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Elaboration of Self-Compacting Concrete (SCC) for Reinforcing Reinforced Concrete Beams

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ABSTRACT: This paper presents an experimental study of the four-point simple bending behaviour of low strength reinforced concrete beams, reinforced with self-compacting concrete (SCC) with two different strength classes (30 and 40MPa) and ordinary strength concrete (30MPa).And to compare the simple bending behaviour of beams reinforced with (SCC) to that of beams reinforced with ordinary concrete, is taken as a reference control concrete. The rheological properties of the materials used were determined using the slump-flow, L-box, V-funnel and sieve stability tests. The mechanical properties of studied concretes were evaluated at 7 and 28 days of cure. The results obtained have shown that self-compacting concrete (SCC) appears to be a very promising material for the reinforcement of concrete structures. The (SCC) offer increased stability, manoeuvrability and adequate filling capacity. This contributed to the improved performance of the self-compacting concrete (SCC) reinforcement configuration compared to ordinary concrete as a reinforcement material.

KEYWORDS: ordinary concrete, self-compacting concrete (SCC), four-point bending test, reinforced beams, behavior.

INTRODUCTION

There is a significant amount of infrastructure that no longer meets current operational requirements due to deterioration or degradation (Salh, 2014). The various pathologies due to human errors during design or construction, or to changes in the functionality of the structure, or to the degradation of the constituent materials have a direct impact on the longevity of structures (Verma *and al*, 2022).The repair and reinforcement of existing concrete structures are among the most important challenges facing civil engineers today and in the years to come.

The objective of repair is to extend the useful life of an existing structure by restoring its original qualities (Vyhlidal *and al*, 2023). However to obtain a lasting repair, it is necessary to first make a judicious choice of material intended for the repair and reinforcement work (Bissonnette *and al*, 2014).

Self-compacting concretes (SCC) was developed in Japan in the 1980 (Turcry, 2004), this concrete has gained wide use in many countries for different applications and structural configurations (Okamura *and al*, 2003).The use of SCC as a material for the reinforcement technique is directly related to its advantages in the fresh state: stability, homogeneity, deformability and it follows perfectly the shapes of the surfaces to be repaired. The research work that has been carried out up to this date on SCC is numerous; however, they mainly focus on the study of the influence of formulation parameters on rheology and mechanical strength. In addition, little research has been done on SCC intended for the repair and strengthening of structures (Tchetgnia *and al*, 2013).

The aim of this research is to understand the four-point bending behaviour of low-strength reinforced concrete beams reinforced with a self-compacting concrete SCC, through an experimental comparative study of the behaviour of these beams with those reinforced with ordinary concrete used as a reference control concrete.

MATERIALS AND EXPERIMENTAL PROCEDURES

Materials used

The materials used in this work are local materials. Cement used for all mixtures is CEM II-A 42,5 R, from El-Hamma cement plant, Constantine, Algeria. Calcareous crushed aggregates from the National Company of Aggregates (NCA) of El-Khroub region of Constantine, Algeria were used. They are of three granular classes: sand 0/3 mm, gravel 3/8 mm and gravel 8/16 mm. Limestone filler used is UF20, from the limestone deposit of the National Company of Aggregates, with average dimensions of 80µm. A high water-reducing superplasticizer of type Medaplast SP 40 of Granitex is used in the preparation of mixtures. The water used is the tap water from the laboratory.

Mixtures

Ordinary concrete (OC) low strength reinforced concrete beams (15MPa) were prepared. The self-compacting concretes used for the reinforcement of low strength reinforced concrete beams in this work are two concretes of different strengths (30 and 40 MPa), namely: SCC30 and SCC40, respectively. Ordinary concrete for reinforcement (OC30) have a compressive strength of 30 MPa, is taken as a reference control concrete. The mixtures of self-compacting concretes are determined by the software BétonlabPro (Sedran *and al*, 2000). The mixtures of ordinary concrete are determined from Dreux-Gorisse method (Dreux *and al*, 2000). Table 1 presents a summary of the different concretes used in this research.

Table 1. Designation of concretes used in this study.

Designation	Definition
OC	Ordinary concrete for low strength beams 15MPa.
OC30	Ordinary concrete used for the reinforcement of low strength beams with strength of 30MPa (reference).
SCC30	Self-compacting concrete used for the reinforcement of low strength beams with strength of 30MPa.
SCC40	Self-compacting concrete used for the reinforcement of low strength beams with strength of 40MPa.

