BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LIX (LXIII), Fasc. 1, 2013
Secţia
CONSTRUCŢII. ARHITECTURĂ

EFFECT OF CONFINEMENT ON BOND STRENGTH BETWEEN SELF-COMPACTING CONCRETE AND REINFORCEMENT

BY

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Received: February 5, 2012
Accepted for publication: March 1, 2012

Abstract. Slippage of the beam reinforcement at beam–column connections is an important cause of damage of reinforced frames under static and dynamic loads. This paper presents the effects of confinement in self-compacting concrete (SCC), on the local bond stress *vs*. slip characteristics of deformed bars in reinforced concrete joints. Prismatic specimens with deformed steel bars embedded for a fixed length equal to three and five equivalent diameters were tested under monotonic loading. The specimens represented the confined region of a beam–column connection. The obtained results indicated that as far as the bond splitting cracks are restrained by reinforcing bars crossing these cracks, confinement of concrete by transverse reinforcement has insignificant effect on the local bond behavior. The specimens having no confining reinforcement failed by splitting of the concrete in the plane of the longitudinal axis of the bar at small bond stress. The failure of specimens with confined concrete was caused by pulling out of the bars at steel stresses below yield strength.

Key words: self-compacting concrete; bond; deformed bars; pull-out test, confined concrete.

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1. Introduction

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement.

The bond resistance of deformed bars in concrete is provided mainly by the mechanical interlocking between the bar lugs and the surrounding concrete (Kienuwa, 1985). In a beam–column connection, the confining reinforcement capable of arresting splitting cracks are the column vertical reinforcement and transverse hoops in joints. To simulate the conditions at beam–column joints for studying the local bond behavior, Eligehausen *et al.* (1983) used a confined concrete block containing a partially bonded deformed bar.

2. Experimental Program

2.1. Materials

The cement used was CEM II/A-S 42.5R. Natural aggregates were used to produce the concrete, including one type of sand 0…4 mm and two types of coarse aggregates (4…8 mm and, respectively, 8…16 mm) with grading curves as presented in Fig. 1.

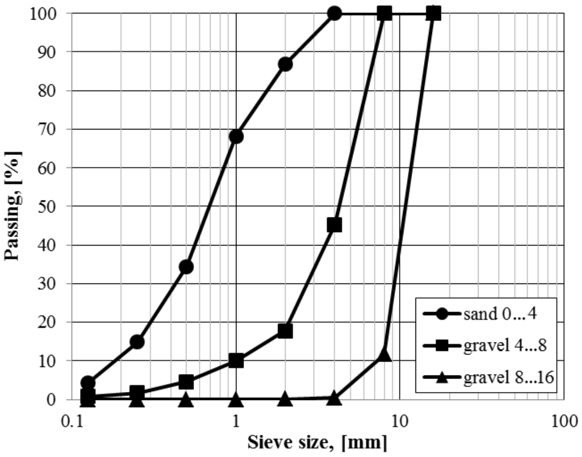


Fig. 1 – Grading curves.

A limestone filler addition with a determined mass density of 2,700 kg/m^3 and a superplasticizer (SP), based on modified polycarboxylic ether (PCE) polymers were used. The mix proportions are summarized in Table 1.

Table 1
Mix Proportions

Materials	
Cement CEM II/A-S 42.5R, [kg]	410
Limestone filler, [kg]	190
Sand 0…4 mm, [kg]	907
Gravel 4…8 mm, [kg]	280
Gravel 8…16 mm, [kg]	462
SP Glenium 51, [kg]	6
Water, [kg]	175
Water/Cement	0.42
Water/Powder	0.29

The properties of the fresh concrete, presented in Table 2, were determined immediately after the mixing procedure. After 3 days, the specimens were demolded and stored at a constant temperature of 20° ± 2°C and a relative humidity of 95% ± 5% until the time of testing. The compressive and flexural tensile strengths were determined at 28 days on cubes with sides of 150 mm for compression ($f_{c,\mathrm{cube}}$) and prisms with a length of 550 mm and a height of 100 mm for tensile strength ($f_{ct,fl}$). The mean results of the hardened properties tests are presented in Table 2.

Table 2
Fresh and Hardened Properties

Slump flow, [mm]	745
V funnel, [s]	6
$f_{c,\mathrm{cube}}$, [MPa]	50.7
$f_{ct,fl}$, [MPa]	7.0

Deformed bars were used for the test bars as well as for the bars of reinforcing cages. The test bars used were ø10 and ø12 mm with the geometrical and mechanical properties presented in Table 3.

Table 3
Characteristics of reinforcement

ø, [mm]	f_y, [MPa]	f_t, [MPa]	$a_{\max}$, [mm]	c, [mm]	f_R
10	600	705	0.75	6.5	0.042
12	560	656	1	7.5	0.048

For each reinforcement type the geometrical characteristics were determined: the area of the projection of a single rib on the cross-section of a bar (F_R), the nominal diameter (d_b), the distance between ribs (c) and the rib height ($a_{\max}$), in order to obtain the relative rib area (f_R), by using the relation

$$f_R = \frac{F_R}{d_b \pi c}, \qquad (1)$$

according to ISO 15630-1/2002.

