International Journal of Scientific & Engineering Research, Volume 7, Issue 10, October-2016
ISSN 2229-5518

Effect of Lightweight Aggregate on the Flexural Behaviour of Self Compacting Concrete

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Abstract—Self-Compacting Concrete (SCC) is a flowing concrete mixture that is able to consolidate under its own weight. Density of all types of concrete depends on the coarse aggregate present in it. Concerns about the depletion of Natural Coarse Aggregate (NCA) and increase in self-weight of building with height, have led to the adoption of several alternatives, like lightweight Coarse aggregates (LCA). In this research work, a study was conducted to replace NCA by fly ash based LCA in SCC based on target compressive strength. An experimental investigation on flexural behaviour of SCC specimens having M50 grade for different percentage (25, 50, 75 and 100%) variation of NCA using LCA was carried out. The results were then compared with the control specimens (SCC containing NCA only).

Index Terms—Flexural behaviour, Lightweight aggregate, Self-compacting concrete, Self weight, Natural Coarse aggregate

1 INTRODUCTION

Self-compacting concrete is described as the most revolutionary development in concrete construction. It is a special type of concrete which is able to flow under its own weight completely filling formwork and achieving full compaction, even in the presence of congested reinforcement without vibrations. The degree and quality of compaction is one of the prime factor which affects the quality of the concrete. Use of normal concrete in situations where reinforced concrete elements contain heavy and congested reinforcement requiresadequate number of skilled labours. The gradual reduction in the number of skilled workers these days has led to reduction in the quality of construction work. One solution for the achievement of concrete structures independent of the quality of construction work is the employment of self-compacting concrete [1]. The advantages of SCC make this concrete more desirable all over the world which includes faster construction, reduces manpower, better finishes, easier placement, better durability, thinner concrete sections, lesser noise levels, no vibration, safer working environment etc[2]. The Concept of SCC originates from Japan in 1980s and the early developed Super Plasticizers were the main reason which made it possible to flow and self consolidate. The use of SCC is rising steadily over the years because of their advantages and many scientists and organizations carried out research on properties of SCC. [3]

Apart from this, another major issue faced by the construction industry regarding reinforced concrete production is the unavailability of adequate natural aggregate required to meet the demand and the increase in self weight of the structure with height [4]. An alternative to the natural aggregate has been a topic of concern for several years and the use of lightweight aggregate has emerged as an effective option.

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Lightweight Aggregates (LAs) are materials used in concrete to make it lighter. They are an excellent substitute to natural aggregates. The use of LAs in concrete can be traced to as early as 3000 BC, when the famous towns of Mohenjo-Daro and Harappa were built during the Indus Valley civilization. In some places, like Malaysia, palm oil shells are used for making lightweight aggregate concrete [5]. LAs are classified into two groups namely, natural lightweight aggregates and artificial lightweight aggregates Earlier LAs were of natural origin. These have been used both as fine and coarse aggregates. Natural aggregates are not found in many places and they are also not of uniform quality. Natural LAs include diatomite, pumice, volcanic slag, volcanic ash and tuff. Out of which pumice is the only one which is used rather widely. With the increasing demand and the non-availability of natural LAs worldwide, techniques have been developed to produce them in factories. These are produced from the natural raw materials like expanded clay, shale, slate, etc., as well as from industrial by-products such as fly ash, bed ash, blast furnace slag, etc. The properties of the aggregates depend upon the raw materials and the process used for producing them. They include sintered fly ash, Brick bats, Foamed slag, Bloated Clay and Expanded Perlite[6].

In this research work the flexural behaviour of beams made of NCA, partially (25,50 and 75%) as well as fully replaced LCA was studied under two point loading in a Universal Testing Machine (UTM) of 1000kN capacity.

2 MATERIALS USED

Portland Pozzolana Cement, Natural Coarse Aggregate (NCA) of maximum size 12.5 mm, fly ash based Lightweight Coarse Aggregate (LCA) of maximum size 12.5 mm, manufactured sand passing through sieve of size 4.75 mm and confirming to zone II of IS 383-1970 (reaffirmed 2002) as fine aggregates (FA) were used [7],[8]. Silica fume was used as mineral admixture and Hyperplast XR-W40 was used for the work as super plasticizer. A comparison between the material properties of FA, NCA and LCA is shown in Table 1.

