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Structural Behaviour of Reinforced Self Compacting Concrete Incorporating Alccofine and Fly ash

C. Sashidhar[1*], J. Guru Jawahar[2], Bode Venkata Kavyateja[3]

[1]Professor, Department of Civil Engineering, Jawaharlal Nehru Technological University, Anantapuramu, Andhra Pradesh, India

[2]Professor, Department of Civil Engineering, Annamacharya Institute of Technology and Sciences, Tirupati, India

[3]Research Scholar, Department of Civil Engineering, Jawaharlal Nehru Technological University, Anantapuramu, Andhra Pradesh, India

Corresponding author: *Prof. C. Sashidhar, Department of Civil Engineering, Jawaharlal Nehru Technological University, Anantapuramu, Andhra Pradesh, India, Email: sashidhar.civil@jntua.ac.in*

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Abstract

Background: The continuous demand for raw materials in the production of concrete needs cost-effective and good quality alternative cementitious materials such as Metakaolin (MK), Silica fume (SF) and Fly ash (FA) are substituting to ordinary Portland cement. Replacement of these raw materials is an added advantage to reducing carbon dioxide emissions and protecting the depleting natural resources. Alccofine is a new generation ultra-fine supplementary cementitious material from the steel industry as a partial replacement of cement.

Findings: The present paper focuses on the structural behaviour of reinforced self-compacting concrete (RSCC) beams under two-point loading incorporating alccofine (AL) and fly ash (FA). A total of five beams were cast and tested for evaluating the effect of alccofine and fly ash on the structural behaviour of different concrete mixes (NC, SCC0, SCC5, SCC10 and SCC15). According to IS 456-2000, the reinforcement of RSCC beams with a length of 1200 mm, width of 150 mm and 250 mm high were designed and tested under two-point loading at 28 days. The beams were supported by simple support with a span of 1000 mm and it was subjected to two-point loading. During two-point load test the structural characteristics viz., load-deflection, failure modes, load characteristics, deflection ductility index and degradation in stiffness were studied.

The experimental results showed that RSCC beams have shown better results in all structural behaviour characteristics with 10% alccofine and 25 % fly ash.

Keywords: Two-point loading; load characteristics; alccofine; fly ash; flexural parameters; structural behavior

Abbreviations

RSCC	Reinforced self-compacting concrete
NC	Normal concrete
FA	Fly ash
AL	Alccofine
RC	Reinforced concrete
DI	Ductility index

Introduction

It is well-known that beam elements are the important components in the concrette structures that carry transverse loads. As a result, research has been carried out over the last few decades on reinforced concrete beams to enhance the strength properties such as modulus of elasticity, shear strength, flexural strength and torsion strength, etc. Plain concrete is strong in compression but weak in tension because it includes many micro-cracks [1]. These micro-cracks spread into the concrete while applying loads. As a result, structural members with plane concrete cannot withstand the tensile stresses that have developed owing to the force applied without the addition of reinforcement elements [2].The addition of supplementary cementitious materials increases its load-carrying capacity, ductility, and stiffness while reducing crack propagation and crack development in the structural concrete elements. In the last 30 years, concrete manufacturers have developed a new generation of composites with high mechanical characteristics and environmental resistance [3].

Vidivelli and Gobi [4] aimed to compare the structural behaviour of self-curing and self-compacting concrete beams. They have used mineral admixtures such as limestone, class F fly ash and silica fume for the cement substitution, and quarry dust to substitute the fine aggregate. They have developed a technique to analyze self-curing and self-compacting concrete beams. Twelve mixes were used to prepare the normal concrete beams, self-curing concrete beams and self-compacting concrete beams. Different tests have been performed for the strength properties of concrete. The ANN modelling has been carried out to compare the deflection, ultimate and yield load. Self-curing and self-compacting concrete beams showed better performance, and the ANN model showed an error of 0.8 to 16.6%, only with those of experimental tests.

Saifullah et al. [5] were studied the structural behaviour of beam elements experimentally for flexure and load-deflection studies under four-point loading. Computer-based analysis of the tests performed in the lab was done using ANSIS and SAS 2005. Empirical analyses have been accomplished on reinforced beams of over, balanced and under reinforcements. The acceptable range of error was observed from the computer-based outcomes. The primary crack was observed at 0.45 L from the left end support. The maximum deflection was observed in the balance reinforced section in concrete beams.