2.2. Specimen Details and Testing Procedure

The test specimens used in this study were similar to those of Eligehausen *et al.* (*op. cit.*) with a deformed bar partially bonded inside a concrete block Fig. 2. The test results presented by Eligehausen *et al.* (*op. cit.*) covered only the effects of transverse confining reinforcement area on the local bond behavior. In this study the effect of transverse bar spacing was considered too.

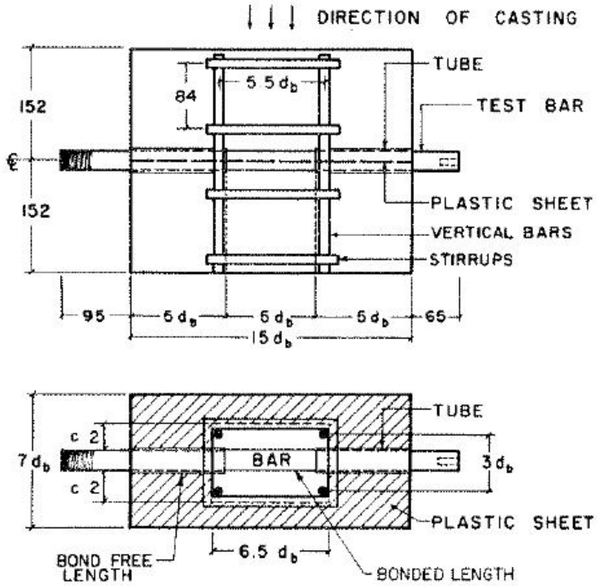


Fig. 2 – Experimental model for local bond study.

The specimens represented the confined region of a beam–column connection. The confining reinforcement (vertical and transverse bars) in the specimens represented the column reinforcement. The embedded length of the test bars was equal to 3 and 5 times the bars diameter. The typical reinforcement cage of a bond-test specimen is shown in Fig. 3. The casting direction was perpendicular to the longitudinal direction of the bars.

The tests were carried out at the age of 28 days. The applied force was measured, during the test, with a load cell. The slip of the unloaded end of the bar was recorded by using one linear variable differential transformer (LVDT) with a precision of 0.001 mm (Fig. 4). According to RILEM (1992) the load rate was 50 N/s for ø 10 test bars and 72 N/sec for ø 12 test bars, in order that the rate of increase of the bond stress to be constant. The test was finished when pull-out failure occurred or splitting of the surrounding concrete was observed.

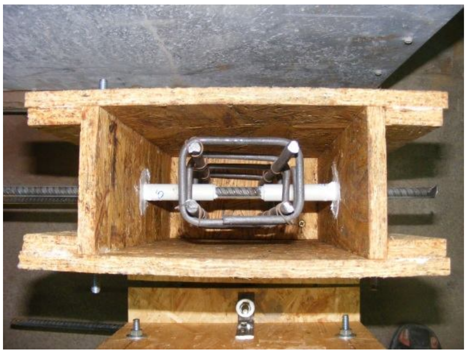


Fig. 3 – Reinforcement cage.

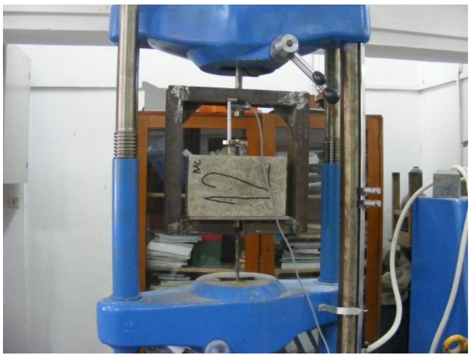


Fig. 4 – Test specimen prepared for pull-out test.

3. Analysis of the Results

According to RILEM (1992) the bond stress between reinforcement and concrete can be quantified by using relation

$$\tau = \frac{F}{\pi d_b l_d}, \qquad (2)$$

where F is the applied force, [N], d_b equals the bar diameter, [mm], and l_d – the embedded length, [mm].

Specimens having no confining reinforcement failed by splitting of the concrete at a small bond stress ($\tau \approx 10$ MPa) as can be seen in Fig. 5.

Specimens with confined concrete failed by the bars pulling out. Because the splitting crack developed in the plane of the longitudinal axis of the bars, only vertical bars crossing this plane were effective in restraining the concrete, while the influence of stirrups was negligible. The presence of vertical steel bars restrained the widening of splitting cracks and changed the failure mode to a pull-out one.

Bond stress *vs*. slip relationships for specimens with different confining reinforcement are shown in Figs. 6 and 7, where ΣA_{SV} is the area of vertical bars and A_S – the area of tested bar.

