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BOND–SLIP BEHAVIOR OF SELF COMPACTING CONCRETE

BY

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Abstract. For the design of structural elements, bond behaviour plays an important role; therefore it is important to investigate the bond behaviour of normal vibrated concrete in comparison with self-compacting concrete. This paper aims to investigate the bond with reinforced bar of a new construction material, self-compacting concrete, the bond strength between reinforcing steel and concrete was determined by beam tests carried out after 28 days. Deformed bars S500 with 16 mm and 18 mm effective diameters were used to evaluate the bond in C50 and self-compacting concrete, according to RILEM procedures. Also in this study the hardened properties of self compacting concrete containing limestone powder were experimentally investigated and compared with those of normal vibrating concrete.

The main parameters were: the concrete compressive strength, the steel bar diameter and the type of concrete. According to the obtained results, self-compacting concrete and normal vibrating concrete presented quite similar behaviour, so it can be concluded that self-compacting concrete has similar or better behaviour in comparison with normal vibrating concrete.

Key words: compressive strength; limestone powder; beam tests.

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1. Introduction

The introduction of self compacting concrete (SCC) represents a major technological advance which leads to better quality of concrete produced and a faster and more economical concrete construction process (Okamura & Ozawa, 1995). Also the elimination of the need to vibrate the concrete has beneficial effect and increases working conditions. Self-compacting concrete is characterized by low yield value and moderate viscosity enabling the concrete spread into place, and flowing between reinforcement without blockage or segregation. A high level of bleeding and segregation can have a direct effect on the bond strength and durability and, more than that, all this will influence the transport properties. Few investigations have been carried out in order to study bond strength of reinforcing bars, but with all this the conclusions are quite different. After a centralization of 70 studies, Damone (2007) said that in some ways SCC may present higher ultimate bond strength. Gibbs and Zhu (1999) found that SCC can be able to present ultimate bond strength higher with 25% than normal vibrated concrete (NVC) and other researchers, like Sonebi *et al*. (1999), Gibbs *et al*. (1999), show contradictory results, about the bond strength of SCC. On the basis of this fact and following my former colleague relating to SCC (Pop , 2012) we decided to implement a research program directed to the type of the concrete on the bond strength of SCC mixes and normal vibrated concrete (NVC).

In the first section, the test condition as well the parameters of the study (embedded length, diameter, concrete nature) are described. In the second section the experimental results are presented and the last section contains the conclusions, which could be drawn from this study.

2. Experimental Method

The experimentation consists in testing the bond strength by using larger specimens, such as beam test specimens. According to RILEM recommendation (1970) the specimen consists of two half-beams connected at the top by a steel hinge and at the bottom by the reinforcement bar. In each of the two half beams an auxiliary cage is providing confinement to avoid excessive splitting.

2.1. Test Parameters

The studied were those regarding the association steel–concrete parameters (embedded length, bar diameter and type of concrete).

Table 1 presents the characteristics of the specimens (18 specimens were experimented).

Table 1
Geometric Characteristic of Specimens

Concrete	Diameter, [mm]	Embedded length, [mm]
SCC	16	80
	18	90
NVC	16	80
	18	90

2.2. Test Set up and Procedure

The bond tests were carried out by beam test in accordance with RILEM RC5 (1970) and the procedure is described in Fig. 1. During the tests, the beams were loaded at a constant rate corresponding to an increase in steel stress of 30 N/mm^2 per min. A hydraulic jack capacity with 300 tf capacity was

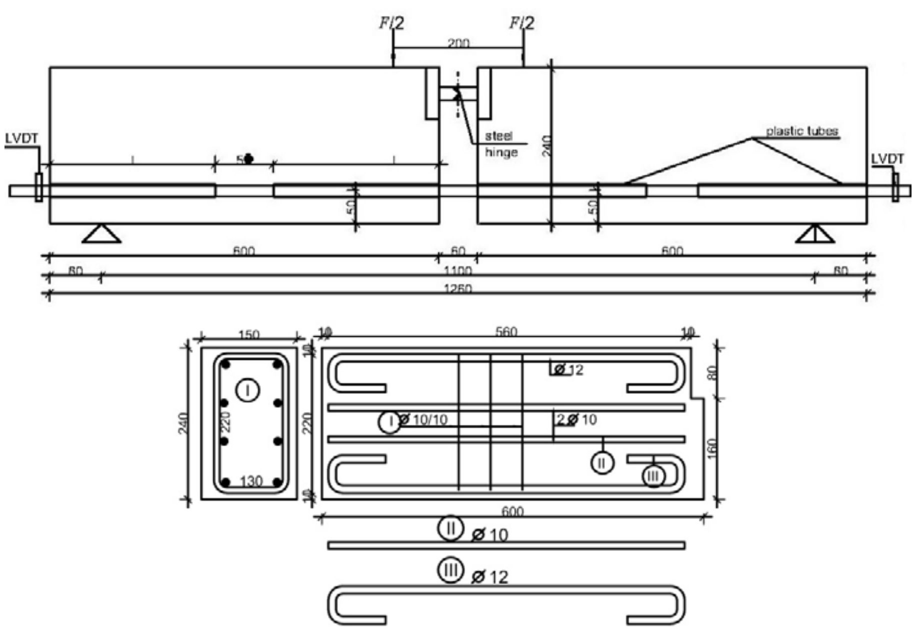

Fig. 1 – Beam test procedure RILEM RC5 (1970).

