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Moment carrying capacity of RSCC beams incorporating alccofine and fly ash

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ABSTRACT

This paper analyses the structural behavior of reinforced self-compacting concrete beams under two-point loading. A total number of five beams were cast with varying quantities of alccofine (i.e., 0, 5, 10, and 15%) and constant dosage of fly ash (i.e., 25%) and tested for examining the load-deflection curves and ultimate moment carrying capacity of reinforced self-compacting concrete beams. From obtained experimental results, it was found that the load-carrying capacity was increased when the beam with the addition of alccofine and fly ash is compared with the normal concrete beam. The experimental obtained ultimate strength values were compared with theoretically predicted values using IS 456-2000, ACI 318-11, and CSA A23.3-04 codes.

KEYWORDS

self-compacting concrete, load-deflection curves, moment of resistance, alccofine, fly ash, reinforced concrete beams

1. INTRODUCTION

Self-Compacting Concrete (SCC) is distinguished by its high fluidity, passing ability and cohesiveness characteristics that eliminate or reduce to a minimum the need for mechanical compaction. Reducing the intervention of the human factor in the concreting stage improves the quality of the project under construction. The advantages associated with SCC have led to the adoption of this relatively advanced technology in many contemporary projects, even before the release of specifications, testing techniques and standards that reflect the behavior of structural elements cast using high consistency concrete.

2. LITERATURE REVIEW

Few studies were found dealing with high strength SCC beams produced using Poly-Carboxylate Ether (PCE) based admixtures. A common procedure was followed in the majority of these studies where beams prepared with SCC, frequently comprising fly ash or silica fume powders, were compared with control beams cast using vibrated concrete mixes made with different constituents and mix proportions. The overlapping effect of the numerous variables engaged in those studies often resulted in losing the track on the effect of each variable on the behavior of the reinforced concrete specimens.

The majority of the research reported in the literature review agreed on the equivalence of the bond strength between normal concrete and SCC [1].

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Desnerck et al. [2] studied the bond characteristics of different bar diameters in beam specimens cast using SCC and conventional Vibrated Concrete (VC) having an f_c' of approximately 60 MPa. The concrete mixes were designed differently where SCC mixes involved PCE superplasticizers and limestone fillers, two additional constituents that were excluded from the conventional VC mix design. The aggregate distribution of VC and SCC mixes was also different. The outcomes of the research study concluded on the similarity of the bond strength between VC and SCC beams for large bar diameters whereas the bond strengths for SCC appeared to be superior in beams with small bar diameters.

Turk et al. [3] also inspected the bond strength of tension lap splices in S1CC beams. Beam specimens with 16 mm and 20 mm bars were used to compare the behavior of SCC and VC elements having a compressive strengths ranging from 41.5 to 44 MPa. The stability of SCC mixes was maintained using silica fume. The self-compactness of concrete was attained using PCE super-plasticizer whereas sulphonated melamine-based super-plasticizer was used for the normal concrete mix. Different concrete mix proportions were adopted. The study led to a conclusion that the enhanced filling ability of SCC results in higher bond strengths.

Foroughi-Asl et al. [4] reported on pullout tests designed to study the effect of SCC on bond strengths. Different bar diameters were tested. The mix designs of the SCC and the companion Normal Concrete (NC) specimens were the same except for the addition of the silica fume and PCE super-plasticizers in the SCC specimens. The experimental data gathered revealed slightly higher bond strengths for the SCC specimens. This similarity in the behavior of SCC and normal concrete specimens was not reflected in the research papers studying the shear resistance of reinforced concrete beam elements. The shear capacity of normal VC appeared to overcome that of SCC.

Veerle Boel et al. [5] tested the shear capacity of beam specimen made with SCC and VC. The SCC mix proportions were marked by the high limestone filler content and the low river gravel volumes. The SCC specimen contained 43% lower aggregate content. Boel associated the lower shear capacity of the SCC beams to the lower aggregate interlock caused by the fewer coarse aggregates.

Hassan et al. [6] also conducted an experimental investigation on the shear strength of SCC beams. The concrete mixes were designed differently where SCC contained 25% coarse aggregate content lower than normal concrete. The difference in volume dedicated for coarse aggregate was compensated by an addition in the sand content of the SCC mixes. The experimental results indicated a similarity in the overall failure mode in terms of the cracking pattern, crack width and height in SCC and NC beams. The ultimate shear capacity of SCC beams appeared to be lower than their NC counterparts. According to the researchers, the lower shear strength could be attributed to the decrease in coarse aggregate content that used to provide additional resistance to shear through aggregate interlock mechanisms.

