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Effects of confinements on the bond strength between concrete and corroded steel bars

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HIGHLIGHTS

- The increase of concrete cover can prevent the degradation of bond strength.
- The stirrups can significantly improve the bond strength of corroded steel bars.
- Bond strength model considering confinements and current density is established.

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ABSTRACT

The bond tests were carried out on 18 beam specimens to investigate the bond behavior between concrete and corroded steel bars, with corrosion and stirrups being the principal parameters. Through systematical analysis of the test results and extensive test data from the literature, the confinements were found to have significant influence on the bond strength. Considering the effects of concrete cover, stirrups and corrosion current density, empirical model for the degradation of bond strength was established. It is concluded that the proposed model can predict the test results with reasonable accuracy.

1. Introduction

The bond between concrete and steel bars is made up of three components: chemical adhesion, friction and mechanical interaction. For deformed steel bars, the bond depends primarily on mechanical interaction [1]. The mechanical interaction is closely related to the confinement conditions which are mostly provided by concrete cover and stirrups. Once the steel bar is corroded due to the chloride contamination or carbonation, the bond behavior between concrete and steel bar is inevitably affected. In the initial stage of steel corrosion, the bond strength increases slightly because of the radial pressure exerted by the expansive corrosion products and the increased roughness at the steel bar surface; afterwards, the bond strength begin to decrease due to substantial reduction of the rib area and cracking of concrete cover [2,3]. Numerous studies have been performed to investigate the degradation of ultimate bond stress, i.e., the bond strength. Auyeung et al. [4], Bhargava et al. [5] and Lee et al. [6] proposed exponential functions for the degradation of bond strength, while Cabrera [7] and Stanish et al. [8] used linear relationships to describe the degradation of bond strength. Analytical models were also proposed by Coronelli [9], Wang and Liu [10], Tastani and Pantazopoulou [11], and Coccia et al. [12] to describe the mechanics of corrosion-induced bond strength degradation. However, Most of the previous studies were carried out on specimens without stirrups. The positive role of stirrups in preventing the degradation of bond strength has been noticed by some researchers. Corroded specimens with stirrups have been proved to exhibit higher ductility by Fang et al. [13], and Fischer et al. [14] pointed out that bond strength of specimens with stirrups is much less sensitive to the corrosion of steel bar. Though preliminary conclusions have been derived as to the confining effect of stirrups on bond degradation, bond tests based on confined specimens are still in small number and few of bond strength models have been proposed for the specimens with stirrups. The investigations about the bond strength of corroded steel bars yet need to be further explored.

Therefore, the aim of this study is to cast deep sight on the bond strength of corroded steel bars from the perspective of confinements. To achieve this target, 18 beam specimens were cast with corrosion level, concrete cover and stirrups being the variables.

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2. Experimental program

2.1. Test specimen

In the present study, 18 beam specimens were cast. All beam specimens had a cross section of 150 × 250 mm. The clear concrete covers on the bottom and the lateral side were 40 mm and 65 mm, respectively. The bond length was 150 mm to ensure that the bond failure would dominate. A plastic tube was used to debond the remaining length of the steel bar. Recesses with a length of 100 mm were made in each of the beams to measure the tensile strain of the steel bar and the slips at the load end. Fig. 1 shows the details of the test beam specimens.

The beam specimens were grouped into three series according to the stirrup spacing, i.e. 150 mm, 100 mm and 70 mm, respectively. Each group has 6 beam specimens with target steel corrosion 0, 3%, 6%, 9%, 12% and 15%, respectively. A three-part specimen designation was used. Notations I, II and III correspond to stirrup spacing; L and R denote the left and right ends of the beam specimen; 0, 3, 6, 9, 12, and 15 correspond to steel corrosion of 0, 3%, 6%, 9%, 12% and 15%, respectively. For example, "I-L-3" represents the left end of the beam specimen with 150 mm stirrup spacing and 3% target steel corrosion.

2.2. Material properties

Commercial concrete was used in this experiment. The concrete used had a cement content of 256 kg/m^3, a water-cement ratio of 0.7 and a maximum aggregate grain size of 25 mm. The concrete mix constituents are presented in Table 1. The slump was 150 mm, and the compressive strength was 30 MPa. The diameter of the tensile steel bar was 20 mm, its yield strength was 540 MPa, and the ultimate tensile strength was 671 MPa. Two 12-mm deformed steel bars with yield strength of 349 MPa were arranged at the top of the beam specimen. The diameter of the round stirrups was 6 mm, the yield strength and the ultimate tensile strength was 318 MPa and 497 MPa respectively.