The compositions of the concretes used in this study are given in Table 2.

Table 2. Mix designs of one cubic meter of concrete in kg/m^3.

Composition(kg/m^3)	Low Strength Concrete OC	Concretes used for the reinforcement of low strength beams		
		(OC30)	(SCC30)	(SCC40)
Cement	277	350	350	400
Limestone filler	/	/	130	80
Sand (0/3)	727	727	770	770
Gravel (3/8)	/	109	420	420
Gravel (8/16)	1111	897	280	280
Superplasticizer	/	/	7.5	7.5
Water Total	219	175	208	206

PREPARATION OF THE SPECIMENS

The experimental program consists of preparing nine low strength beams (15MPa) of dimensions of: 18 cm high, 10 cm wide and 200 cm length, with longitudinal reinforcement 2 bottom bars Ø8 and 2 other top bars Ø8. Transverse reinforcement is with Ø6 frames. The frames are spaced 10 cm apart at the support and 15 cm apart at the span (see Fig. 1).

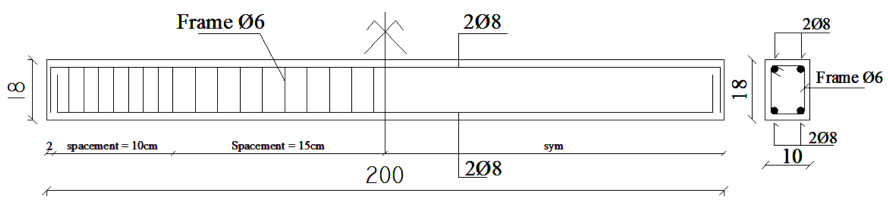

Figure 1. Presentation of the low strength beams of 15MPa.

In this study three reinforcement configurations were used, namely:

- [B(OC30)]: two of the nine beams are reinforced with a (OC30) with Ø6 frames at 15 cm spacing along the length of the beams (Fig.2).

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- [B(SCC30)]: two other beams are reinforced with a (SCC30) with Ø6 frames at 15 cm spacing along the length of the beams (Fig.2).
- [B(SCC40)]: two other beams are reinforced with a (SCC40) with Ø6 frames at 15 cm spacing along the length of the beams (Fig.2).

The arrangement of the Ø6 frames along the length of the beams is designed to avoid excessive concentrations of shear forces which can lead to premature failure.

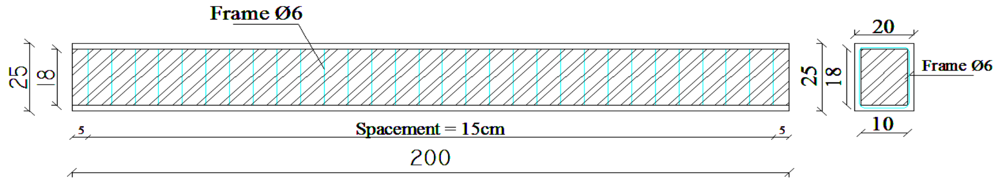


Figure 2. Reinforcement configurations used for low strength beams: B(OC30), B(SCC30) and B(SCC40).

To summarize, the specimens used in this experimental program are:

- Two beams are reinforced by (OC30): B(OC30).
- Two beams are reinforced by (SCC30): B(SCC30).
- Two beams are reinforced by (SCC40): B(SCC40).
- Three low-strength (OC) beams remained unreinforced: B(OC).

METHODS

The tests carried out in this work are divided into two stages namely:

- The first step is intended for the characterization of self-compacting concrete (SCC30) and (SCC40) in the fresh state, namely: Slump-flow, L-box, V funnel and sieve stability tests, and in the hardened state. Compressive strength of all the mixtures of concretes (OC), (OC30), (SCC30) and (SCC40) were measured using cylindrical specimens (16x32) cm². Three samples were tested for each mixture at 7 and 28 days of cure.
- The second step consist to measure the vertical displacement (deflection) of the reinforced beams, after setting the comparator at mid-span, then increase the load gradually from 5kN until it breaks. This is a four-point bending test performed on beams B(OC), B(OC30), B(SCC30) and B(SCC40). The test is made by a hydraulic press of type schenck trebel with a capacity of 3000kN. Beams are positioned between a support below and the load above as shown in Fig.3 :