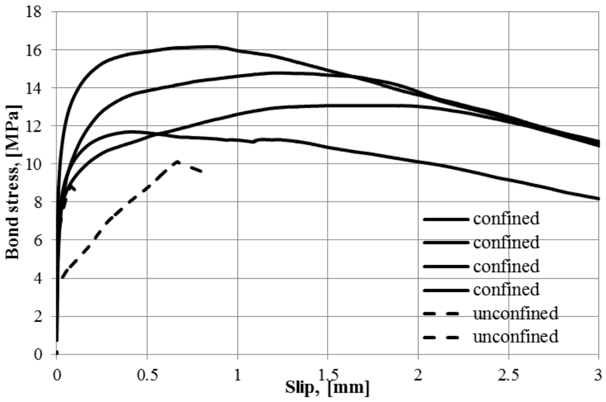
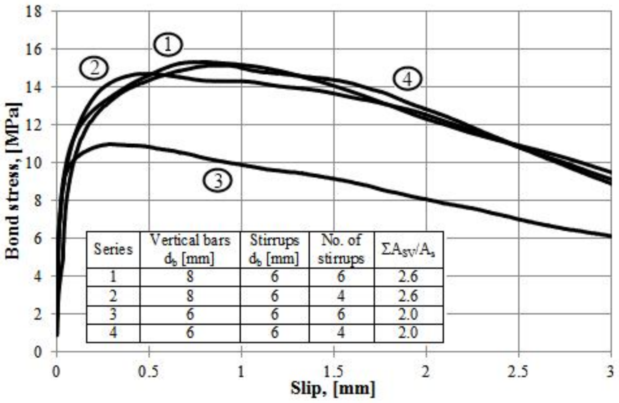
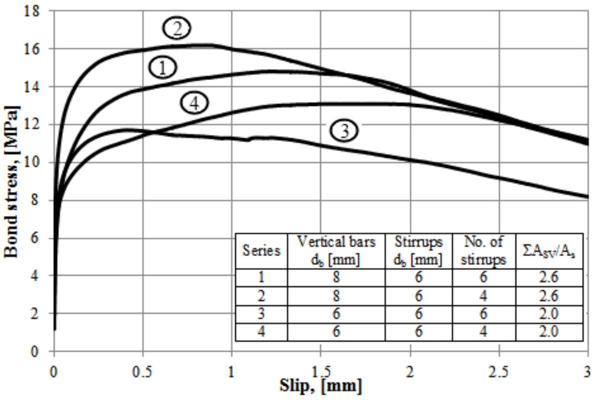


Fig. 5 – Local bond stress *vs*. slip relationships of test bars ø12.



Series	Vertical bars d_b [mm]	Stirrups d_b [mm]	No. of stirrups	$\Sigma A_{SV}/A_s$
1	8	6	6	2.6
2	8	6	4	2.6
3	6	6	6	2.0
4	6	6	4	2.0

Fig. 6 – Effects of confining reinforcement area on local bond stress *vs*. slip relationship of test bars ø10.



Series	Vertical bars d_b [mm]	Stirrups d_b [mm]	No. of stirrups	$\Sigma A_{SV}/A_s$
1	8	6	6	2.6
2	8	6	4	2.6
3	6	6	6	2.0
4	6	6	4	2.0

Fig. 7 – Effects of confining reinforcement area on local bond stress *vs*. slip relationship of test bars ø12.

The bond stress–slip relationships for specimens with ø 6 and ø 8 vertical bars were practically identical as for ø 10 test bars. In case of ø 12 test bars, the specimens with ø 8 vertical bars had a higher ultimate bond stress than specimens with ø 6 vertical bars.

4. Conclusions

Experimental results regarding local bond stress *vs.* slip tests on reinforcing bars embedded in self-compacting concrete were presented. The test data indicated that

1. Confinement of concrete by transverse reinforcement does not directly influence the local bond behavior of deformed bars in joint conditions where the vertical column bars are sufficient to restrain the widening of bond splitting cracks.
2. To ensure that the bond failure is caused by pull-out, a restraining reinforcement must be provided.

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EFECTUL CONFINĂRII ASUPRA ADERENŢEI DINTRE BETONUL AUTOCOMPACTANT ŞI ARMĂTURĂ

(Rezumat)

Lunecarea armăturii din grindă la un nod de cadru este o cauză importantă de avarie pentru structurile în cadre din beton armat sub acțiunea încărcărilor statice şi dinamice. Se studiază efectul confinării în betonul autocompactant (BAC), asupra relației efort aderență–lunecare pentru barele de armătură în nodurile de cadre. Elemente în formă de prismă, cu bare de armătură din oțel înglobate în beton pe o lungime egală cu trei şi cinci diametre, au fost testate sub acțiunea unei încărcări monotone. Elementele au reprezentat regiunea confinată a unui nod de cadru. Rezultatele studiului au indicat că atât timp cât fisurile de despicare sunt împiedicate să se propage de către

armătura verticală din stâlp care traversează aceste fisuri, confinarea betonului cu armătură transversală (etrieri) are un efect nesemnificativ asupra aderenței. Elementele care nu au avut armătură de confinare au cedat prin despicarea betonului în planul axei longitudinale a barei de armătură la un efort de aderență redus. Cedarea elementelor confinate a fost cauzată de smulgerea barelor de armătură la eforturi mai mici decât limita de curgere a oțelului.