ASIAN JOURNAL OF CIVIL ENGINEERING (BUILDING AND HOUSING) VOL. 1, NO. 4, (2000)
PAGES 61-68

A STUDY ON PULL-OUT STRENGTH BETWEEN LIGHTWEIGHT AGGREGATE CONCRETE AND REINFORCING BARS

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ABSTRACT

This paper discusses the results of an experimental investigation into the bond strength between reinforcing bars and lightweight aggregate concrete (LWC). The parameters studied are unit weight of concrete and thickness of the concrete cover over the reinforcing bar. Normal-weight control concrete had a compressive strength of 24 MPa, and lightweight aggregate concrete had a compressive strength of 20 MPa. The study included tests of twenty pullout specimens in two series. The test specimens consist of concrete blocks with a single 80-mm reinforcing bar embedded horizontally. Each series comprised two groups with different concrete covers over the reinforcing bars. Each group included five similar specimens. Test results show that the pullout strength of lightweight concrete is generally higher than that of normal concrete. It is also concluded that the reduction factor recommended by the provisions of different codes for the bond strength of lightweight concrete is unnecessary conservative.

Keywords: bond strength, lightweight aggregate, lightweight concrete, reinforcing bars.

1. INTRODUCTION

Adequate bonding between reinforcing bars and concrete is a fundamental requirement for the satisfactory performance of reinforced concrete structures. It affects many aspects of the behavior of reinforced concrete such as cracking, deformation, internal damping, and instability. The findings of previous research into the bond strength of lightweight aggregate concrete are contradictory. Some studies showed that the bond strength of LWC was larger than that of normal concrete [1,2]. On the other hand, there are some experimental results showing that the bond strength of LWC is comparatively smaller [3]. Martin [4] and Berge [5] using standard RILEM pull-out test specimens found that the bond strength from the pull-out test was approximately the same for both types of concrete using lightweight and normal weight aggregates. Similar contradiction is seen in the studies on the influence of silica fume on bond strength [6,7]. In a discussion [8], the author has shown that the contradiction between the results of different studies on bond strength is caused by the following problems; (i) The concrete compressive strength of different specimens has generally been different in each study. That is why researchers have used the normalized bond strengths with respect to the square root of concrete strength and compared them in different tests. However, as previously shown [8], the normalized bond strength may not be independent of the concrete compressive strength. (ii)

In full-scale beam tests, the bond stress distribution influences the bond strength [9]. Many researchers have not considered this effect. (iii) The scatter in the bond strength test results is naturally significant. Therefore, the number of specimens tested by past researchers is not adequate to reach an exact conclusion.

To study the influence of different parameters on bond strength it is appropriate to keep the concrete strength constant in different test specimens. Otherwise, an equation that could appropriately account for the concrete strength is needed. Esfahani and Rangoon [9, 10] studied the bond strength in the cases of normal strength and high strength concrete in two types of specimens, pull-out and splices in beams. Using the test results and the bond strength theories, they proposed equations to calculate the bond strength in the cases of NSC and HSC. They showed that the normalized bond strength with respect to the square root of concrete compressive strength $u/(f_c')^{0.5}$ was not independent of the concrete strength in different pull-out and splice tests. In short length pull-out specimens in which the bond stress distribution over the embedded length is almost uniform, $u/(f_c')^{0.5}$ versus C/d_b relationship was obtained for NSC and HSC. It was seen that, in short lengths, the normalized bond strength increased with increasing the concrete strength. Equations 1 and 2, proposed by Esfahani and Rangoon [9], determines the bond strength of short embedded lengths in the cases of normal strength and high strength concrete.

$$u_c = 2.7\frac{C/d_b + 0.5}{C/d_b + 3.6}\sqrt{f_c'} \qquad (1)$$

$$u_c = 4.7\frac{C/d_b + 0.5}{C/d_b + 5.5}\sqrt{f_c'} \qquad (2)$$

u_c is local bond strength in MPa, d_b is the bar diameter, C is minimum concrete cover. f_c' is the concrete compressive strength in MPa. Figure 1 shows the normalized bond strength versus C/d_b relationship based on Equations 1 and 2.