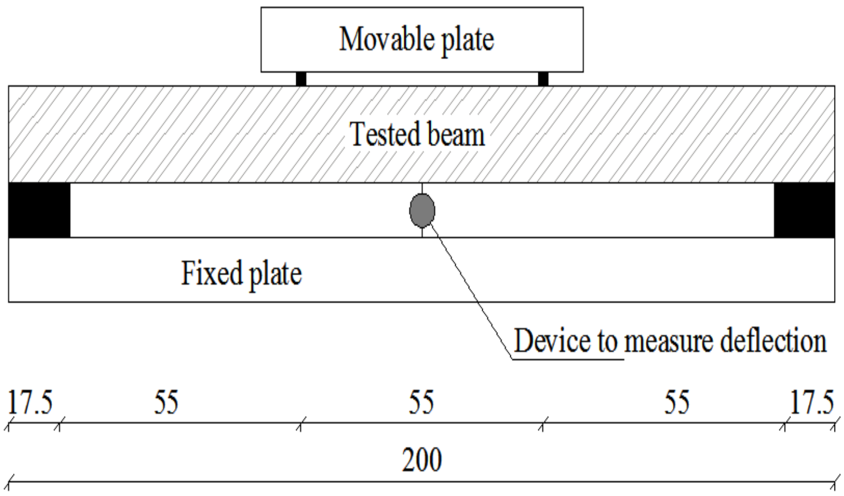


Figure 3. Four-point bending test device.

The characterization in the fresh state of the self-compacting concretes was carried out according to the procedures recommended by (EFNARC, 2005; AFGC, 2002).

- **Slump-flow:** According to the standard (EN 12350-8(2010)).This involves removing an Abrams cone of fresh concrete and measuring the diameter of the concrete final spread obtained.

- **L box test:** According to the standard (EN 12350-10(2010)).This test is performed to characterize mobility of concrete in a confined environment, the vertical part of the L Box is filled with concrete in one go. After opening the hatch, the concrete flows through standard reinforcement.
- **V funnel test:** According to the standard (EN12350-9(2010)). Another parameter to check for all self-compacting concrete is the flow time. This test is also used to evaluate the viscosity and filling capacity of concrete.
- **Sieve stability test:** According to the standard (EN 12350-11(2010)). The sieve stability test is performed to characterize the static segregation, the test consists of evaluating the percentage by mass of laitance of a concrete sample (4.8 ± 0.2 kg) passing through a sieve with a 5 mm opening mesh.

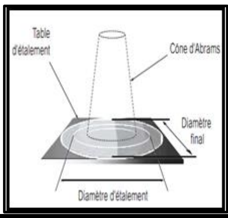
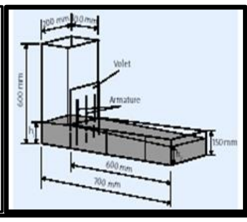
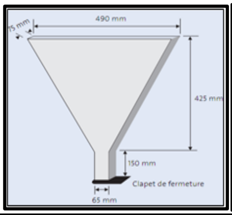
The results obtained for all the tests are shown below. They represent the average of the tests carried out on three to four specimens.

RESULTS AND DISCUSSIONS

Evaluation of properties of fresh and hardened of self-compacting concretes

The properties of fresh and hardened studied mixtures are shown in Tables 3 and Tables 4.

Table 3. Properties of self-compacting concretes in the fresh state.

	Slump-flow (cm)	L-Box	V funnel (s)	Sieve stability (%)
Tests				
SCC30	70	0.85	17.91	8.70
SCC40	78	0.95	18.02	14.30
Standard values	55 ≤ SF ≤ 85 cm	PL ≥ 80%	0 < VF2 ≤ 25s	SR ≤ 20%

The results obtained and reported in Table 3 show that all the concretes have values which fall within the field of self-compacting concretes.

Table 4 presents a classic characterization of the concretes used according to standard (EN 12390-3(2012)) in the hardened state, was carried out at 7 and 28 days.

Table 4. Compressive strength of hardened concretes.

Concretes	Compressive strength at 7 days of cure [MPa]	Compressive strength at 28 days of cure [MPa]
OC	11.55 ± 0.52	15.35 ± 0.13
OC30	22.01 ± 0.76	28.97 ± 0.25
SCC30	20.73 ± 0.34	29.02 ± 0.88
SCC40	24.29 ± 0.15	39.84 ± 0.46

According to Table 4, it was observed that the compressive strengths after 28 days of cure are very close to the desirable values of the reinforcing concretes used.