From the literature review it is observed that, addition of alccofine and fly ash up to certain percentage in concrete or cements composites, improve strength and also can be used for behavior of structures. And also it has been observed that not much work has been done on fly ash and alccofine based reinforced concrete in flexure loading for structural elements like beams/slabs etc. Therefore it is very important to study the flexural response of Reinforced Self-Compacting Concrete (RSCC) on structural element like reinforced concrete beam and hence present study focuses on the same. Comparative study has been conducted on ultimate moment carrying capacity of RSCC beams with Indian codes, ACI and Canadian.

3. THE USED MATERIALS

All raw materials that used to cast the beam specimens were tested. The materials like cement, aggregates, alccofine and fly ash as filling materials for self-compact concrete are as follows: Ordinary Portland Cement - Type I had been utilized, the testing result complies to Indian standard specification IS 8112: 1989 [7]. Natural sands, which having max size of 4.75 mm were utilized and crushed gravels, which having a maxi size of 12 mm was utilized and grading of coarse aggregate comply with the Indian specifications BIS 383-1970 [8].

Alccofine (AL-1203) was obtained from Ambuja Cement Ltd, Goa [9–14] having the specific gravity of 2.9, specific surface area of 1,200 m^2/kg bulk density of 800 kg/m^3 confirming to ASTM C989-1999 [15] was used in entire study. Fly ash was obtained from thermal power plant having 540–860 kg/m^3 and confirming to ASTM C-618.

A chemical admixture based on modified sulphonated naphthalene polymers had been utilized as a high performance super plasticizing admixture. It has no chlorides and meets with ASTM C-494 specification. All the beams had uniform dimensions with length 1,200 mm, width 150 mm and depth 250 mm.

4. FABRICATION OF REINFORCED SELF-COMPACTING CONCRETE MIXTURES

Commercially available High Yield Strength Deformation (HYSD) round steel bars of different diameters were used for the fabrication of cages of reinforced self-compacting concrete beam samples. Steel samples at required frequency were tested in the automatic Universal Testing Machine (UTM) of capacity 1,000 kN, mounted in the structure laboratory of the department. The average test results are shown in Table 1 and plot of stress-strain is shown in Fig. 1.

Many mixing trials were done to reach the required compressive strength. The final mix proportion is given in Table 2. Slump Flow, T50, L-box and V-funnel testing was conducted to ensure that the concrete working as self-compacting. Moreover, a comparison was done between the findings and the limit of EFNARC-2002 [16] along with ACI

Table 1. Material properties of reinforcement

Steel type	d_S (mm)	A_S (mm^2)	*fy* (MPa)	Standard value (MPa)	*fu* (MPa)	Standard *fu* value (MPa)	*Es* (GPa)	Elongat ion (%)
Bars	8	50.2	617	≮ 500	717.7	≮ 545	200	14.2
	10	78.5	540		658.8		201	14.0
	12	113	690		771.9		200	17.1
	16	201	545		687.1		198	10.0

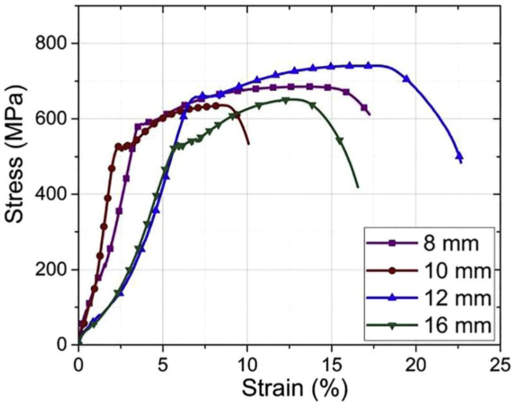

Fig. 1. Stress–strain diagram of steel bars

Table 2. SCC mixing proportions

Materials	NM	SCC0	SCC1	SCC2	SCC3
Cement (kg/m^3)	384	374.25	349.3	324.35	299.4
Water (kg/m^3)	202	179.64	179.64	179.64	179.64
Fly ash (kg/m^3)	0	124.75	124.75	124.75	124.75
Alccofine (kg/m^3)	0	0	24.95	49.90	74.85
Fine aggregate (kg/m^3)	639	863.36	863.36	863.36	863.36
Coarse aggregate (kg/m^3)	1,139	721.60	721.60	721.60	721.60
Super plasticizer (l/m^3)	0	5.99	5.99	5.99	5.99

237R-07. The utilized potable water was taken from the water-supplying network system (tap water).