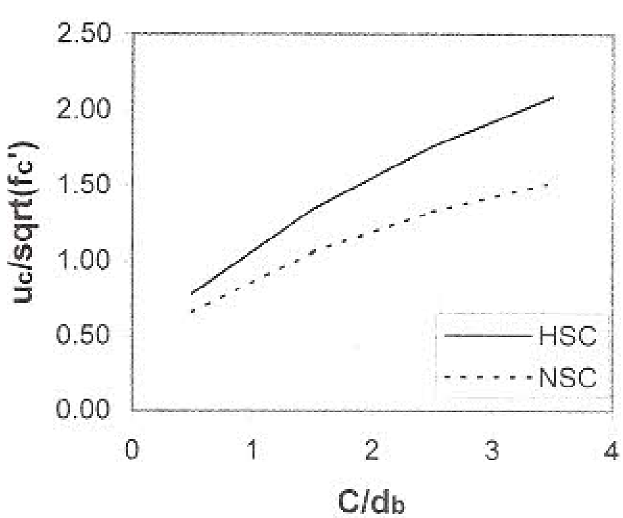

Figure 1 Normalized bond strength versus C/d_b relationship

2. EXPERIMENTAL PROGRAM

Twenty specimens in two series were manufactured and tested. Each series comprised two groups with different C/d_b. Each group included five similar specimens. These specimens were cast in one set of formwork at the same time. The concrete strength of the two groups of each series was the same. Each specimen was a concrete block having a reinforcing bar of 20 mm nominal diameter with a short embedded length (Fig. 1). Specimens of the first series were made of normal strength. Second series included specimens made of lightweight aggregate concrete. The concrete mixture of Test Series 2 was carefully designed in order to attain a compressive strength close to that of Series 1. The admixtures of silica fume and superplasticizer were added to the concrete mixture in order to increase the compressive strength of lightweight concrete.

The values of C/d_b for the first and second groups of each series were 2 and 4, respectively. In all specimens, the ratio of the side cover to the bottom cover C_x/C_y was 1, and the embedded length of bars was 80 mm (Fig. 1). The dimensions of specimens in the first group were 80×100 × 240 mm and in the second group were 80 ×180 × 240 mm. Other details of test specimens are given in Fig. 1. All reinforcing bars were bottom cast bars.

2.1 Materials

Tensile test was carried out on 20-mm diameter reinforcing bar. The measured yield and ultimate strengths of the bar were 370 MPa and 610 MPa, respectively. The reinforcing bars were longitudinally sliced in order to measure the rib geometric. The relative rib area, R, for the bar was approximately 0.12.

$$R = \frac{\text{projected rib area normal to the bar axis}}{\text{nominal bar perimeter} \times (\text{center - to center rib spacing})}$$

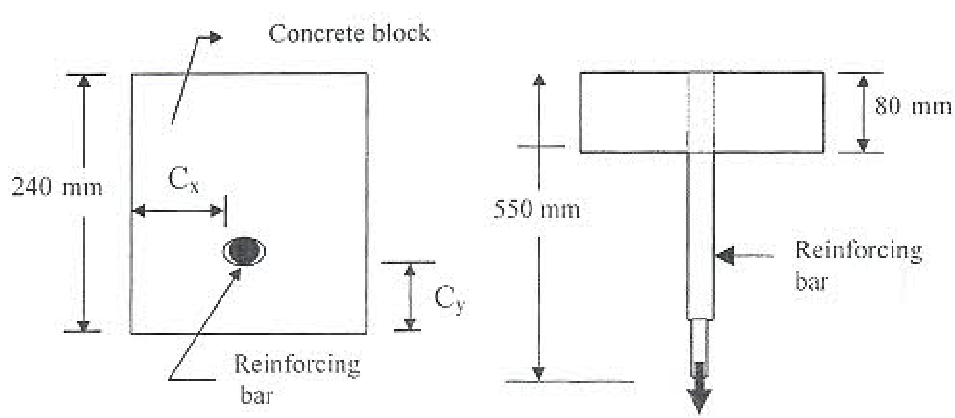

Figure 2 Details of specimens

Cement type 2 was used for the concrete mixtures. The maximum size of LWA and normal aggregate was 9.5-mm. Expanded shale LWA was used for lightweight concrete. The physical properties of LWA and fine aggregate are given in Tables 1 and 2, respectively.