TABLE 1
PROPERTIES OF AGGREGATES

Properties	Results		
	FA	LCA	NCA
Fineness Modulus	2.900	6.585	6.446
Sieve analysis	Conforming to IS specification	Conforming to IS specification	Conforming to IS specification
Bulk Density (g/cc)	1.789	1.079	1.593
Loose Bulk density(g/cc)	1.594	0.865	1.454
Void ratio	0.373	0.725	0.795
Porosity (%)	27.2	42.02	44.275
Specific Gravity	2.458	1.86	2.859
Water Absorption (%)	1.622	16.830	0.548

Mix Designation	Mix Details
NA100SCC	Normal Self –compacting concrete (control mix)
NA75SCC	75% NCA and 25 % LCA
NA50SCC	50% NCA and 50 % LCA
NA25SCC	25% NCA and 75 % LCA
NA0SCC	100 % LCA

3 EXPERIMENTAL PROGRAMME

3.1Mix Design

Nan et al. method of mix design was adopted in this work [9]. In order to attain the target strength the contents of cement, silica fume, super plasticizer, water powder ratio etc. were varied in each trail. A total of five different SCC mixes were used in this study. The mix designation and the details are shown in Table 2. The trail mixes that were adopted for all the five mixes i.e. for 0 to 100% replacement of NCA by LCA at an increment of 25% was based on target compressive strength. After attaining the required mix for each percentage replacement of NCA with LCA, the fresh properties of SCC like V funnel, L box and U box were carried out for the selected mixes.

Table 2
MIX DESIGNATION AND DETAILS

3.2 Flexural Behaviour

3.2.1 Specimen Details

The beams were designed as under reinforced section[10]. For studying the flexural behaviour beams of size 100x 150x 1000 mm was cast for 0, 25, 50, 75 and 100% replacement of NCA with LCA (3 beams each). The reinforcement consists of two numbers of 10 mm diameter bars at the tension face and two numbers 8 mm diameter bars at the compression face. Two legged 6 mm stirrups were used at a spacing of 90 mm center to center. Fig.1 shows the geometry and reinforcement detailing of SCC beams. After 24 hours of casting, the specimens were demoulded and kept immersed in water for 28 days.

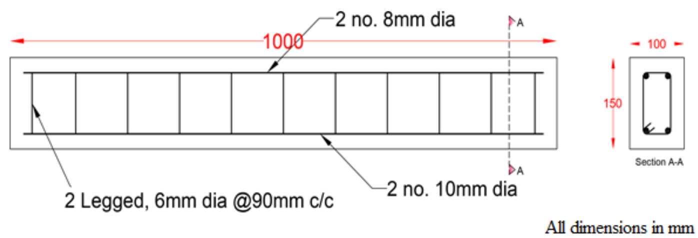


Fig.1 Specimen Detailing

3.2.2 Testing

All the beams were tested under two point loading in an UTM of capacity 1000kN. Three LVDTs were provided at mid span and at tension and compression reinforcement level for measuring deflection and strains as shown in Fig. 2. Two dial gauges were provided at support spans for measuring the deflection at supports. The readings on the dial gauges and LVDTs were noted down for a load increment of 2.5kN. The values obtained from the LVDT at mid span was used to plot the load deflection curve and strain values are used for the moment curvature plot. . The value of moment is given by Eqn.1. and the curvature was obtained from Eqn. 2[11].

Fig. 2 Test Setup

ISSN 2229-5518

$$M = Pl/6 \quad (1)$$

Where,
M = Moment at mid span
P = Applied load
l = Span of the beam between the supports

$$\varphi = (\epsilon_s+\epsilon_c)/d'' \quad (2)$$

Where,
ϕ =Curvature
ϵs = Tension steel strain
ϵc = compression steel strain
d″ = Gauge length between points where strains are measured.