Bending test of unreinforced beams

Figure 4 shows the deformations of the three unreinforced beams, which subjected to the four-point simple bending test.

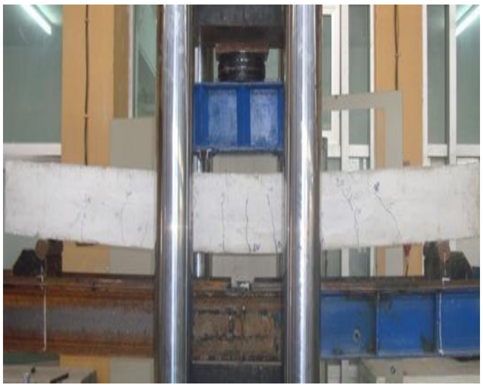


Figure 4. Deformations of unreinforced beams B(OC).

From Figure 4, we can observe that: (1) the concrete cracks appear in the central third of the length between the beam supports, on the tensioned face, and (2) the beams continue to support the load and the deflection increases more rapidly, which leads to an increase in the number of these cracks and an increase in their lengths and openings. Figure 5 shows the load-deflection curves of three unreinforced beams.

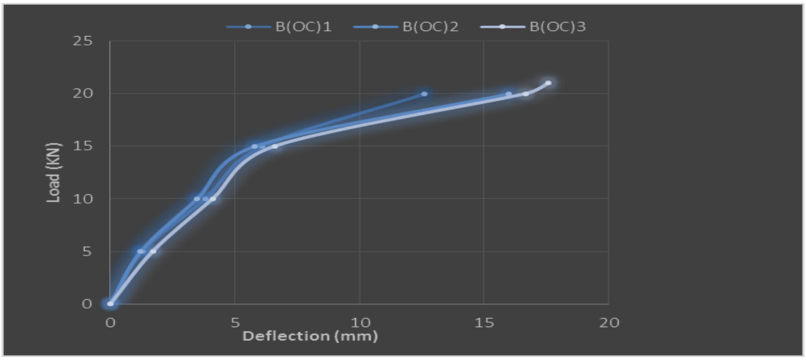


Figure 5. Load-deflection curves of unreinforced beams B(OC).

According to (Fig.5) the main findings are:

- The curves of the three unreinforced beams have a similar appearance. Starting with a linear part, then a second when the load increases slightly, while the deformations continue to evolve until break.
- The deflection reached at mid-span for the three unreinforced beams [B(OC1) – B(OC2)–B(OC3)] is [12.60 – 16 –17.6] mm respectively under an ultimate breaking load is (20 – 20 – 21) kN.

Bending test of reinforced beams

In the present test, the reinforced beams were subjected to the four-point bending test under a hydraulic press. Figure 6 shows the deformations of the reinforced beams by (OC30), (SCC30) and (SCC40).

Figure 6. Deformations of reinforced beams.

Elaboration of self-compacting concrete (SCC) for reinforcing reinforced concrete beams

From Figure 6 we can note (1) the appearance of superficial micro cracks fine vertical in the concrete on the tensioned face of all reinforced beams, the accumulation of these micro cracks gives vertical concentrated cracks, with a regular spacing of 15cm equal to the distance between the transverse reinforcement, and (2) a new diagonal cracks which propagate towards the supports, these cracks appear in beams reinforced with (SCC30) and (SCC40), after the application of a load three times more than the breaking load of the beams B(OC). In the case of beams reinforced with (OC30), the appearance of these diagonal cracks from a load twice the breaking load of the beams B(OC). All the cracks are concentrated in the central third of the length between supports.