Table 1 Physical properties of LWA

LWA (expanded shale)	standard	value
Normal maximum size	ASTM C330	9.5 mm
Absorption, 24 hr submerged	ASTM C127	14.2%
Bulk specific gravity 24 hr submerged	ASTM C127	0.80
Bulk specific gravity (SSD)	ASTM C127	0.84
Unit weight (dry rotted)	ASTM C29	527.4 Kg/m^3
Unit weight (dry loose)	ASTM C29	437.9 Kg/m^3

Table 2 Physical properties of fine aggregate

Fine aggregate	standard	value
grading	ASTM C33	OK
Absorption, 24 hr submerged	ASTM C128	3.2%
Bulk specific gravity, 24 hr submerged	ASTM C128	1.99
Bulk specific gravity (SSD)	ASTM C128	2.07

Both concrete series were made in the laboratory. Concertes were vibrated thoroughly during casting. After two days of casting, the moulds were opened and the specimens were cured wet until a day before testing. Table 3 shows some details of mixtures. For each casting, ten 100 mm x 200 mm concrete cylinders were made to determine the concrete compressive strength.

Table 3 Details of concrete mixtures

series	f_c' MPa	unit weight Kg/m^3	W/C	cement Kg/m^3	SF Kg/m^3	SP* Lit.
NC-24	24	2350	0.50	500	-	-
LWA-20	20	1460	0.32	500	80	9

* liquid (based on 40% solution)
† series label: a-b: "a" stands for the concrete mixture, NC for normal concrete, LWA for lightweight aggregate concrete. "b" is the concrete compressive strength.

2.2 Test Set-up and Test Procedure

A tensile test apparatus was used for applying the load. A steel plate located between the specimen and test apparatus was used as a bearing plate (Fig. 2). The dimensions of the plate were 100 × 100 × 20 mm. The interfaces between the plate and the specimen were greased slightly to reduce the frictional forces between them. The specimens were loaded at the rate of about 7 kN/minute. All specimens failed due to splitting of concrete.

2.3. Test Results

The test results are summarized in Table 4. Bond strength, u, was calculated by the relation $u=P/(\pi d_b L)$, where P is the measured load at failure, d_b is the bar diameter, and L is the embedded length of bar. To compare the bond strength of specimens in the two series, all bond strengths were normalized with respect to the square root of concrete compressive strength. Figure 3 shows the relationship between $u/(f_c')^{0.5}$ and C/d_b in different tests.

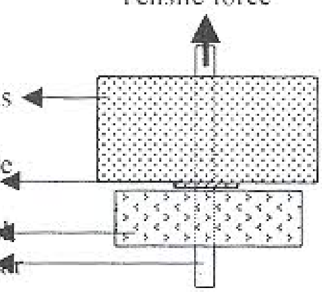

Figure 3 Test set up

Table 4 Measured bond strengths at failure

Specimen	f_c'	$f_c'^{(0.5)}$	L	d_b	C/d_b	P	u_{test}	$u_t/f_c'^{(0.5)}$	mean
	MPa		mm	Mm		kN	MPa		SD
1-NC24/2	24.0	4.9	80	20	2	33.80	6.73	1.37	
2-NC24/2	24.0	4.9	80	20	2	29.80	5.93	1.21	
3-NC24/2	24.0	4.9	80	20	2	26.00	5.18	1.06	
4-NC24/2	24.0	4.9	80	20	2	24.00	4.78	0.98	1.10
5-NC24/2	24.0	4.9	80	20	2	22.10	4.40	0.90	0.17
1-NC24/4	24.0	4.9	80	20	4	33.50	6.67	1.36	
2-NC24/4	24.0	4.9	80	20	4	35.10	6.99	1.43	
3-NC24/4	24.0	4.9	80	20	4	36.50	7.27	1.48	
4-NC24/4	24.0	4.9	80	20	4	44.60	8.88	1.81	1.48
5-NC24/4	24.0	4.9	80	20	4	32.10	6.39	1.30	0.18
1-LWA20/2	20.0	4.5	80	20	2	22.00	4.38	0.98	
2-LWA20/2	20.0	4.5	80	20	2	33.20	6.61	1.48	
3-LWA20/2	20.0	4.5	80	20	2	25.80	5.14	1.15	
4-LWA20/2	20.0	4.5	80	20	2	26.70	5.31	1.19	1.28
5-LWA20/2	20.0	4.5	80	20	2	35.90	7.15	1.60	0.23
1-LWA20/4	20.0	4.5	80	20	4	38.00	7.56	1.69	
2-LWA20/4	20.0	4.5	80	20	4	31.40	6.25	1.40	
3-LWA20/4	20.0	4.5	80	20	4	26.00	5.18	1.16	
4-LWA20/4	20.0	4.5	80	20	4	29.00	5.77	1.29	1.41
5-LWA20/4	20.0	4.5	80	20	4	33.50	6.67	1.49	0.18

