Experimental Study on the Bond Strength Between Reinforcement Bars and Concrete as a Function of Concrete Strength and Confinement Effect

Vinh Tran Xuan, Hung Nguyen Manh, Hieu Nguyen Trung, and Dat Pham Xuan

Abstract This paper presents the results of the experimental investigations on the influence of concrete strength, and confinement effect of different arrangements of hoops on the bond-slip relationship between reinforcing steel bars and concrete. The Pull-out tests according to the recommendations of RILEM CEB RC6 were conducted to determine the bond strength-slips relationship. A set of 27 specimens were prepared for the testing with two main parameters, including concrete strength and stirrup spacing. Based on the current test results, the effects of such variable of interest on the behavior of RC structural elements are discussed.

Keywords Bond strength · Confinement effect · Pull-out tests

1 Introduction

Reinforced concrete structures are widely used in housing construction, bridges, roads, irrigation. Bond slip relationship between reinforcing bar and surrounding concrete is the basic factor that ensures the general working of concrete and reinforcement in reinforced concrete structures. Among the factors affecting the adhesion force between the concrete and the reinforcement, the influence of the strength of the concrete and the reinforcement is very important. The research purpose of the topic is to clarify the effect of compressive strength of concrete and columnar stirrup on adhesion between concrete and longitudinal reinforcement.

This paper presents an Experimental study on the bond strength between reinforcement bars and concrete as a function of concrete strength and confinement effect.

V. T. Xuan · H. N. Manh (✉)
Vinh University, Nghe An, Vietnam

H. N. Trung · D. P. Xuan
National University of Civil Engineering, Hanoi, Vietnam
e-mail: hieunt@nuce.edu.vn

D. P. Xuan
e-mail: datpx@nuce.edu.vn

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2 Experimental Research

2.1 Test Specimens and Materials

The pull-out tests were conducted on the recommendations of RILEM-CEB RC 6 (Fig. 1). The bond length between rebar and concrete of 60 mm (5Φ) were located in the mid of specimens and two PVC tubes with 45 mm length were used to isolate the non-bonding length. The free-end were elongated to measure the slip deformation. The planning of the tests is shown in Table 1, including two groups. The 18 cube specimens with dimensions of 150 × 150 × 150 mm^3 were fabricated and test for determining the influence of concrete compressive strength, called Group 1. The 9 rectangular prism specimens with dimensions of 150 × 100 × 300 mm^3 and the different arrangements of stirrup space were performed for determining the influence of stirrups on the bond strength between the steel bars and concrete, called Group 2.

The ribbed steel bars with 12 mm diameters and AII grade were used in the total specimens. The stirrups with 6 mm diameters spaced at 40 mm and 80 mm were arranged perpendicular to the steel bars, as shown in Fig. 2.

A range of 17.52 to 75.58 MPa strength concrete was used to produce the specimens of the test (refer to Table 1).

The mix ratios of concrete are shown in Table 2. The types of cement are Portland cement with strength grade of PCB30 for concrete with compressive strengths from