Five simply supported beams with 150 × 250 × 1,200 mm dimensions were cast to know the structural behavior of RC beams. This figure also shows testing configurations. The testing of the beams was carried out on a 1,200 mm span with different proportion of alccofine and fly ash quantities. The loads were applied at four points of the beam and the distance between the rollers is $L/3$ as shown in Fig. 2. The beams were tested up to failure.

5. RESULTS AND DISCUSSION

5.1. Load-deflection behavior of RSCC

From Fig. 3, it can be observed that each load-deflection curve shows two types of behaviors i.e., linear and nonlinear behavior of RSCC beam. The linear part of the curve represents the un-cracked behavior of the beam up to the first crack load, whereas the nonlinear part shows the behavior of cracked beam after the first crack load up to the failure of specimen.

Fig. 2. Test setup

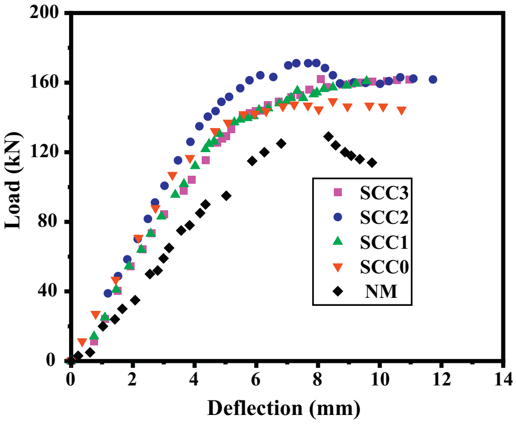

Fig. 3. Load–deflection curves

From Fig. 3 it is also noted that the load-deflection curves of the RSCC beams have two turning points, which indicate the behavior of the beam specimens used in this study. The portion in between the starting (initial) point to the first turning point reflects the elastic behavior, whereas the portion in between the first turning point to the second turning point represents the ductility (plastic) behavior of the RSCC beam. The load at the second turning point represents the ultimate load. The portion after the second turning point reveals the fracture behavior of the specimen [17]. In this research, it is also observed that the load-deflection curves of RSCC beams have mainly two turning points which represent the behavior of RSCC beams [18].

Ultimate load can be obtained at the second turning point. After the second turning point represent the fracture behavior of beam specimen. The ultimate deflection was seen at mid span of the RSCC mixes for 28 days as it is shown in Fig. 3. The normal concrete mix showed a deflection of 8.33 mm at the ultimate load of 129 kN, whereas 25%FA+0%AL, 25%FA+5%AL, 25%FA+10%AL and 25%FA+15%AL mixtures showed the deflections of 8.47, 9.57, 7.94, and 8.08 mm at the ultimate load of 149.27, 160.87, 171.24, and 162.12 kN, respectively.

6. ULTIMATE MOMENTS

By considering different material factor according to different codes, equations for neutral axis and ultimate moment carrying capacity are shown from Eqs (1)–(10) as follows:

6.1. American concrete institute's building code (ACI 318-11)

The most significant specification for design of reinforced concrete structures in the United States, ACI 318-11, [19]. ACI 318-11 is primarily used for the design of buildings. The calculation of moment of resistance as follows below.

Moment of resistance

$$M_u = Tjd, \tag{1}$$

$$T = A_s f_s, \tag{2}$$

$$C = 0.85 f_c^l ab, \tag{3}$$

$$jd = d - 0.5a. \tag{4}$$

From equilibrium $C = T$,

$$0.85 f_c^l ab = A_s f_y. \tag{5}$$

Therefore

$$a = \left(\frac{A_s f_y}{0.85 f_c^l b} \right). \tag{6}$$

Hence from Eqs (1) and (4) the following equation can be written as

$$Mu = A_s f_y (d - 0.5a), \tag{7}$$

$$M_u = A_s f_y \left(d - 0.59 \frac{A_s f_y}{f_c^l b} \right). \tag{8}$$

6.2. Indian Standard Code (IS: 456-2000)

The most important code in the India for plain and reinforced concrete structures design is the Indian Standard Code IS: 456-2000, [20]. The determination of moment of resistance as follows below:

$$C = \varnothing_s (0.8) f_c^l ab, \tag{9}$$

$$T = \varnothing_s 7 f_y A_s. \tag{10}$$

From Eqs (9) and (10)

$$a = \left(\frac{\varnothing_s A_s f_y}{0.36(0.8) f_c^l b} \right), \tag{11}$$

$$M_u = \varnothing_s A_s f_y d \left(1 - \frac{A_{st} f_y}{(0.8) f_c^l bd} \right). \tag{12}$$