4.RESULTS AND DISCUSSION

4.1 Mix Proportion

On the basis of Nan et al. method of mix design, many trials were conducted to find a mix which gives the required target strength for all the percentage replacement of NCA with LCA. After the mix was prepared, the slump flow was found out and only those mixes which satisfied the EFNARC criteria of slump flow were considered for the target strength. The mix was finalized on the basis slump flow and 28 days of compressive strength. Table 3 shows the mix proportion of the selected mixes for each percentage replacement. It was found that, the strength of the mix increases by decreasing the water-binder (w/b) ratio and increasing the super plasticizer (SP) content. Once the target strength for the control mix was achieved, then the cement content was kept constant. When LCA were added to make SCC, the strength was found to be decreasing. This may be due to the high porous nature of LCA. In order to attain the target strength for each percentage replacement, the silica

Table 3
TRAIL MIXES

Designation	Cement (kg/m³)	FA (kg/m³)	NCA (kg/m³)	LCA (kg/m³)	SF (%)	SP (%)	Water (kg/m³)	Slump (mm)	Compressive Strength(MPa)	
									7th day	28th day
NA100SCC1	460	1008.21	751.93	--	5.0	1.30	157.78	685	26.67	39.11
NA100SCC2	470	1008.21	751.93	--	5.0	1.50	157.92	700	26.67	39.11
NA100SCC3	480	1008.21	751.93	--	5.0	1.50	159.21	705	26.22	37.78
NA100SCC4	480	1008.21	751.93	--	7.5	1.50	156.72	695	29.55	41.21
NA100SCC5	500	1008.21	751.93	--	5.0	1.60	157.00	710	31.24	45.67
NA100SCC6	**510**	**953.21**	**802.05**	**--**	**5.0**	**1.50**	**153.51**	**703**	**42.67**	**57.01**
NA75SCC1	510	953.21	601.54	111.91	5.0	1.50	153.51	715	38.11	52.06
NA75SCC2	**510**	**953.21**	**601.54**	**111.91**	**5.0**	**1.60**	**145.86**	**705.5**	**43.55**	**56.89**
NA50SCC1	510	953.21	401.03	223.82	5.0	1.60	144.83	695	35.15	48.64
NA50SCC2	**510**	**953.21**	**401.03**	**223.82**	**6.0**	**1.65**	**142.29**	**707**	**42.22**	**56.15**
NA25SCC1	510	953.21	200.51	335.41	6.0	1.65	141.12	695	32.56	44.67
NA25SCC2	**510**	**953.21**	**200.51**	**335.41**	**6.5**	**1.70**	**139.23**	**710**	**42.22**	**55.86**
NA0SCC1	510	953.21	--	487.21	6.5	1.60	139.12	695	31.56	42.65
NA0SCC2	510	953.21	--	487.21	7.0	1.60	138.44	690	35.69	47.36
NA0SCC3	510	1008.21	--	447.21	7.0	1.60	135.36	695	37.65	49.65
NA0SCC4	**510**	**1008.21**	**--**	**447.21**	**7.0**	**1.70**	**134.64**	**712**	**42.64**	**55.21**

fume, super plasticizer and water powder ratio were varied. The fresh properties of the selected mixes for each percentage replacement of NCA with LCA is shown in Table 4. From the test results it was found that, the selected mixes shows all properties of SCC as per EFNARC guidelines and it was not affected due to the implementation of LCA as replacement of NCA. Fresh properties such as slump flow and T50cm slump flow was found to improve, which indicates that SCC mix containing LCA had better flowability may be due to the round shape of LCA. All other fresh properties were almost similar. L box test value was less than 0.8 for all the mixes.The unit weight of different percentage replacments are shown in table 5.

Table 4
FRESH PROPERTIES TEST RESULTS

Sl no.	Fresh property test	Unit	Typical range		Test results				
			min	max	NA100SCC	NA75CCC	NA50SCC	NA25SCC	NA0SCC
1	Slump Flow	mm	650	700	703	705.5	707	710	712
2	$T_{50\ cm}$ slump flow test	sec	2	5	4.50	4.40	4.40	4.30	4.20
3	V- funnel test	sec	8	12	12.00	13.30	11.50	13.00	12.20
4	V- Funnel test at T_{5min}	sec	0	+3	+3.00	+3.30	+3.70	+3.70	+3.00
5	L- box test(H_2/H_1)	----	0.8	1	0.82	0.83	0.83	0.88	0.92
6	U- box test ($H_2 - H_1$)	mm	0	30	30.50	30.40	30.25	29.3	29.00

Table 5
UNIT WEIGHT RESULTS

Percentage Replacement (%)	Unit Weight (kN/mm^3)	Percentage Reduction in Unit Weight(%)
0	25.30	----
25	23.41	7.47
50	22.52	10.98
75	21.33	15.70
100	20.21	20.10

The unit weight of SCC decreased as the percentage replacement of LCA increased with the mix containing 100% LCA having the least value of unit weight. The unit weight can be reduced to a maximum of 20% for complete replacement of NCA by LCA.