Jeenu et al. [6] researched the bending behaviour of hybrid fibre added SCC beams. The prototype concrete beams have been produced without fibres, with optimum percentages of macro and hybrid fibres were produced to investigate the flexural behaviour under two-point loading. The concrete beam specimens with 0.75% macro fibres were seen to be good, but when 50% macro fibres were substituted with microfibres, better results were seen. The mechanical properties of concrete have been improved with micro fibres addition. With hybrid fibres in SCC beams performed well ductility compared to the normal beams under two-point loading.

Mithra et al. [7] explored the structural behaviour with GGBFS based reinforced SCC beams a partial substitute for OPC and addition of high range water reducer. The goal was to examine the flexural behaviour of simply supported SCC beams were cast with HYSD bars. Data were collected for load-deflection under two-point loading. The effect of GGBFS, which ranges from 0 to 50 percent as a partial substitute of cement, was examined preliminarily. It was noted that the primary crack load was improved for the SCC beams with 30-40% GGBFS and 40% GGBFS substituted was shown good performance compared to all other beams.

In this work an attempt was made to study the structural characteristics viz., load-deflection, failure modes, load characteristics, deflection ductility index and degradation in stiffness of SCC reinforced concrete beams made using varying dosage of alccofine and fly ash as a constant replacement for cement.

Materials and Methods

The materials used for concrete production were ordinary Portland cement, alccofine, fly ash, natural sand with maximum size of 4.75 mm and coarse aggregate with a maximum aggregate size of 12 mm. The mix ingredients of reinforced self-compacting concrete (RSCC) mixes are shown in Table 1. The quantities of cement, alccofine and fly ash are in different quantities for all concrete mixes. The quantities of fine aggregate, coarse aggregate, water and chemical admixture are same for all concrete mixtures as followed by 863.36 kg/m^3, 721.60kg/m^3, 179.64 kg/m^3 and 5.99 kg/m^3, respectively.

The formwork with wood material comprises of inner dimensions 150 mm * 250 mm * 1200 mm was prepared. The prepared formwork should be leak proof otherwise poured SCC would escape out from the formwork science it is fluid in green state. The reinforcement details as shown in Figure 1 consists of two number of 10 mm diameter bas as bottom longitudinal (main) tension reinforcement and two number of 8 mm diameter bar as hanger bars provided on the compression face with clear cover of 25 mm. the shear reinforcement consists of 8 mm diameter bar with two legged stirrups at 165 mm centre to centre.

The inner face of the formwork was rushed with oil before placing reinforcement and concreting. The reinforcement skeleton was placed in the formwork with a cover of 25 mm. Total five beams were cast. Once the prepared SCC mix attained desired workability, then it was poured in the beam mould without compaction. SCC in hardened state was shown in Figure 2.

The formwork was removed after the duration of 24 hours of concreting. The beam identification was given by marking NC, SCC0, SCC5, SCC10 and SCC15. The beam specimens were immersed in the water tank for the hydration period of 28 days to attain adequate strength. The normal water curing was carried out for all beam specimens.

Table 1: Mix proportions for RSCC beams

Mix	Cement	Fly ash	Alccofine	Super plasticizer	Coarse aggregate	Fine aggregate	Water
NC	384	0	0	0	1139	639	202
SCC0	349.3	149.7	0	5.99	721.60	863.36	179.64
SCC5	331.8	149.7	17.40				
SCC10	314.3	149.7	34.93				
SCC15	296.9	149.7	52.39				

*All quantities are in kg/m3

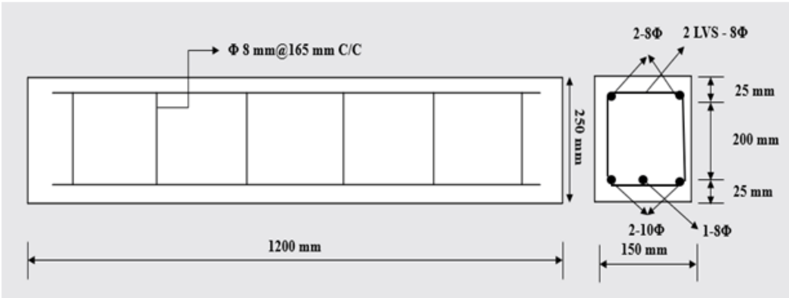

Figure 1: Reinforcement detailing of RSCC beams

Figure 2: SCC in hardened state

After 28 days of curing, the beam specimens were taken out from the water tank. The surfaces of beam specimens were made dry by placing it in the open atmosphere for the minimum duration of 3 hours. Once its surface became dry off, the position of support rollers with a projection of 100 mm on either ends, the span of the beam (L), mid span (L/2) and the position of loading rollers say L/3 were indicated on the longitudinal section of the beam. The loads were applied at two points of the beam and the distance between the rollers is L/3 as shown in Figure 3. The beams were tested up to failure.

