Experimental study on bonding performance of stainless steel bar and concrete

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Abstract. The purpose of this paper is to study the bond behavior between stainless steel bar and concrete. Through the bonding test between reinforcement and concrete, the average bonding force and the distribution of the bonding force between stainless steel bar and concrete are studied. The test results showed that the bond performance between stainless steel bars and concrete was excellent. Within a certain range, the bond performance between stainless steel bars and concrete was proportional to the compressive strength of concrete. The bonding performance of stainless steel bars and concrete was related to the diameter of reinforcement. The larger the diameter of reinforcement, the greater the average bonding stress between reinforcement and concrete. In addition, the area affected by the bonding stress between reinforcement and concrete showed a linear growth trend with the diameter of reinforcement roughly affected as 10 times as the diameter of reinforcements. Stainless bar were similar to ordinary bar, and the peaks of their bond stress with concrete were roughly distributed near the loading end. As the load increased, the effective bond length increased slowly, while the peak stress increased significantly. The peak stress showed an internal shift only when the specimen was near damage.

1. Introduction
In recent years, stainless steel reinforced concrete has been applied in the project of serious corrosion area of the word, especially in the bridge project of coastal area. At present, domestic and foreign scholars have carried out many theoretical and experimental studies on stainless steel reinforced concrete, but most of these studies focus on the corrosion resistance of stainless steel reinforced concrete, and the bond between stainless steel reinforced concrete is less[1]. The bond between stainless steel bars and concrete belongs to the interface problem of stainless steel bars concrete. The interface problem of stainless steel bars concrete is a very important and special problem in the structural analysis and design of stainless steel bars concrete, which is related to the rationality and reliability of structural analysis and design model. At present, there are generally three kinds of testing methods for the adhesion of ordinary reinforcement bars, pull out test, beam test and axial pull test [2]. In order to study the mechanical properties of stainless steel bars, Calderon et al. [3]analyzed the effects of corrosion on the properties of reinforced concrete by simulating the marine environment. The results show that the effect of curing age on the bond strength of duplex stainless steel bars was significant. Higher water-cement ratio and steel corrosion degree would reduce the bond strength of stainless steel bars. BaiZhang et al.[4] investigated the bond performance between corroded steel bars and concrete after high temperature exposure. The results show that the decrease of the bond property, including bond strength, bond stiffness, bond energy dissipation and residual bond stress, were affected by the corrosion and exposure.
temperature. S. Coccia [5] analysed the corrosion effects at the steel–concrete interface. An analytical model was developed to evaluate the internal pressures caused by corrosion products. Zhao, YX[6] studied the bond between normal aggregate concrete (NAC) or recycled aggregate concrete (RAC) and corroded steel bars. The results show that the corrosion - induced bond degradation characteristics of NAC and RAC specimens were similar. HongweiLina[7]studied the potential relationship between crack width and bond strength. The results show that the width of surface crack is closely related to the degree of corrosion. Congqi Fangevaluate[8] studied the effect of corrosion on bonding and bond-slip behavior, and believed that when the degree of corrosion was very low, the bond strength would increase with the increase of the degree of corrosion.

2. Experimental design and method

Figure 1 shows a schematic of the specimen used in the average bonding test. The specimens tested for average cohesive force were drawn from the cube center without transverse reinforcement, and the size of the concrete test block was 150mm×150mm×150mm. The center of the test block was equipped with steel bar, which could be divided into three types: 12mm, 16mm and 32mm. In order to avoid local damage, the 25mm of each end of the steel in the concrete was covered with a plastic sleeve to form a non-bonded length.

![Figure 1. The schematic plot of average bond test block.](image)

In this test, considering that the strength of concrete and the diameter of reinforcement may affect the bonding force between reinforcement and concrete, three kinds of concrete with different strengths C30, C40 and C50, were designed. And the steel bar was also divided into 12mm, 16mm and 32mm according to different diameters. The test was carried out in three batches according to the concrete strength grade. The main instrument used was a 300-ton hydraulic servo test machine. In addition, in order to prevent the use of impact cracks, the puller pull-out device and the 300-ton press were used for slow loading until the tester replacement or twisting curve could not be reloaded instead of zero. Theoretically, it is believed that the end of the test should be caused by the following two conditions: one is the yielding phenomenon of the steel bar or the steel bar is pulled out; the other is the concrete test block splitting or cone crushing [9]. Pulling the test for each batch of samples can obtain the average load stress of the damaged load of the sample and concrete. It can be obtained by using Equation (1), Equation (2) and Equation (3) [10].

\[ \tau_f = \alpha \tau \]  
\[ \alpha = \frac{f_{cu,k}}{f_{cu}} \]  
\[ \tau = \frac{1000F}{\pi d I} \]

Where \( \tau_f \) is the average bond stress of steel and concrete, \( \alpha \) is the concrete compressive strength correction factor, \( \tau \) is the average bond stress without considering the concrete strength deviation,
\( f_{cu,k} \) is the concrete strength grade, \( f_{cu} \) is the measured compressive strength of concrete, \( F \) is the breaking load, \( d \) is the diameter of the steel bar, \( l_a \) is the bond length of steel and concrete.