4.2 Behaviour of SCC Beam

4.2.1Crack Pattern

Fig. 3 shows the crack pattern for all the reinforced SCC beams. Cracks were not observed at the beginning of the test. After some time, flexural cracks were initiated at the bending zone. As the load increased, the existing cracks started to propagate and new cracks were also developed. At the ultimate stage most of the cracks travelled up to the top of the beam.

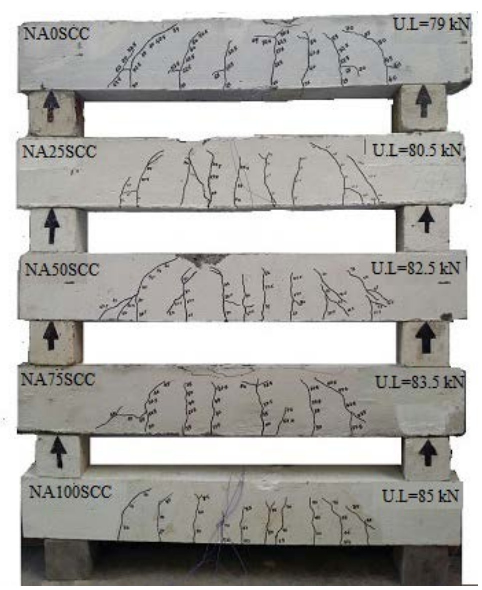


Fig.3 Crack Pattern

Even though the number and size of the cracks are different, for all the specimens the mode of failure and crack pattern were similar. All the cracks were of flexural type and no shear cracks were observed. As the percentage replacement increased, wider cracks were noticed, the number of cracks also increased.

4.2.2 Crack Propogation

During testing, the crack widths were measured using a crack detection microscope of 50x magnification. At each loading, crack width of major cracks were noted. Fig. 4 shows the crack propagation graph of all the mixes. The maximum crack width value was observed for the mix containing LCA only which was 1.48 mm and the minimum was observed for the control mix.

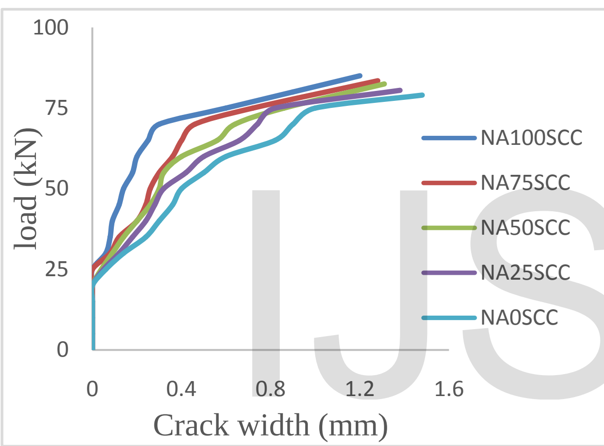


Fig. 4 Crack Propagation of Beams

4.2.3 Load Deflection Behaviour

Fig. 5 shows the load deflection curve for all the mixes. The load deflection curve was linear up to the first crack load for all the specimens. Further application of load makes the curve deviate from linearity. Further with a slight increase in load, the steel was found to yield and the curve becomes flat till the ultimate load was reached. The load deflection plots for partial and complete replacement of NCA with LCA showed similar pattern when compared with the control specimen.