used for this test. The slip of the bar, at its free end, was recorded using three linear variable differential transducers (LVDT) on both ends of the specimen. Loading continued until the slip at one end of the half beam reached 2...3 mm; the test continued for the other half of the beam until the second half exceeded 2...3 mm as well.

2.3. Experimental Concrete

The concrete mixes and the characteristics of the concretes used in this study are given in Table 2. We are looking for 50 MPa strength at 28 days. Concrete was mixed in 3 m^3 tilting drum mixers and delivered to the laboratory by ready-mix trucks. The mixing of SCC was similar with NVC, the limestone was added in the same time with the aggregate and the cement. After casting the specimens were stored at a constant temperature of 20ºC and after 3 days were demoulded and stored in the same controled enviroment until testing.

Table 2
Mixture Proportion of Concrete

	Materials	Proportioning kg/m^3		Proportioning kg/m^3
	Ciment CEM II-AS 42.5R	410		450
	Limestone	190		–
SCC	Sand 0...4	907	NVC	869.72
	Broken up particles 4...8	280		364.62
	Broken up particles 8...16	462		680.52
	Glenium 51	6l		3.15l
	Water	1,75l		1,75l

2.4. Characteristic of Concretes in Fresh State

The three basic requirements to obtain a stable SCC mixes are: stability, filling ability, passing ability. According to EFNARC 2005 two methods were applied : the slump flow test shows the flowability and the V-funnel test is used to show the viscosity and filling ability. The results are presented in Table 3.

Table 3
Characteristics of Concretes in Fresh State

	EFNARC-2005	Test results
Slump flow	660 mm < SF2 < 750 mm	SF = 750 mm
V-Funel	5 s < VF1 < 25 s	VF = 6 s

No external bleeding was observed on top surface of any SCC specimen.

2.5. Characteristic of Concretes in Hardened State

Table 4
Characteristics of Concretes in Hardened State

	SCC	NVC
f_c, [Mpa]	50.67	50.20
f_t, [Mpa]	7	5.42

2.6. Reinforcement

Besides the concrete type, the steel bar diameter has been varied, in total two different diameters of the embedded reinforcement bars were chosen: ø 16, ø 18 mm. The nominal diameter yield stress, f_y , and tensile strengh, f_u , reinforcing bars, were measured in the laboratory and presented in Table 5.

Table 5
Characteristics of Reinforcement

	ø 16 mm	ø 18 mm
f_y , [Mpa]	568.17	569.63
f_u , [Mpa]	678.24	685.93

3. Results and Observations

From the obtained results, values of the mean bond stress along the surface of the bonded part of reinforcing can be derived. The mean bond stress can be calculated by assuming the force, *F*, in the reinforcing bar to be transfered to the concrete in the cylindrical zone of the embedment length, $l_{d.}$ Bond strength was evaluated by the ultimate bond stress namely

$$\tau_u = \frac{1.5f}{\pi d l_d}, \tag{1}$$

$$\tau_m = \frac{\tau_{0.01} + \tau_{0.1} + \tau_1}{3}, \tag{2}$$

where: t_u is the ultimate bond strength; *F* – maximal force; *d* – bar diameter; l_d – embedment length; t_m – the mean value of the bond stress; $t_{0.01}$, $t_{0.1}$, t_1 – the values of the bond stresses corresponding to a slip of 0.01, 0.1 and, respectively, 1.0.

3.1. Influence of Concrete Type

A comparison of the bond strengths of self-compacting concrete and those of normal vibrated concrete can be made based on the obtained results. In Figs. 2 and 3 the recorded bond stress *vs*. slip curves are plotted for the two types of the bar diameters and concrete composition.

Comparing the two types of concrete, NVC and SCC, for the same bar, which have cube compressive strength close one to another, it is noticed that for 16 mm diameter, from the obtained results, in all tests the SCC bond stress, τ_r (maximum bond stress), is above the maximum bond stress of NVC.

