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Bond behavior of steel bar embedded in recycled coarse aggregate concrete under lateral compression load

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HIGHLIGHTS

- Bond behavior of steel bar under lateral compression load was studied.
- Two types of steel bars, four levels of lateral compressive load were considered.
- The bond strength for deformed steel bar are larger than that for plain steel bar.

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ABSTRACT

Steel bars and concrete in practical engineering is served under a complex stress state, the bond behavior of steel bar embedded in concrete, inevitably, was affected by the stress state. So, the center pull out tests were conducted to investigate the bond strength and the bond stress-slip curves of steel bar embedded in recycled coarse aggregate concrete under the action of lateral compression load. For recycled coarse aggregate concrete, the replacement percentage of recycled coarse aggregate to the sum of natural coarse aggregates and recycled coarse aggregates was 30%. The variables of two types of steel bars (deformed steel bars with diameter 14 mm, 18 mm, 22 mm and plain steel bars with diameter 12 mm), four levels of lateral compressive load (0 kN, 200 kN, 320 kN and 450 kN) were considered in the experimental study. The failure modes of center pull out specimen were observed and recorded. Based on the test results, the influences of lateral compressive stress, type of steel bars and diameter of deformed steel bars on the bond behavior of steel bar embedded in recycled aggregate concrete were studied and analysed. It was found that the pull out force and bond strength for deformed steel bar are larger than that for plain steel bar under the same lateral compressive load, the bond strength increases with the increase of lateral compressive load.

1. Introduction

1.1. Bond behavior between steel bar and concrete

In reinforced concrete members, there are two different kinds of materials, i.e. concrete and steel bar, with different physical properties and mechanical properties [1–3]. As the foundation enable two different kinds of materials work together, adequate bond behavior (strength and stress-slip) between steel bar and concrete has a profound influence on the performance of reinforced concrete members or structures [4,5] in ultimate limit state and serviceability limit state.

During the past decades, lots of researchers have investigated the bond behavior and bond mechanisms between steel bars and various types of concrete [6–9]. Rashid et al. [6] investigated the bond stress-slip behavior of steel reinforcing bar embedded in hybrid fibre-reinforced concrete. It was found that the confinement effects of hybrid fibres enhanced the bond strength of reinforcing bars embedded in hybrid fibres reinforced high performance concrete when compared to plain high performance concrete. Larrard et al. [7] investigated the bond strength between reinforcing steels and a high-performance concrete with a 28-day strength of 95 MPa. And the conclusion that the bond strength increases with the tensile strength of the concrete was got. The bond characteristics of plain and deformed bars embedded in light weight pumice

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concrete was carried out by Hossain et al. [8]. Foroughi et al. [9] studied the bond strength of reinforcement steel bars embedded in self-compacting concrete, the conclusion that bond strength for steel bar in self-compacting concrete specimens was higher than that in normal concrete specimens was got.

1.2. The influence of lateral compressive load on bond behavior

Steel bars in reinforced concrete members in practical engineering is inevitably subjected to lateral compression (such as the steel bars in slab in slab-bearing wall edge in solid walled structure, etc.), lateral tension (such as the steel bars in beam in beam-slab joints may be in lateral tension when seismic loads are considered [10], etc.), lateral tension-compression (such as the steel bars at the top in beam in the side joint in frame structure) or lateral compression-compression (such as the steel bars at the bottom in beam in the side joint in frame structure) etc. The bond behavior between steel bars and concrete will be affected by the lateral load. The influence of uniaxial lateral pressure on the bond behavior of plain round bars embedded in concrete was studied by Robins and Standish with pull out tests and beam test [11,12]. Moosavi M et al. [13] studied the bond behavior of cement grouted reinforcing bars under the action of "constant radial confining pressure". Malvar LJ [14] investigated the bond behavior of steel bar embedded in 3-in. diameter concrete cylinder under controlled confinement. The experimental study of the effect of lateral pressure on the bond behavior of deformed round bars and plain round bars was carried out by Feng Xu et al. [15], the conclusion that for plain round bars, the bond capacity increases with increase of lateral pressure, while for deformed bars, the bond capacity was influenced by the direction between lateral compression stress and transverse rib of steel bars was got. An experimental study on the bond behavior of plain round bars embedded in plain concrete under the action of lateral tension was conducted by Xue Zhang et al. [16]. The conclusion that the experimental results that the bond strength is a decreasing function of the lateral tension stress was got. According to the above experimental study and analysis on the bond behavior, it can be found that lateral load has a great influence on bond performance.