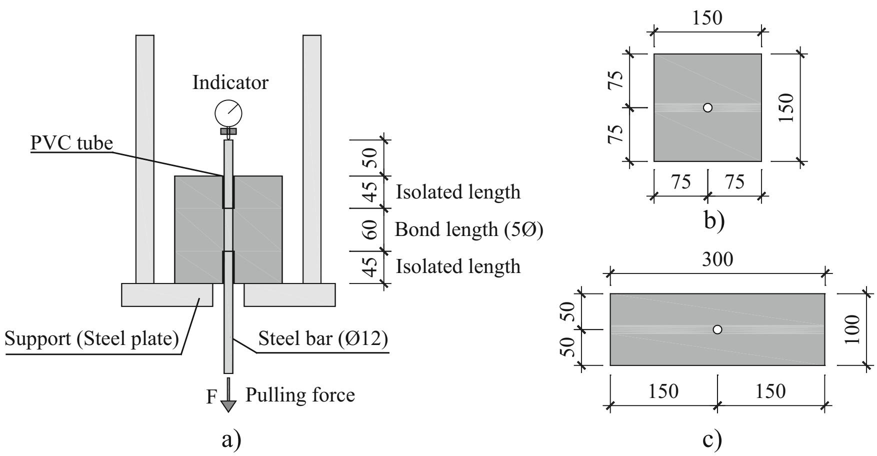

Fig. 1 Details of testing

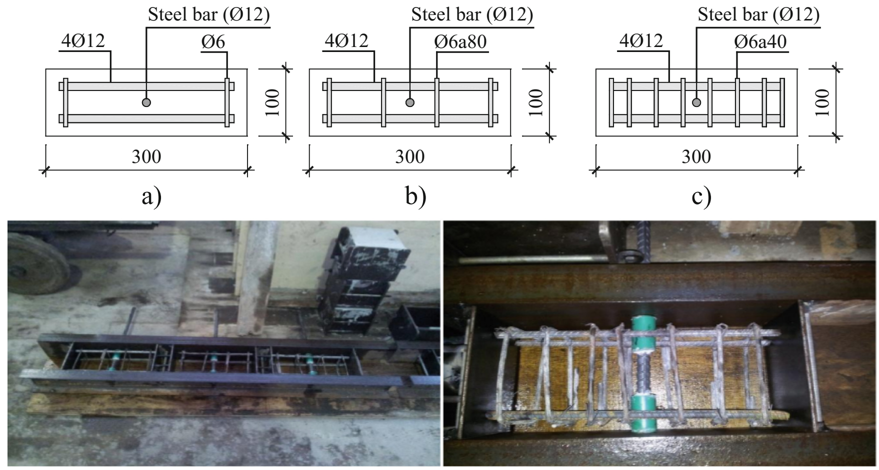

Fig. 2 Detail of Group 2 specimens (unit: mm)

Table 1 Test planning

Test type	Distance of stirrup (mm)	Concrete strength (MPa)	Number of specimens
Group 1 (150 × 150 × 150 mm^3)	–	17.52	3
	–	21.89	3
	–	28.9	3
	–	33.14	3
	–	59.82	3
	–	75.58	3
Group 2 (150 × 100 × 400 mm^3)	0	22.22	3
	80	20.35	3
	40	23.11	3

17.2 MPa to 33.4 MPa and strength grade of PCB40 for concretes with compressive strengths from 59.82 MPa to 75.58 MPa.

Three 150 × 150 × 150 mm3 concrete cube per each sample were tested in order to obtain its compressive strength. The average concrete strengths after 28 days are shown in Table 1.

2.2 *Test Setup and Instrumentation*

During the test, the applied forces were recorded through a computerized data-logger system. The test procedure is described as follows:

Table 2 Mix ratio for 1m^3 volume of concrete (kg/m^3)

Concrete strength (MPa)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (liter/m^3)	Superplasticizer ACE 388 (kg/m^3)
17.52	311.32	710	1285	193	–
21.89	357.86	681	1272	193	–
28.9	409.54	650	1259	202	–
33.14	467.20	597	1242	188	–
59.82	435	671	1180	148	3.48
75.58	510	681	1100	153	4.95

a. Arranging instrumentation for the test specimen (Fig. 3)
b. Carrying out loading increment (100kg/step)
c. At each increment, reading and recording the value of the indicator.
d. Repeat the b and c step until failure phenomena occurs

At every loading step, all test data including the applied load and vertical deformations are recorded with Data Logger TDS-530.