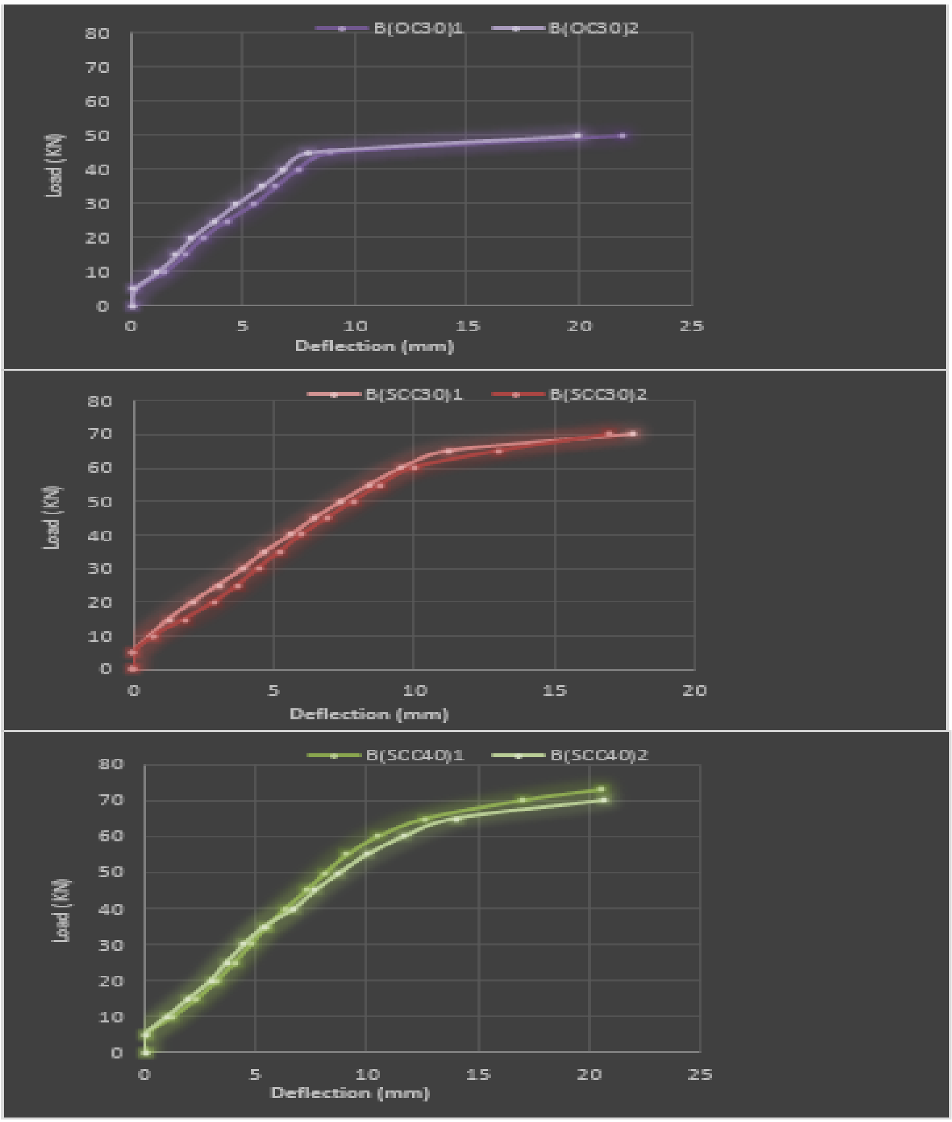


Figure 7. Load-deflection curves of reinforced beams B(OC30), B(SCC30) and B(SCC40).

According to (Fig. 7) the main findings are:

- The curves of the two beams reinforced with (OC30) have a similar appearance, starting with a linear part, then a second when the load increases, while the deformations continue to evolve until failure.
- The appearance of the first crack for beams reinforced with (OC30), after a load of 5kN.
- The deflection at break, for the two beams [B(OC30)1 – B(OC30)2] is (21.9 – 19.9) mm respectively.
- All the curves of the beams reinforced by (SCC) have a curve that is characterized by two parts, linear and the other increases slightly until the break.
- The appearance of the first crack in beams B(SCC30) and B(SCC40) after loading of 10 kN and 8 kN respectively.
- An increase in ultimate breaking load from 70 kN for beams B(SCC30) to 73 kN for beams B(SCC40), therefore this increase is proportional to the increase in the compressive strength. In other words a difference of 10 MPa in compressive strength of (SCC) intended for reinforcement offers an increase of 4.28% in ultimate breaking load;

- A slight difference between the deflections of the beams reinforced by the two types of (SCC) is varied between 0.25 mm and 1.85 mm.

Comparative study between reinforcement types

Figure 8 illustrates the superposition of the average load-deflection curves of the beams B(OC), B(OC30), B(SCC30) and B(SCC40).