1.3. The study on bond behavior between steel bar and recycled coarse aggregate concrete

Concrete is the most commonly used constructional material in the world. However, on the one hand, the production process and transportation of concrete's constituent materials, such as cement and coarse aggregates, consume a great deal of energy. On the other hand, large amount of construction waste generates from demolished old structures during the urban construction process. Then, the ecological problems will be caused due to the disposal and removal of the construction waste. So, it is necessary to develop concrete with recycled materials from the perspective of environmental protection. Due to the great environmental effect, the study and application of recycled aggregate has become the focus in the direction of civil engineering [17,18]. Now, the percentages of construction waste recycling in Japan and Hongkong are about 85% and 50% [19,20], respectively.

According to the previous studies [21], it was demonstrated that the experimental study of bond strength of steel bars in recycled coarse aggregate concrete has been conducted, while the influence of lateral compressive load on bond strength of steel bars in recycled coarse aggregate concrete has not been studied. Compared with ordinary coarse aggregate, the strength and elastic modulus of recycled coarse aggregate is weak. And it is revealed that the material properties of recycled coarse aggregate are lower than those of ordinary concrete [22,23]. It is well known that the bond behavior is affected by the concrete type, loading conditions, rebar geometry and construction details, etc. [24,25]. Thus, it is necessary to continue the further investigation on the bond behavior between steel bars and recycled coarse aggregate concrete under lateral load.

In this paper, the experimental investigation on the bond behavior of steel bar (plain steel bar with diameter (d) 12 mm, deformed steel bar with diameter 14 mm, 18 mm and 22 mm) embedded in recycled coarse aggregate concrete under lateral compressive load (0 kN, 200 kN, 320 kN and 450 kN) through the center pull out test was carried out. Based on the results of center pull out test, the cracking process and failure mode were observed and described, bond strength and bond stress-slip curves between steel bar and recycled coarse aggregate concrete were recorded and discussed.

2. Experiment

2.1. Materials and mix proportions

In this paper, a crushed stone with a diameter 5 mm–31.5 mm as shown in Fig. 1(a) and recycled coarse aggregate as shown in Fig. 1(b) (got through crushing the old concrete member and the strength grade of the concrete in the old concrete member was C30) were used as coarse aggregate, Table 1 listed the physical properties of recycled coarse aggregates and natural coarse aggregates. The apparent density and bulk density of natural coarse aggregate was 2730 kg/m^3, 1395 kg/m^3, respectively. The apparent density and bulk density of recycled coarse aggregate was 2431 kg/m^3 and 1280 kg/m^3, respectively. The saturated water absorption of recycled coarse aggregate and natural coarse aggregate was 7.33% and 0.41%, respectively. The cubic compressive strength of the RCAC specimens at 28-day was 33.93 MPa.

In this experiment, 1) 42.5$^{\#}$ common Portland cement (the standard compressive strength at 28 days is 42.5 MPa) [26] was used, 2) natural river sand was used as fine aggregate (fineness modulus was greater than 2.6), 3) the replacement percentage of recycled coarse aggregate over natural aggregate by weight was 30%, 4) regular tap water was used as the mix water. And, the water/cement ratio was 0.56. Table 2 demonstrates the mix proportions by weight.

In the experiment, the center pull out test was carried out according to "Standard Methods for testing of Concrete Structures" GB50152-2012 [27]. One plain round steel bar (diameter is 12 mm and yield strength is 300 MPa) and there deformed (crescent ribbed) steel bars (yield strength is 400 MPa and diameter was 14 mm, 18 mm and 22 mm, respectively) and Cubic specimens (length of a side is 150 mm) were used, the steel bars are shown in Fig. 2. Fig. 3 shows the plastics mold with fixed steel bar.

2.2. Samples and testing programs

A laboratory mixer with a volume of 0.08 m^3 was used to mix the concrete mixtures. Production process of recycled coarse aggregate concrete was as follows: 1) the cementitious materials, fine aggregates and coarse aggregates were added, and then mixed for 1 min, 2) added tap water, and mixed the ingredients for 2–3 min, 3) the fresh concrete was poured into 150 mm × 150 mm × 150 mm plastics molds (center pull out concrete specimens and cube specimens) and compacted by a vibrating table, and 4) 24 h after casting, all the center pull out specimens and cube specimens were removed from plastic molds and placed into a curing room with condition of 20 ± 2 °C and 95% relative humidity for 28 days according to "Standard for test