6.3. Canadian Code A23.3-04

The moment of resistance of singly reinforced concrete beam is calculated using Canadian Code [21] given below equation, $C = T$:

$$C = \alpha_1 \varnothing_c (0.8) f_c' ab, \tag{13}$$

$$T = \varnothing_s A_s f_y, \tag{14}$$

$$\alpha_1 \varnothing_c f_c' ab = \varnothing_s A_s f_y, \tag{15}$$

$$a = \frac{\varnothing_s A_s f_y}{\alpha_1 \varnothing_c f_c' b}, \tag{16}$$

$$M_u = T_r \left(d - \frac{a}{2} \right), \tag{17}$$

$$M_u = \varnothing_s A_s f_y \left(d - \frac{a}{2} \right). \tag{18}$$

The experimental ultimate moment carrying capacities of all the tested beams are shown in Table 3. It was observed that as constant fly ash quantity and increasing dosages of alccofine the ultimate moment carrying capacity was enhanced when all other parameters are constant. It was also

Table 3. Experimental and theoretical bending moment of tested beams

Beam Designation	Mu(exp) /(kN-m)	Mu(th-IND) /(kN-m)	Mu(th-ACI) /(kN-m)	Mu(th-CSA) /(kN-m)	Mu(exp) /Mu(th-IND)	Mu(exp) /Mu(th-ACI)	Mu(exp) /Mu(th-CSA)
NM	21.48	17.35	20.99	16.57	1.23	1.02	1.29
SCC0	24.85	17.50	21.09	16.73	1.42	1.17	1.48
SCC1	26.78	17.59	21.15	16.84	1.52	1.26	1.59
SCC2	28.51	17.68	19.37	16.94	1.61	1.47	1.68
SCC3	26.99	17.60	21.16	16.86	1.53	1.27	1.60
Average value					1.462	1.238	1.528

found that fly ash and alccofine plays significant role in ultimate moment carrying capacity of the beam. Ultimate moment carrying capacity of the beam without alccofine and fly ash is found to be less than the beam with alccofine and fly ash [21].

Mu(th-IND), Mu(th-ACI) and Mu(th-CSA) are the theoretical ultimate moments calculated using Eqs (1)–(18) based on Indian (IS456-2000) [20], American(ACI 318-11) [19] and Canadian(CSA A23.3-04) [21] codes respectively. Mu(exp) is the experimental ultimate moment obtained from peak or ultimate load during testing. The comparison of predicted theoretical values using above mentioned codes and experimental values are shown in Table 3. It was observed that the experimental ultimate moment carrying capacity was close to the theoretically calculated values in case of CSA A23.3-04, [21] and ACI 318-11, [19] codes. It was observed that theoretical ultimate moment values [22] calculated for their work, ACI 318-11, [19] code predicts higher values compared to other two codes [23].

7. CONCLUSIONS

An experimental study on the structural performance of RSCC beams with and without alccofine and fly ash under flexural loading was conducted to investigate the load–deflection curves and effect of alccofine-fly ash based concrete on the ultimate moment carrying capacity of RCC beams. Based on the experimental results following conclusions can be drawn:

- Load carrying capacity of the beam with alccofine and fly ash has increased when compared to beam without alccofine and fly ash;
- Experimental ultimate moment carrying capacities of all beams are observed to be quite comparable with the values obtained using theoretical equations of ACI 318-11 and CSA A23.3-04 code but were less variation when compared to IS 456-2000. The prediction of high theoretical strength using ACI 318-11 code is due to the fact that ACI predicts higher values due to considerations of less factor of safety for steel and concrete when compared to IS and CSA codes.

NOMENCLATURE

ρs	longitudinal reinforcement ratio
ds	diameter of steel bar
C	resultant concrete compression force
T	tension force in the reinforcement
$\varnothing c$	material resistance factor for concrete
$\varnothing s$	material resistance factor for steel
fc	concrete cube compressive strength
a	depth of compression zone
As	area of steel in tension
fy	yielding stress in steel
Mr	factored moment resistance
a	depth of equivalent rectangular stress block
fs	steel stress, for tension failure $fs = fy$
d	distance from extreme compression fiber to the centroid of steel area
M_U	moment of resistance
a	depth of equivalent rectangular stress block
b	specified compressive strength of concrete

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