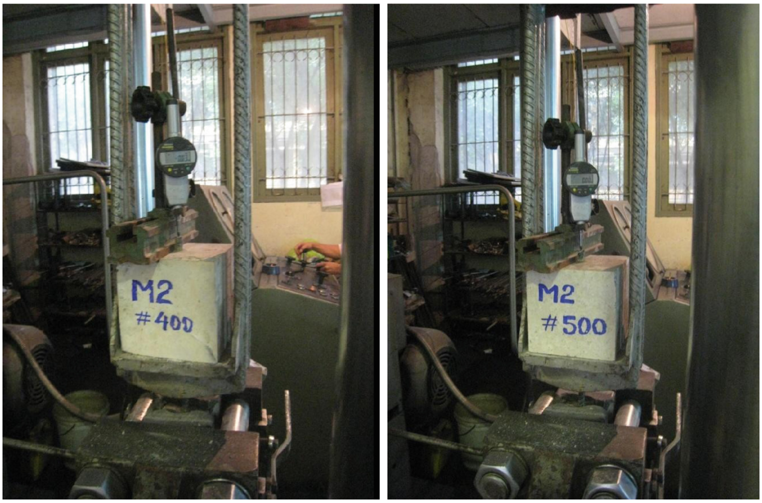

Fig. 3 Typical test setup and instrumentation

3 Test Results and Discussions

3.1 Influence of the Concrete Strength

Figure 3 shows the comparison of bond strength—slip curves of specimens Group 1 that has six values of concrete strength, ranging from 17,5 MPa to 75,58 MPa. Each curve in Fig. 3 is set of average values from results of three same test specimens. From the graph, it is clear that the bond strength between steel bar and concrete increases with increasing concrete strength. The change of compressive strength from 17.5 MPa to 33.14 MPa, the behavior of the bond-slip divided into four states, while the others is unclear.

The process of developing adhesion force is divided into 04 stages as follows:

Stage 1: Choosing adhesion at this time is mainly the adhesive force of cement mortar. This phase does not appear cracks in the concrete. Shift δ increases slowly.

Stage 2: Starting to appear cracks between the concrete and the reinforcement, the pressure of the reinforcement on the concrete increases, the displacement δ increases gradually.

Stage 3: Cracks develop, adhesion force reaches maximum value. Teleport δ increases rapidly. Adhesion force is mainly due to the edge of the reinforcement acting on the concrete.

Stage 4: The force value remains constant for a short time and then decreases rapidly, the displacement δ continues to increase rapidly until the concrete-reinforced linkage is damaged (Fig. 4).

When the concrete strength increases from 17.5 MPa and 75.58Mpa, the τ_{max} value increases 2 times while the τ_{min} value increases 4.4 times. Relative displacement of concrete and reinforcement (δ max) decreases gradually as the concrete strength increases. The detail shows in Fig. 5.

