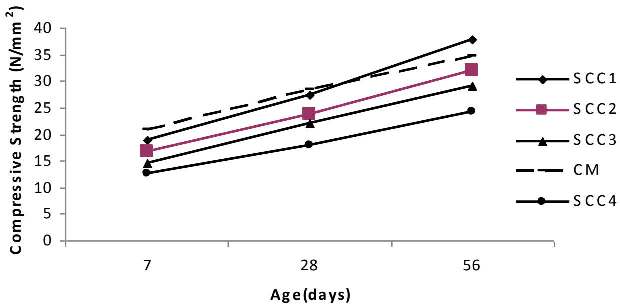

Figure 2 Compressive strength of SCC mixes at various ages

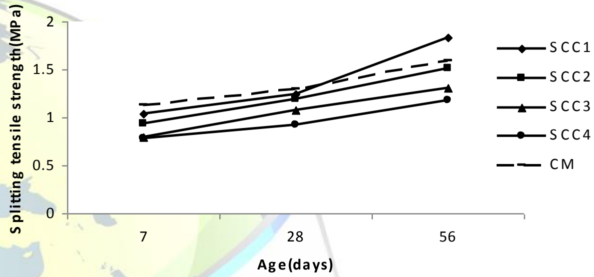

Figure 3 Variation of split tensile strength with age

Table 1 Physical Properties of fine aggregates

S.No.	Characteristics	Value
1	Specific gravity	2.56
2	Bulk density	1792 kg/m^3
3	Fineness modulus	2.57
4	Water absorption	0.87 %
5	Grading Zone (Based on percentage passing 0.60 mm)	Zone III

Table 2 Chemical requirements of fly ash

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Characteristics	Requirements (% by weight)	Fly Ash used (% by weight)
Silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) plus iron oxide (Fe_2O_3)	70 (min)	95.36
Silicon dioxide (SiO_2)	35 (min)	58.55

Magnesium Oxide (MgO)	5 (max.)	0.32
Total sulphur as sulphur trioxide (SO_3)	2.75 (max.)	0.23
Available alkalies as sodium oxide (Na_2O)	1.5 (max.)	0.05
Loss on ignition	12 (max.)	0.29
Chlorides		0.009

Table 3 Physical requirements of fly ash

S No	Characteristics	Requirements for grade of flyash (IS:3812-1981)		Experimental Results
		Grade – I	Grade – II	
1	Fineness by Blain's apparatus in m^2/kg	320	250	325
2	Lime reactivity (Mpa)	4.0	3.0	9.1%
3	Compressive strength at 28 days as percentage of strength of corresponding plain cement mortar cubes	Not less than 80%		83%
4	Soundness by Autoclave expansion			Nil

Table 4 Mix proportions of SCC

Mixture ID	Cement (kg/m^3)	FA (kg/m^3)	Sand (Kg/m^3)	C.A (Kg/m^3)	Water (Kg/m^3)	w/p	SP (Kg/m^3)
CM	540	-	900	580	250	0.46	9.2
SCC1	459	81	900	580	228	0.42	10.71

SCC2	405	135	900
SCC3	351	189	900
SCC4	[illegible]	243	900

Table 5 Fresh concrete properties

Mixture ID	Slump (mm)	V-funnel (seconds)	L-Box (H2/H1)	U-box (H1-H2)	J-Ring Dia. (mm)	h2-h1 (mm)
SCC1(15% FA)	680	9	0.9	[illegible]	[illegible]	[illegible]
SCC1(15% FA)	613	10	0.85	[illegible]	[illegible]	[illegible]

SCC1 (15% FA)	648	8	0.9	2
SCC2(25% FA)	698	12	0.85	3
SCC2(25% FA)	598	10	0.9	3
SCC2(25% FA)	640	9	1.0	3

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SCC3(35% FA)	642	10		0.85
SCC3(35% FA)	676	9		0.9
SCC3(35% FA)	653	11		0.8
SCC4(45% FA)	620/603	10	12	0.9
SCC4(45% FA)	598/590	9	10	0.8
SCC4(45% FA)	631/630	8	9	1.0

Table 7 Compressive strength of SCC mixes

Mix	Compressive Strength (N/mm^2) 7 days	28days	56 days	Average Compressive Strength(N/mm^2) 7 days	28days	56 days
CM	20.0 23.1 19.2	28.0 29.1 28.3	36.0 34.8 33.1	20.77	28.47	
SCC1 (15% FA)	18.8 18.6 19.2	27.0 26.6 28.8	36.0 38.6 39.0	18.6	27.46	
SCC2 (25% FA)	16.0 16.3 18.0	24.0 23.0 24.2	33.0 31.2 32.0	16.76	23.8	
SCC3 (35% FA)	15.0 14.6 13.8	22.6 22.3 21.6	29.0 30.0 28.1	14.47	22.17	
SCC4 (45% FA)	13.3 12.8 11.7	18.6 17.9 17.4	24.9 23.8 24.1	12.6	17.97	

Mix	Modulus of Rupture (MPa) experimental	as per IS: 456 $(0.7\sqrt{f_{ck}})$
CM	3.74	3.52
SCC1	3.62	3.47
SCC2	3.47	3.23
SCC3	3.21	2.94
SCC4	2.98	2.65

Table 8 Modulus of rupture for various SCC mixes

Mix	Water to powder ratio	Optimum SP dosage (% of solids by weight of powder)	Optimum VMA dosage (% of solids by weight of powder)
CM	0.46	0.42	0.005
SCC1	0.42	0.43	0.002
SCC2	0.43	0.45	0.003
SCC3	0.44	0.44	0.004
SCC4	0.46	0.42	0.005

Table 9 Optimum dosage of superplasticiser and viscosity modifying agent

Table 10 Fresh concrete properties with optimized mix

Mixture ID	Slump (mm)	V-funnel (seconds)	L-Box (H2/H1)	U-box (H1-H2)	J-Ring Dia.(mm)	h2-h1 (mm)
SCC1 (15% FA)	662	9	0.8	22	610	9
SCC2 (25% FA)	674	10	0.85	36	620	10
SCC3 (35% FA)	665	10	0.85	35	618	10
SCC4 (45% FA)	653	9	0.9	30	600	9

Table 11 Compressive strength of SCC mixes with optimized paste

MIX	Average Compressive Strength(N/mm^2)

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	7 days	28days	56 days
CM	22.34	30.65	35.78
SCC1 (15% FA)	19.65	28.97	39.43
SCC2 (25% FA)	17.21	24.52	33.67
SCC3 (35% FA)	14.97	23.21	30.01
SCC4 (45% FA)	12.92	18.85	25.32

Table 12 Modulus of rupture for various SCC mixes with optimized mix

Mix	**Modulus of Rupture (MPa)**	
	experimental	**as per IS: 456 ($0.7\sqrt{f_{ck}}$)**
CM	3.78	3.52
SCC1	3.67	3.47
SCC2	3.51	3.23
SCC3	3.28	2.94
SCC4	2.99	2.65