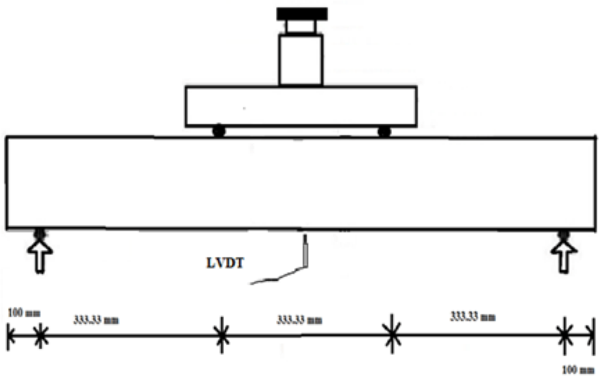

Figure 3: Two-point loading setup

Results

From an experimental investigation on the beams, the most important independent parameter to understand the behaviour of beam was its load-deflection profile. Deflections were measured along the beam at L/3 points at every load stage of reinforced SCC beams. For present study, the load-deflection plot was prepared at L/3 position. Figure 4 shows the load-deflection curves of RSCC beams. The values of test results of all beams from each mix tested for flexure at the age of 28 days. Comparison of primary crack load, service load, yield load and ultimate load for all the beams are shown in Figures 5. Both flexure and shear failure were observed in all the tested beams. Crack patterns of RSCC beams are shown in Figure 6. Ductility is the ability to sustain inelastic deformation without substantial decrease in the load carrying capacity. The ductility factors of the tested beams were calculated by finding the ratio of deflection at the ultimate load to the deflection at the yield load. The mid span deflection at yield and ultimate loads, ductility indices are illustrated in Table 2.The ratio between the load and the corresponding deflection gives the stiffness of the beam specimens. The stiffness is calculated at two stages such as yield and ultimate load level. The variation of stiffness in all the three stages for all the 5 beams are presented in Table 3.The moment at the ultimate load capacity of all the beams are given in Figure 7.

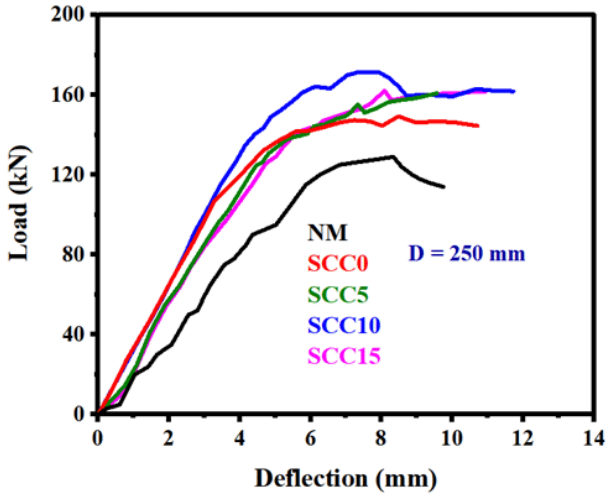

Figure 4: Load-deflection curves

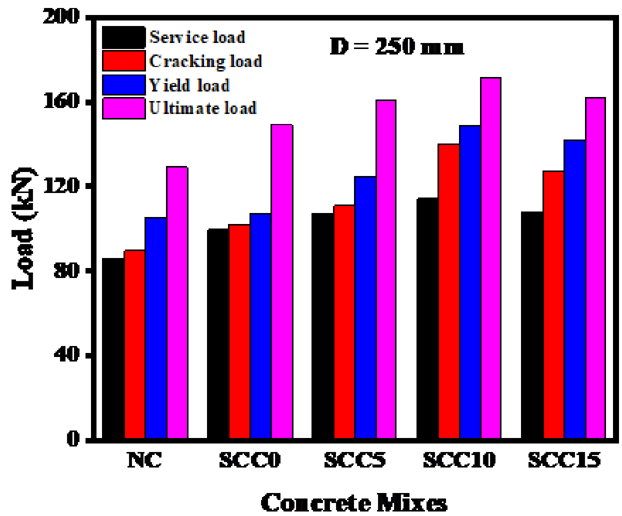

Figure 5: Load characteristics of RSCC beams

Table 2: Displacement ductility index values of RSCC mixes

Beam Designation	Displacement (mm)		DDI
	Yielding state	Ultimate state	
NC	5.36	8.33	1.55
SCC0	3.80	8.47	2.23
SCC5	4.46	9.57	2.15
SCC10	4.86	7.94	1.63
SCC15	4.61	8.08	1.75

