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Bond behavior between recycled aggregate concrete and deformed bars under uniaxial lateral pressure

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HIGHLIGHTS

- The anchorage length for steel rebar embedded in RAC can be designed as NAC code.
- The bond ductility of RAC specimens was inferior to that of NAC specimens.
- Lateral pressure promotes the ductility and bond energy density of RAC specimens.

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ABSTRACT

This paper investigates the bond behavior of deformed bars embedded in recycled aggregate concrete (RAC) subjected to uniaxial lateral pressure. Sixty pull-out specimens with different levels of recycled coarse aggregate (RA; i.e. 0%, 30%, 50%, 70% and 100%) were manufactured, and then these specimens were submitted to test the bond-slip curves under different levels of uniaxial lateral pressure (i. e. 0, $0.1f_{cu}$, $0.2f_{cu}$, and $0.3f_{cu}$). The effects of lateral pressure and RA content on bond strength, peak slip, residual bond strength and bond energy density were analyzed; the bond-slip relationship between RAC and deformed bars was also established. The results demonstrated that the bond strength of reinforced RAC is comparable with that of reinforced natural aggregate concrete (NAC). It is feasible to adopt RA in structural application but the bond ductility should be improved before it can be reliable reused. With the incremental of lateral pressure, the peak slip, relative bond strength and the bond energy density gradually increased, while the relationship between these parameters and RA content could not be clearly observed. In addition, the parameter value for descending bond-slip curve was abruptly decreased after lateral pressure was applied, demonstrating that the lateral pressure increased the bond ductility of RAC specimens.

1. Introduction

There has been an international consensus on reusing demolished concrete as aggregate to reproduce recycled aggregate concrete (RAC) due to the resource shortage and the environment deterioration in the worldwide [1–3]. However, it is generally accepted that some drawbacks of RA, such as higher water absorption and causing more weakness in interfacial transition zone [4,5] degrade the mechanical properties of RAC. Furthermore, the bond performance between RAC and steel rebar, which plays an important role in structural behavior, would also be affected owing to the mechanics deterioration of RAC. Consequently the bond property of steel rebar embedded in RAC has been widely investigated [6–11]. Nonetheless, most of these literatures focused the study only on the influences of RA sources and RA content on bond behavior without lateral pressure. However, some of reinforced RAC structural members (such as beam-column joint) are usually subjected to triaxial stresses in their lifecycle. Hence it is necessary to study the bond behavior of steel rebar in RAC under lateral pressure before RAC can be reliable reused.

The steel-concrete bond performance under lateral pressure has been previously studied by other researchers. Most of these literatures stated that the bond strength was improved when the lateral pressure or confinement was applied. For example, Untrauer and Henry [12] found that the bond strength increased with the increase of lateral compressive stress, and bond strength was proportional to the square root of the lateral compressive stress. The

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similar conclusion was also obtained by Batayneh and Walker [13] according to their test results. Concerning the influence of restraint pressure, Torre-Casanova and Jason [14] studied the effect of passive (concrete cover) and active confinement (external pressure) on maximal bond strength using experimental and numerical approaches, with two equations were finally proposed to distinguish splitting failure and pull-out failure. Xu [15] and Li [16] studied the steel-concrete bond strength under lateral pressure and hysteretic loading, with results showed that the bond strength and decay of bond strength were greatly influenced by lateral pressure. Nonetheless, so far the effect of confinement on bond performance between deformed bars and RAC has not yet been clearly understood. Therefore, the goal of this study is to investigate the bond behavior of deformed bars embedded in RAC subjected to different levels of lateral pressure.

2. Experimental program

2.1. Materials and mixtures

Portland cement type 32.5 was used in this test. The natural river sand was employed as fine aggregate. The natural coarse aggregate (NA) was crushed stone bought from local commercial aggregate plant. The waste concrete originated from the demolition of road pavement was first crushed and then sieved as RA, which fell into grade II according to Chinese standard GB/T25177-2010 [17]. The physical properties of NA and RA were presented in Table 1. Deformed bars with diameter of 20 mm were used in the pull-out specimens, having a yield strength and elastic modulus of 678 MPa and 2.17×10^5 MPa respectively.

Five mix proportions, with different replacement levels of RA, were designed to obtain a comparable target compressive strength by adjusting water/cement ratio (Table 2). For each mixture, 6 cubic specimens measuring 150 mm × 150 mm × 150 mm were casted to test the 28-day compressive strength and splitting tensile strength, the mean values of these measured mechanical parameters and the slumps of fresh concrete were also listed in Table 2.