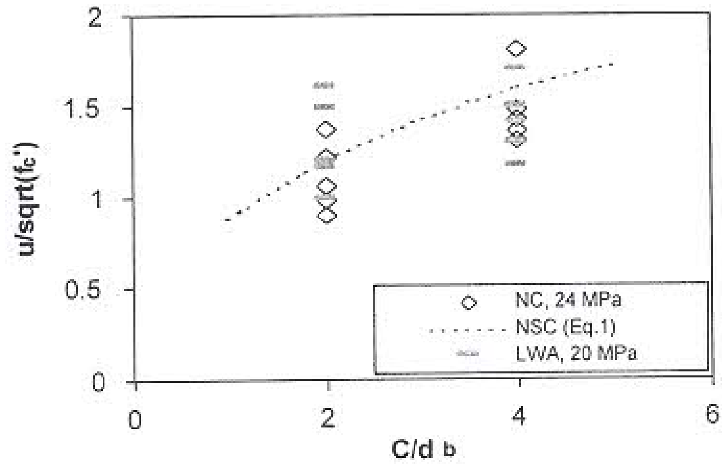

Figure 4 $u/(f_c')^{0.5}$ versus C/d_b relationship of different specimens

To be able to compare the bond strength of lightweight concrete with that of normal concrete, the average normalized bond strength of 5 specimens in each group was calculated (Table 5) and plotted against C/d_b as shown in Fig. 4.

3. CALCULATION OF BOND STRENGTH

Equation 1, previously proposed for normal strength concrete, is used to calculate the local bond strength $u_{calc.}$ for normal and lightweight concertos. The results are given in Table 5. Equation 1 and the test results are also shown in Figure 4. It is seen that Equation 1 correlates well with the test results.

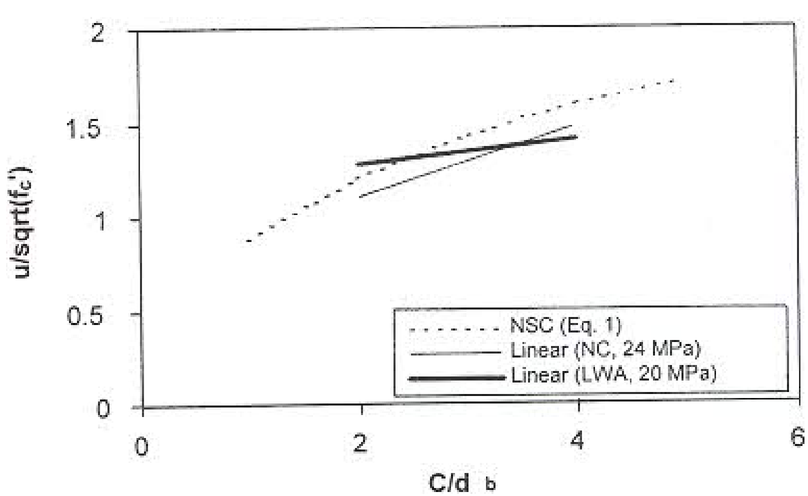

Figure 5 $u/(f_c')^{0.5}$ versus C/d_b relationship for lightweight and normal concrete

Table 5 Average normalized bond strength for different test groups

Series	f_c' (MPa)	Groups*	C/d_b	P (kN)	u_{test} (MPa)	$u/(f_c')^{0.5}$	u_c (Eq. 1)	u_t/u_c
NC-24	24	NC-24/2	2	27.1	5.40	1.10	5.89	0.92
		NC-24/4	4	36.4	7.24	1.48	7.82	0.93
LWA-20	20	LWA-20/2	2	27.0	5.72	1.28	5.38	1.06
		LWA-20/4	4	31.6	6.29	1.41	7.14	0.88

* Group labels A/B: A stands for the test series, B is the ratio of C/d_b in each group.

4. CONCLUSIONS

An experimental investigation to study the steel-concrete bond strength of lightweight concrete was conducted. Twenty short length specimens were manufactured and tested. Bond strength normalized with respect to the square root of concrete compressive strength was calculated in each test. Using the comparison of the test results, the following conclusions are drawn.

1. Local bond strength of lightweight aggregate concrete is generally larger than that of normal concrete, especially for smaller concrete covers. It seems that the reduction factor recommended by the provisions of different codes for the bond strength of lightweight concrete is unnecessary conservative.
2. The equation previously proposed for local bond strength of normal concrete could be used for calculation of the steel-concrete bond strength in the case of lightweight concrete.

Acknowledgements: The experimental study was conducted at the concrete laboratory of Freedoms University, Mashed, Iran.

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