In the presented figure both type of concrete, SCC and NVC, show linear branch in the first part of the curve. Bond stresses are increasing resulting

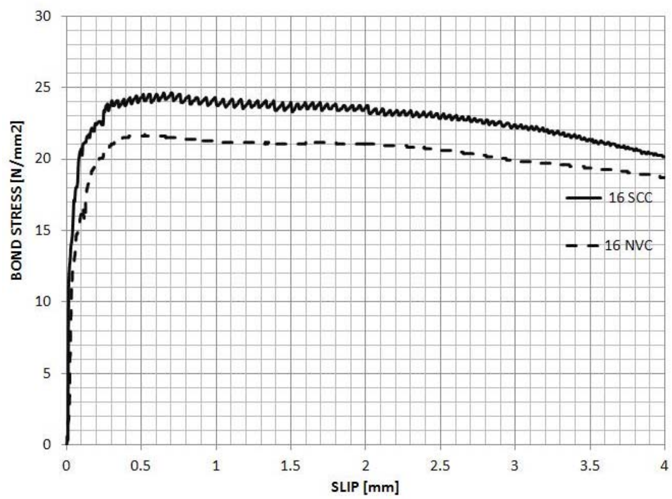

Fig. 2 – Bond stress *vs*. slip diagrams for bar diameter of 16 mm.

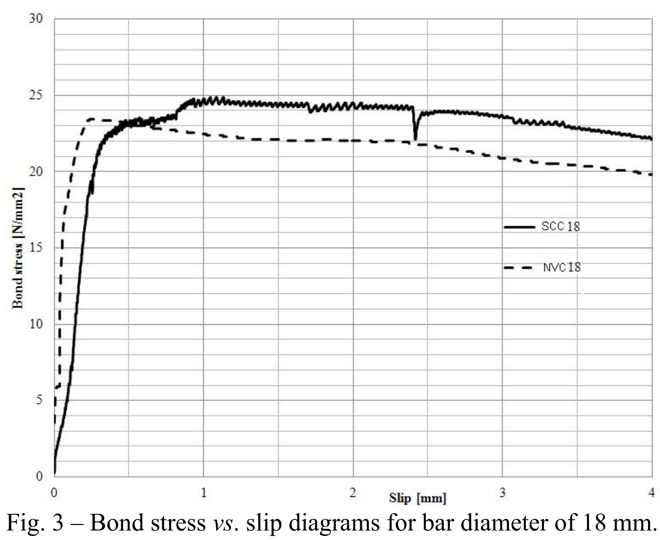

Fig. 3 – Bond stress *vs*. slip diagrams for bar diameter of 18 mm.

very small slip values. Once bond stresses exceed a level of 40%...50% of the ultimate bond strength, the slip is increasing more rapidly with rising stresses.

After the ultimate bond strength is reached, the slip between the concrete and the steel is increasing for almost constant stress levels.

3.2. Comparison SCC-NVC

Table 6 represents the average of test results of τ_u / f_c ratio maximum bond stress in SCC and NVC.

Table 6
τ_u / f_c Ratio for SCC and NVC

	SCC		NVC	
	16	18	16	18
τ_u/f_c , [N/mm^2]	0.49	0.50	0.44	0.45

τ_u – ultimate bond stress; f_c – compressive strength.

4. Conclusions

From this study it result the following conclusions:

1. Self-compacting concrete presents quite similar performances with normal vibrated concrete, the only difference observed was 8.5% between the two types of concretes.

2. When the bond stress *vs*. slip relations of different concrete types are plotted for tests on specimens with reinforcing bar of same diameter, it can be seen that the bond strength of NVC at all stress levels, resulting in a steeper curve.

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RELAŢIA EFORT ADERENŢĂ–LUNECARE ÎN BETONUL AUTOCOMPACTANT

(Rezumat)

Se prezintă rezultatele unui studiu de cercetare a fenomenului de aderenţă a betonului cu armătură. În acest studiu se foloseşte un beton inovativ, betonul autocompactant, făcându-se o comparaţie cu betonul normal vibrat. Determinarea efortului de aderenţă s-a realizat pe grinzi supuse la incărcări monotone. Testul s-a realizat conform standardului internaţional de încercări RILEM. Clasa betonului normal vibrat a fost C50, barele testate sunt bare profilate S500 având diametre de 16 mm şi 18 mm. Odată cu determinarea efortului de aderenţă s-au mai studiat şi proprietăţile în stare intărită a betonului autocompactant, a cărui compoziţie s-a realizat cu filer de calcar facându-se o comparaţie cu betonul normal vibrat.

Principalii parametri urmăriţi în acest studiu au fost: rezistenţa la compresiune, diametrul barei şi tipul betonului. Ca o concluzie se poate afirma că betonul autocompactant se comportă la fel şi în unele cazuri chiar mai bine decât betonul normal vibrat.