Discussion

Load-deflection behaviour of RSCC

Figure 4 shows the load-deflection curves of RSCC beams. From Figure 4, it can be seen that the deflection curves of RSCC beam show mainly two kinds of behaviours, i.e., linear and non-linear [8]. First part (i.e., linear) curve indicates the un-cracked characteristic of the beam upto the initial crack load. In contrast, the second part (i.e., non-linear) of RSCC beam represents the cracked beam behaviour after initial crack up to the specimen failure. In this research, it is also observed that the load-deflection curves of RSCC beams have mainly two turning points representing the behaviour of RSCC beams. First turning point indicates elastic behavior and second turning point (i.e., from first turning point to second turning point) indicates ductility behavior of RSCC beams [9]. The 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 as shown in Figure 4. For 250 mm depth RSCC beams, the normal concrete mix showed a deflection of 8.33 mm at the ultimate load of 129 kN, whereas SCC0, SCC5, SCC10 and SCC15 mixtures showed the deflections of 8.47 mm, 9.57 mm, 7.944 mm and 8.0898 mm at the ultimate load of 149.27 kN, 160.87 kN, 171.248 kN and 162.12 kN, respectively.

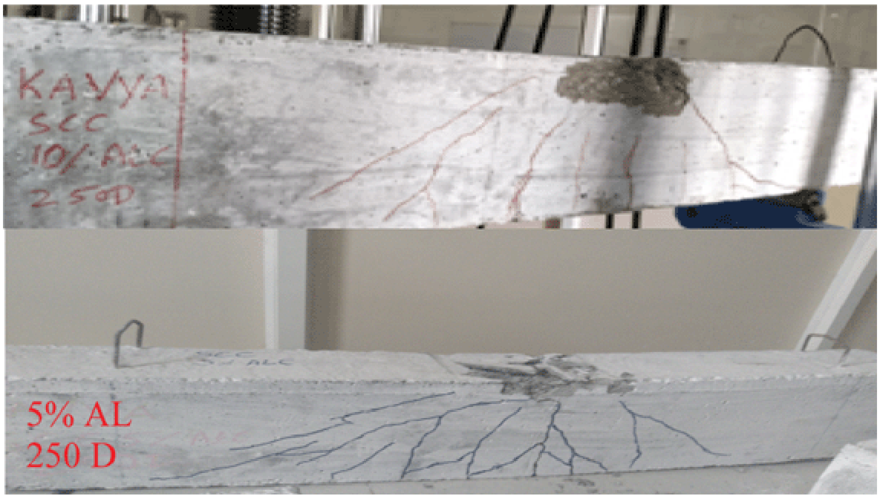

Figure 6: Cracking pattern of RSCC beams

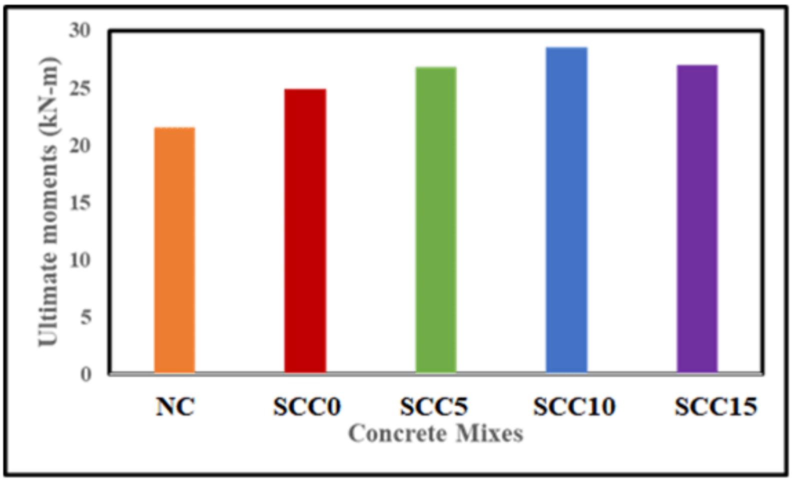

Figure 7: Ultimate moment carrying capacity results

Table 3: Relative stiffness degradation

Beam Designation	Stiffness (N/mm)		Variation in stiffness degradation
	Yielding state	Ultimate state	
NC	19589.55	15486.19	0.790533
SCC0	28131.58	17623.38	0.626462
SCC5	27959.64	16809.82	0.601217
SCC10	30637.86	21566.75	0.703925
SCC15	25412.19	20064.36	0.789556