The average value of the average stress \( \tau \) and \( \tau_f \) of a steel bar and concrete is \( \bar{\tau} \) and \( \bar{\tau_f} \), respectively. They determined by referring to Equation (4) and Equation (5):

\[
\bar{\tau} = \frac{\sum_{i=1}^{n} \tau_i}{n}
\]
\[
\bar{\tau_f} = \frac{\sum_{i=1}^{n} \tau_{f_i}}{n}
\]

After the end of each batch of drawing test, the compressive test was carried out on the reserved concrete block, and the failure load of the reserved concrete block can be measured, so that the compressive strength \( f_{cu} \) of the reserved concrete block can be obtained, and the calculation is performed, as presented in the Equations (6):

\[
f_{cu} = \frac{F}{A}
\]

Equation 7 represents the compressive strength of a reserved concrete block of a strength grade.

\[
\bar{f}_{cu} = \frac{\sum_{i=1}^{n} f_{cu_i}}{A}
\]

Table 1 shows the failure load, compressive strength and average value of the obtained reserved concrete block.

| Classification | C30PYL | C40PYL | C50PYL |
|----------------|--------|--------|--------|
| \( \bar{f}_{cu} \) (Mpa) | 52.55  | 61.16  | 69.91  |

3. Experimental phenomena

Through observation of the test process, it was found that the test was generally divided into five stages from the start of loading to the end of the test: (1) When the test machine began to load, the load was proportional to the time. At this stage, the bond between the steel and the concrete was small, mainly due to the action of the chemical bond, the sliding at the loading end was small, and the free end did not slip. As the load increased, the free end begins to show a slight slip. At this stage, the amount of slip was small, called the micro-slip phase. (2) The test load increased continuously, and the concrete on the surface of the sample showed tiny cracks. At this stage, the amount of slip increased, the slip accelerated, and rapidly developed to the free end, called the slip stage. (3) As the test was carried out, the load slowly rose with time, and the load growth rate slowed down. At this stage, slight dislocation occurred between the reinforcement and concrete, and the reinforcement of some test blocks was even pulled out directly. This stage became the pull-out stage. (4) The test load continued to increase until the maximum value was reached. The surface crack of the specimen quickly developed to the free end, and the free end slip amount and the load end slip amount were almost close. This stage is called the splitting stage. (5) After loading to the maximum load, the load time curve dropped rapidly, and the specimen had cracked and destroyed, and this stage became the descending stage.
4. Experiment analysis

Figure 2 shows the average bond stress under different concrete strengths. It can be seen from Figure 2 that the bond stress and concrete strength of stainless steel bar and stainless steel bar and ordinary steel increase linearly.

The average bond stress of stainless steel bar and ordinary steel bar are respectively drawn as graphs, which are represented by Figure 3 and Figure 4. It can be seen from Figure 3 and Figure 4 that under the same concrete strength condition, except for BP32, the concrete bond stress of stainless steel bar and the ordinary steel bar increases with the increase of steel bar diameter. The bonding stress of steel bars with a diameter of 32 mm is obviously smaller than that of steel bars with diameters of 12 mm and 16 mm. This is because the larger the diameter of the steel bar, the greater the influence range of the bond stress between the steel bar and the concrete, which is generally considered to affect the range of 10 times the diameter of the bar. The concrete dimensions of the specimens are all 150mm×150mm×150mm, so for the steel bar test block with a diameter of 32mm, the influence range of bond stress between steel bar and concrete has exceeded the size of the test block concrete.

Figure 5 shows the average bond stress between stainless steel bar with a diameter of 12mm and an ordinary steel bar. It can be seen from Fig. 5 that the three kinds of steel bars of 022Cr22Ni5MO3N stainless steel rib, 06Cr17Ni12MO2 stainless steel rib and HRB335 ordinary steel bar with diameter of 12mm are in the same concrete strength condition, the order of bond stress of concrete is 022Cr22Ni5MO3N stainless steel bar, 06Cr17Ni12MO2 stainless steel bar and HRB335 ordinary steel bar. And the bonding stress of 06Cr17Ni12MO2 stainless steel bar and HRB335 ordinary steel bar is similar. The average bond stress between stainless steel bars and concrete can be calculated according to Equation 8.
\[
\tau_b = \frac{f_{cu,k}}{f_{cu}} \frac{1000F}{\pi d I_b}
\]

Where \( \tau_b \) is the average bond strain between deformed stainless steel bars and concrete, \( f_{cu,k} \) is the concrete strength grade, \( f_{cu} \) is the measured compressive strength of concrete, \( F \) is the measured value of the load when the deformed stainless steel bar is broken, \( d \) is the diameter of the deformed stainless steel bar, \( I_b \) is the effective bond length between the deformed stainless steel bar and the concrete.

5. Conclusion

The following conclusions can be drawn from the average bonding force test and the bonding force distribution test of reinforcement and concrete:

1) The bond performance between deformed stainless steel bars and concrete was better than that between deformed ordinary steel bars, and the bond performance between deformed stainless steel bars and concrete was the best.

2) In a certain range, the bond performance of deformed stainless steel bars and concrete was directly proportional to the strength of concrete, the greater the strength of concrete, the better the bond performance of stainless steel bars and concrete.

3) In the range of common deformed steel bars, the bond performance between stainless steel bars and concrete was related to the diameter of the steel bars. The larger the steel bar diameter, the greater the average bond stress between stainless steel bars and concrete. Moreover, the bond stress affected zone between steel bar and concrete increased with the increase of steel bar diameter, which was about 10 times of the diameter of steel bar.

4) Whether it was stainless steel or ordinary steel, the peak of the bond stress of concrete was mostly near the loading end. As the load increases, the effective bond length increases slowly, while the stress peak increases significantly, only in the sample. At the end of the damage, the peak of the stress will appear to shift. As the load increased, the effective bond length increased slowly, while the stress peak increased significantly. Only when the specimen was near the damage, the peak stress appeared to shift.

Acknowledgment

The authors would like to acknowledge the financial support provided by the National Natural Science Foundation of China (Grant No. 51679220).

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