2.2. Specimens and test

The pull-out specimens were casted with a deformed bar placed in the center of the concrete block (Fig. 1), the embedment length of deformed bar was 5d (d is diameter of deformed bar). Five RA replacement percentages (0%, 30%, 50%, 70%, and 100%) and four different levels of lateral pressure (0, 0.1fcu, 0.2fcu, and 0.3fcu) were considered in this test. In total, 20 groups with 60 specimens were manufactured. All the specimens were cured for 28 days and then submitted to pull-out test.

The pull-out tests were conducted in a servo static/dynamic triaxial machine (TAWZ-5000/3000). During the test, lateral load was applied first with rate of 2 kN/s until it reached to the expected value, and then the pull out force was gradually applied with displacement rate of 0.5 mm/min. In addition, four displacement sensors were installed to measure the relative slips between deformed rebar and concrete at both ends, two for each end, details can be seen in Fig. 2. Displacement data were recorded using a static strain acquisition instrument synchronized to the vertical loading.

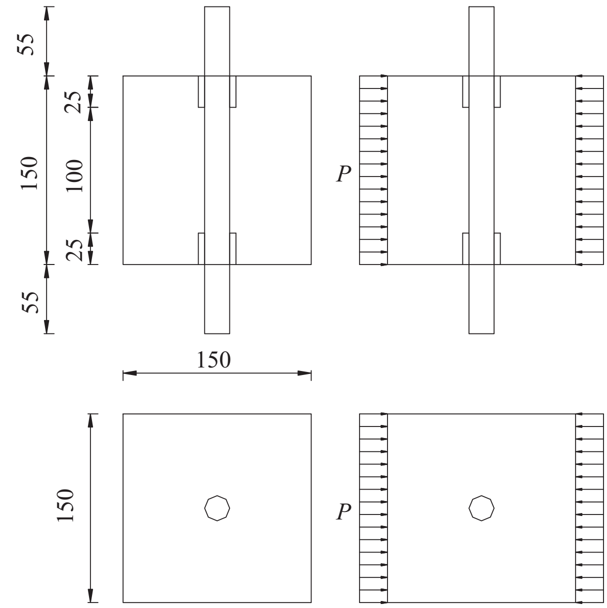

Fig. 1. Pull-out specimen.

3. Results and discussion

3.1. Failure patterns and the mechanical mechanism

The typical failure patterns of pull-out specimens are shown in Fig. 3. As can be seen from Fig. 3, two different failure patterns can be obviously observed for the specimens with and without lateral pressure. The specimens without lateral pressure were split along the radial direction accompanied by several main cracks, which can be classified as splitting failure. This is due to the relative slip occurred at the interface between deformed bars and RAC block, resulting in the extrusion of RAC (ahead of ribs) along the radial direction. For the specimens with lateral pressure, only one main crack was observed and it was nearly perpendicular to the lateral pressure surface. The deformed bar was finally pulled out from the concrete block, which can be classified as splitting-pull out failure. Another difference was that the crack width for the specimens with lateral pressure was obviously smaller than those specimens without lateral pressure.

According to the research conducted by Zhao [18], the main stresses in concrete were hoop stress (σ_φ), radial stress (σ_ρ) and

Table 1
Physical properties of coarse aggregate.

Aggregate type	Size (mm)	Apparent Density (kg/m^3)	Bulk density (kg/m^3)	Water Absorption (%)	Crushed index (%)
RA	5–26.5	2606	1325	4.54	12.6
NA	5–26.5	3105	1521	0.35	11.4

Table 2
Mixtures.

No.	R (%)	W/C	Ingredients (kg/ m^3)						Slump (mm)	f_{cu} (MPa)	f_t (MPa)
			C	S	NA	RA	W	AW			
NAC0	0	0.46	402	544	1269	0	185	0	48	45.41	2.88
RAC30	30	0.39	475	522	853	365	185	18	35	44.41	2.73
RAC50	50	0.38	487	518	605	605	185	30	30	44.93	2.67
RAC70	70	0.37	500	515	360	840	185	42	28	44.79	2.54
RAC100	100	0.35	529	506	0	1180	185	59	23	45.92	2.80

Note: R is RA replacement percentage, C is cement, S is sand, W is mixing water, AW is additional water, f_{cu} is compressive strength. f_t is tensile strength.