Table 1
Mixture proportion of concrete (kg/m^3).

Water	Cement	Fly ash	Mineral powder	Fine aggregate	Coarse aggregate	Water reducing agent
178	256	49	56	703	1052	6.26

2.3. Accelerated corrosion

Accelerated corrosion techniques are widely used by researchers to accelerate steel bar corrosion in concrete. The durations of the corrosion period can be substantially reduced from the order of years to the order of weeks or months. In addition to saving in time and cost, the desired corrosion degree can also be easily controlled. The advantages of impressed current technique enables researchers to evaluate the effects of corrosion on deterioration of mechanical properties such as bond behavior in the laboratories. However, the suitability of the technique to model natural corrosion has been criticized. The major problem is the high current density and moisture conditions. The current densities measured on real RC structures can be as low as 0.1 μA/cm^2 [15–18], while the current densities used in the laboratories are 100 or even more times greater. Compared with natural corrosion, the high current densities will lead to different corrosion characteristics on the surface of the steel bar. Researchers have found that the impressed current densities have a significant influence on the concrete cover

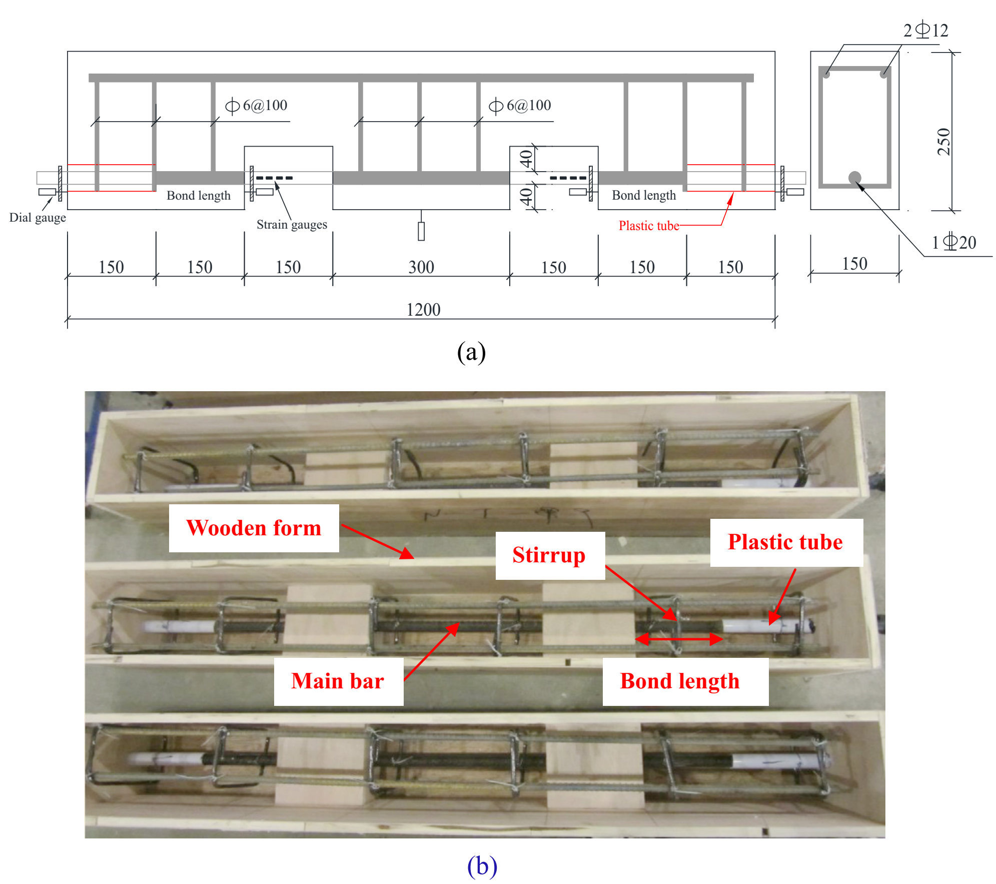

Fig. 1. Details of the test beams: (a) Geometry and reinforcement, all dimensions are in millimeters; (b) Formwork and reinforcement.