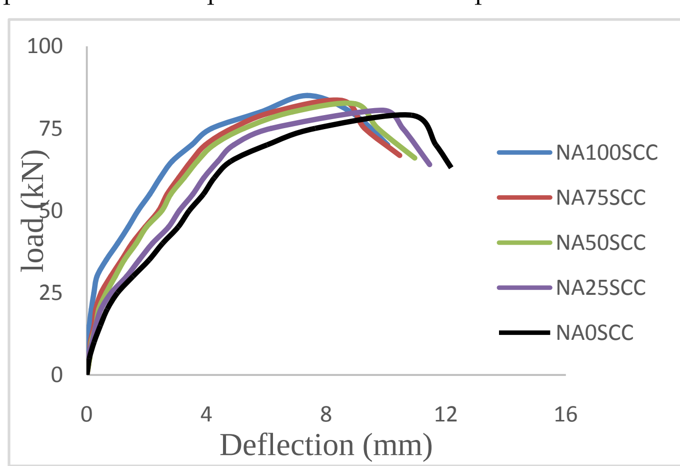


Fig. 5 Load Deflection Curve

4.2.4 First Crack Load, Yield Load and Ultimate Load

The yield load for all the beams were found to be in the same range. The ultimate load was found experimentally. The results are shown in Table 6. It can be seen that the first crack, yield and ultimate load for mixes containing LCA were comparable with the control mix. As the percentage of lightweight aggregate increased the ultimate load decreased. Similar decrease was noted for first crack load as well as the yield load. The minimum ultimate load value was observed as 79kN for the mix containing LCA only, which was 7% less than the control mix.

Table 6 FIRST CRACK, YIELD AND ULTIMATE LOAD

Mix	First crack load (kN)	Yield load (kN)	Ultimate load (kN)
NA100SCC	26.5	70.23	85
NA75SCC	22	69.85	83.5
NA50SCC	20	68.14	82.5
NA25SCC	18	66.58	80
NA0SCC	17.5	65.34	79

4.2.5 Energy Absorbtion Capacity, Stiffness and Toughness

The area under the load deflection plot gave the value of Energy Absorption Capacity (EAC). Due to the limitations in the experimental setup, the load deflection graph could be plotted only up to 80 % of the peak load, in the descending portion of the curve. Stiffness of the beam was estimated by the slope of the initial linear portion of the load deflection curve. The ratio of area of the load deflection curve till 80% of the ultimate load to the area of the load deflection curve till the initial crack load gave the toughness value [12]. Table 7shows the EAC, stiffness and toughness value of all the mix-

Mix	EAC (kNmm)	Stiffness (kN/mm)	Toughness
NA100SCC	783.895	60.48	36.33
NA75SCC	793.31	54.95	37.07
NA50SCC	830.64	48.69	38.58
NA25SCC	868.09	45.77	39.33
NA0SCC	909.17	41.89	40.14

ISSN 2229-5518

Specimen	Displacement Ductility	Curvature Ductility
	Absolute	Absolute
NA100SCC	2.1	4.1
NA75SCC	2.16	4.77
NA50SCC	2.23	4.86
NA25SCC	2.27	4.95
NA0SCC	2.31	5.08

es. From the table it can be seen that as the LCA percent increased, the EAC and toughness increased, but the stiffness decreased. The maximum EAC and toughness was observed for NA0SCC.

Table 7
EAC, STIFFNESS AND TOUGHNESS OF BEAMS

4.2.6 Moment Curvature Relation

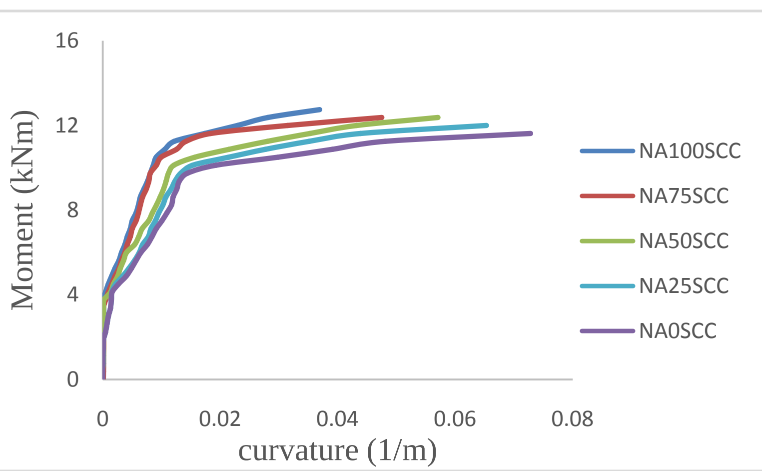
The moment curvature can be said to have three stages. First stage is till cracking, second stage till yielding of tension steel and the third stage to limit of useful strain in concrete. The curve is linear up to first crack moment. Further when the moment increases, the curve shifts from linearity. When the moment reaches yield moment, the curves become flat. When steel yields, a large increase in curvature occurs with a small change in moment. The moment curvature plot for the beams are shown in Fig. 5.