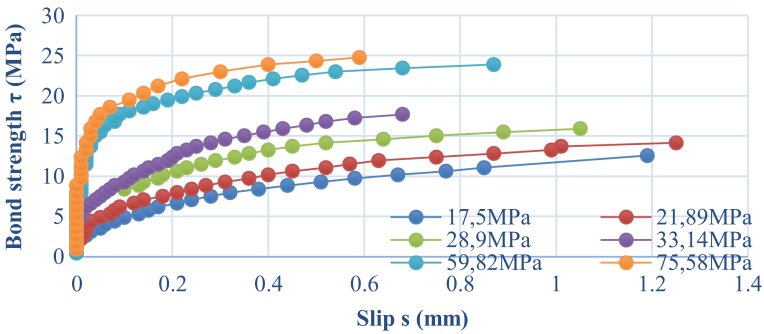

Fig. 4 Bond strength—slip curves of all specimens Group 1

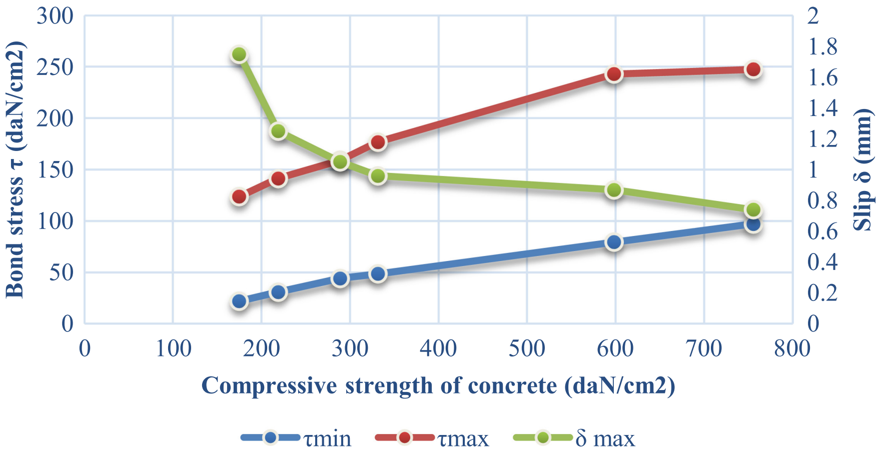

Fig. 5 Bond strength—slip curves of all specimens Group 1

3.2 The Effect of Stirrup Spacing

The value of the adhesion force at the onset of the relative displacement between the reinforcement and the concrete τ_{min} of the sample with the smaller belt spacing (a = 40) is larger than that of the sample with a large belt spacing (a = 80) (Fig. 6).

Experimental results show that the sample with a smaller distance (a = 40mm) has the largest value of adhesion force (τ_{max}) than the sample with a large belt distance (a = 80mm).

For the test sample with a belt arrangement, when the concrete is expanded, the belt acts to prevent the lateral expansion of the concrete, the more expands the concrete, the tighter the belt will squeeze the concrete. Concrete holds the reinforcement tighter

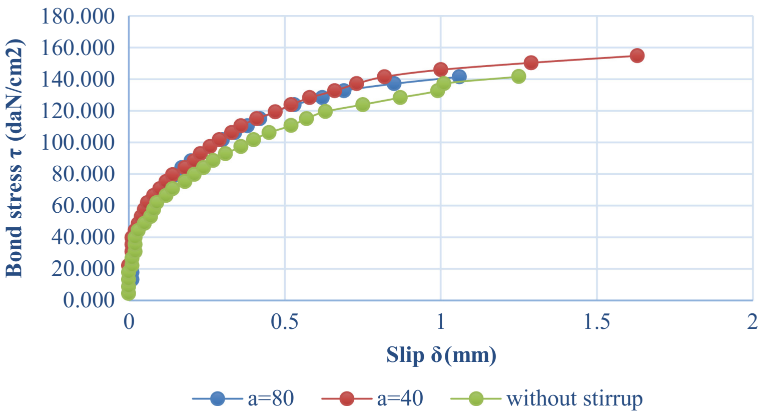

Fig. 6 Diagram of the relationship between adhesion force τ and displacement δ

or increases the adhesion force between the reinforcement and the concrete in the concrete-reinforced structure.

4 Conclusions

Stirrups and the compressive strength of concrete have significant effects on bond force between concrete and reinforcing bars in reinforced concrete structures. Bond force is directly proportional with the compressive strength of concrete. An increase in the compressive strength of concrete may slows down the process of breaking the bond between concrete and reinforcements.

Failure mechanism of the bond has its root from the failure of concrete zones contacting with steel interfaces. Stirrups in reinforced concrete members play a role in confining horizontal expansion, which increases the bond force between concrete and reinforcements. In addition, the bond stress increases when increasing the percentage of stirrup.

References

1. ACI 318—99, Building code requirements for Structural Concrete,
2. AS 3600—2009, Australian Standard for concrete structures, Standard Australia, Sydney
3. Eurocode 2, Design of Concrete Structures.
4. RILEM TC, "RILEM Recommendations for the Testing and Use of Construction Materials,
5. RC 6 Bond Test for Reinforcement Steel. Pull-Out Test, 1983". E&FN SPON, 1994.
6. TCVN 5754–2018: Design of Concrete and Reinforced Concrete Structures, Vienamese Standard (2018)
7. SNIP 2.03.01–84, "Guidelines for Design of Concrete and reinforced concrete structures made of heavy—weight and light—weight concrete without reinforcement prestress