Load characteristics

Self-compacting reinforced concrete beams were failed in both flexure and shear. Primary crack load, service load, yield load and ultimate load of RSCC beams are shown in Figure 5. From IS 456-2000, the service load was determined by using factor of safety 1.5. The addition of fly ash and alccofine improved its homogeneity and flow-ability and enhanced the ultimate flexural strength due to interlocking effects between mortar with aggregate and reinforcement in RSCC beams. Figure 5 shows that the service loads of SCC0, SCC5, SCC10 and SCC15 are found to be enhanced by 15.70%, 24.69%, 32.74%, and 25.67% respectively, when compared to that of beam with mix NC. The crack load of SCC beams with mix SCC0, SCC5, SCC10 and SCC15 are found to be improved by 14.10%, 23.921%, 56.40% and 42.18%, respectively, when compared to that of beam with mix NC. The yield load of SCC beams with mix SCC0, SCC5, SCC10 and SCC15 are found to be enhanced by 1.85%, 18.82%, 41.83% and 35.05%, respectively, when compared to that of beam with mix NC. The same pattern was followed by the ultimate load-carrying capacity in all SCC mixes [10].

Failure mode and crack pattern

From Figure 6 showed that the flexural cracking was initially observed for all the beams for low loadings in mid-span at bottom zone, indicating that steel reinforcement did not play any significant role in enhancing cracking load. After initial flexure crack, as load increases, the beam's load-carrying capacity and ultimate failure were observed due to shear and flexure.

Hairline cracks occurred initially in the pure bending zone during the first crack load. As the load increased, new cracks occurred and the existing cracks extended and spread from the bottom of the beam (tension zone) to top of the beam (compression zone) and spalling of concrete was examined in the compression zone. The width of the crack has been increased to a greater extent at ultimate load. Figure 4 displays the crack patterns of tested beams evaluated at ultimate loads.

Ductility index

Ductility index is presented in the ratio of deflection at ultimate stage to yield stage. DI has been calculated from the load-deflection curves and presented in Table 2. The deformation of SCC10 and SCC15showed the medium ductility index values compared to SCC5 mix, whereas SCC0 concrete mix showed the high DI value compared to the other concrete mixes. The highest yielding capacity or the property of ductility was exhibited in SCC beams with alccofine and fly ash when compared with normal concrete beams [12-15]. Degradation in stiffness

Relative stiffness values at yielding and ultimate load points are calculated and are shown in Table 3.Secant stiffness is used to do stiffness degradation analysis. It is observed that as the alccofine dosage increases the overall stiffness of beam increases. Table 3 shows that stiffness descends very fast at initial stage till cracking point and after cracking point it becomes slower until it reaches failure point. It is observed that in case of beam with alccofine and fly ash the yield cracking stiffness and ultimate stiffness were higher values when compared to beam without alccofine and fly ash. The stiffness degradation of SCC0 mix specimen showed 21.5% lesser than the normal mix specimen, whereas SCC5, SCC10 and SCC15 mixtures showed the degradation in stiffness of 24%, 11% and 1.26%, respectively compared to the normal mix specimen.

Ultimate Moments

The experimental ultimate moment carrying capacities of all the tested beams are shown in Figure 7. It was observed that as constant fly ash quantity and alccofine dosage increases the ultimate moment carrying capacity increases when all other parameters are kept constant [17]. It was also found that fly ash and alccofine play a significant role in the beam's ultimate moment carrying capacity. 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. With 25% fly ash addition, the moment carrying capacity has been enhanced by 15.68%, whereas the combination of constant fly ash quantity with varying dosage of alccofine from 5%, 10% and 15% enhanced by 24.67%, 32.72% and 25.65% compared to normal concrete mix, respectively [18].

Conclusions

On the basis of the present investigation, the following Conclusions are drawn

- The load-deflection behaviour of RSCC beams were studied with the addition of constant dosage of fly ash (i.e., 25% by mass) and varying dosage of alccofine (i.e., 0-15% by mass).
- The ultimate load carrying capacity of RSCC beams were enhanced up to 10% alccofine addition and further increment it decreased.
- The combination of shear and flexural mode of failures were observed in RSCC beams.
- The load characteristics (i.e., primary crack, service, yield and ultimate load) of RSCC beams enhanced with constant fly ash and alccofine dosage from 0-15% replacement.
- RSCC beams with alccofine and fly ash showed lesser values in stiffness degradation compared to normal concrete mix.

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Declaration

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Conflict of Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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