Fig. 5 Moment Curvature comparison

4.2.7 Ductility Index

Displacement ductility was calculated as the ratio of the displacement at ultimate load to the displacement at yield load. The large increase in curvature, before collapse of the beam is an indication of ductile failure of beam. Curvature ductility was calculated as the ratio of curvature at ultimate load to that of curvature at yield load [12]. The ductility index of beams are shown in Table 8.

Table8
DUCTILITY INDEX OF BEAMS



5. CONCLUSION

Following are the conclusions drawn from the study.

- From the target compressive strength and fresh properties test results it can be said that replacement of NCA with LCA is possible in SCC.
- The addition of LCA reduced the unit weight of SCC. The unit weight decreased by 7.5, 11, 15 and 20% respectively for 25 to 100% replacement of NCA with LCA at an increment of 25%.
- All the beam specimens failed in bending. The crack pattern developed were similar to each other. The crack width propagation plot also showed similar trend with the control mix having the smallest crack width.
- The Energy Absorption Capacity (EAC) and toughness improved as the percentage replacement increased, while the stiffness decreased. The toughness value increased from 36.33 to 40.13 for complete replacement.
- The maximum value of ultimate load was observed for the control mix .The ultimate load decreased by 1.76, 2.9, 5.3 and 7% respectively for corresponding 25, 50, 75 and 100% replacement of NCA with LCA. Similar trends were noticed for first crack load and yield load. The yield load for the mixes ranged between 70.23 kN to 65.34 kN with the control mix having the largest value.
- Both displacement ductility as well as curvature ductility improved as the percentage replacement increased, which shows that LCA has better ductility property when compared with NCA.

From these inferences it can be concluded that lightweight aggregates are a good substitute to natural coarse aggregates and 100% replacement of NCA by LCA is possible with the help of admixtures.

6. ACKNOWLEDGEMENT

The author would like to thank the Chandak and Associates for providing the lightweight aggregate for this work and the Mar Baselios College of Engineering and

REFERNCES

[1] H. Okamura, "Self Compacting High Performance Concrete – Ferguson Lecture for 1996," Concrete International, Vol. 19, No. 7, pp. 50 – 54, 1997.
[2] H. Okamura, "Self Compacting Concrete", Journal of Advanced Concrete Technology, Vol. 1, No. 1, pp. 5-15, April 2003
[3] H. Okamura and M. Ouchi, "Applications of Self-Compacting Concrete in Japan," Proceedings of the 3rd International RILEM Symposium on Self-Compacting Concrete, O. Wallevik and I. Nielsson, Ed., RILEM Publications,

ISSN 2229-5518
pp. 3 – 5, 2003

[4] M.A. Mannan, C. Ganapathy, Concrete from an agricultural waste oil palm shell(OPS), Build. Enviro, Vol. 39, 441–448, 2004

[5] U.J. Alengaram, M.Z. Jumaat, H. Mahmud, "Influence of cementations materials and aggregates content on strength of palm kernel shell concrete", Journal on Applied Science, Vol. 8, No. 18, pp. 3207–3213,2008

[6] Shetty, M. S.,' Concrete Technology- Theory and Practice,' Multicolour Illustrative Edition, S. Chand & Company Ltd., New Delhi, 2006, pp. 505-514

[7] IS 1489 (Part 1) – 1991 (Reaffirmed 2005), Specification for Portland Pozzolana Cement, Bureau of Indian Standards, New Delhi, India, 1991.

[8] IS 383 – 1970 (reaffirmed 2002), Specifications for Coarse and Fine Aggregate from Natural Sources for Concrete, Bureau of Indian Standards, New Delhi, India, 2002

[9] Nan, S., Hsu, K.C. and Chai, H.W., "A simple mix design method for self-compacting concrete", Cement and Concrete Research, 31, 1799–1807, 2001

[10] IS 456: 2000," Plain and Reinforced Concrete Code for Practice", Bureau of Indian Standards, New Delhi, India, 2000.

[11] Park, R. and Thomas Pauley, T., "Reinforced Concrete Structures", Wiley India, Third Edition, 2009.

[12] S. Jayasree, N. Ganesan, and Ruby Abraham., "Effect of ferrocement jacketing on the flexural behaviour of beams with corroded reinforcements" Construction and Building Materials, Vol. 121, 92–99, 2016