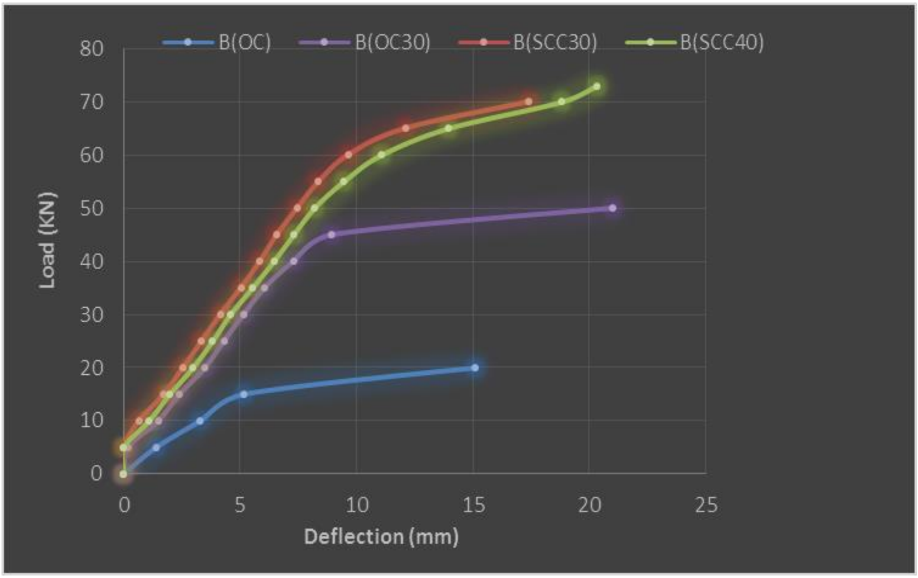


Figure 8. Average load-deflection curves of beams B(OC30), B(SCC30) and B(SCC40).

After analysing the curves of Fig. 8, it can be seen that:

- The beams B(OC30) are behaved in the same way as the beams B(OC).
- The load-displacement curve of the beams B(OC30) was characterized by an elastic phase and a plastic phase, it is more ductile behaviour. The ductility factor is approximately 2.35 (remember that the ductility factor is the ratio between the maximum deformation and the deformation at the end of the elastic phase (Neville, 2000)).
- And for beams B(SCC30) and B(SCC40), the curves are characterized by an elastic phase then a second phase which increases slightly. The elastic phase is more extensive than that of the beams B(OC30).
- An ultimate breaking load of (20 kN) of the beams B(OC), which reaches (50 kN) for beams B(OC30). And in the case of (SCC) reinforcement, the ultimate breaking load reaches a certain equivalence between the two configurations B(SCC30) and B(SCC40) of (70 kN – 73 kN) respectively.
- A significant gain in terms of load-bearing capacity represents an increase in the ultimate breaking load of the beams B(SCC30), B(SCC40) respectively of : 40% and 46% compared to the beams B(OC30).
- The plastic bearing observed in the case of beams B(OC30) is absent for the other beams B(SCC30) and B(SCC40), which translates a very high rigidity, which is approximately identical for the two types of beams B(SCC30) and B(SCC40).
- The rigidity of the beams B(OC30) is 5.03 kN/mm. While the beams B(SCC30) and B(SCC40) have a similar rigidity in the order of 6.20 kN/mm, an increase of 23.26% compared to beams B(OC30). (Recall that the rigidity E is the ratio between the load and the corresponding deformation (Neville, 2000)).
- The appearance of cracks for beams B(OC30) was more advanced compared to beams B(SCC30) and B(SCC40).
- The appearance of the first crack for beams B(SCC30) was delayed compared to beams B(SCC40). So the appearance of cracks starts in the reinforcement (SCC) which has a higher dosage of cement.

CONCLUSION

The objective of this work is to understand the behaviour in four-point bending test of low strength reinforced concrete beams reinforced with self-compacting concrete (SCC) by an experimental comparative study of low strength reinforced concrete beams reinforced with self-compacting concrete to those reinforced with ordinary concrete, used as a reference control concrete.

It was observed that B(SCC30) and (B(SCC40) beams have a higher load-bearing capacity than beams B(OC30), this is due to the compactness of self-compacting concrete (SCC) by the presence of fines. An equivalent increase in rigidity of the beams B(SCC30) and B(SCC40) compared to the beam B(OC30) which has a more ductile behaviour. A decrease in the deflection of the beams B(SCC30) and B(SCC40) was observed. This is mainly due to the increase in their rigidity.

Finally, this study showed that (SCC) constitute a very promising material for the reinforcement and rehabilitation of concrete structures in civil engineering. These concretes (SCC) offer increased stability, workability and satisfactory filling capacity. This has contributed to an improvement in the performance of the self-compacting concrete (SCC) reinforcement configuration compared to ordinary concrete as the reinforcement material.

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