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Experiment study on bond slip behavior between section steel and RAC in SRRC structures

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HIGHLIGHTS

- Design of recycled concrete and profiled steel structure.
- Influence of recycled aggregate replacement ratio and strength of recycled aggregate concrete on bond slip.
- Influence of cover thickness and embedment length on bond slip.
- The bond strength increases as the thickness of the protective layer increases.

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ABSTRACT

Twenty-seven standard push-out specimens which were designed based on orthogonal design method to study bond-slip behavior between section and RAC (Recycled Aggregate Concrete) in SRRC (Steel Reinforced Recycled Concrete). Test results showed: In terms of failure mechanism and failure pattern, SRRC was similar to SRC, experiencing no-slipping, slipping, destroying, decline and residual stage. Average bond strength of SRRC was influenced by RCA, RAC strength, embedment length as well as thickness of concrete cover of SRC in some degree. Based on test data, the calculation formula of bond strength was established by statistical fitting. Compared with the test results, the calculation results could satisfy computational accuracy.

1. Introduction

Recycled aggregate concrete is a new type of concrete that is configured by replacing all or part of natural aggregate with recycled aggregate. Recycled concrete can consume a large amount of waste concrete to solve the shortage of natural aggregate resources [1]. According to the existing published literature, it can be found that recycled concrete is lighter than ordinary concrete but has low structural bearing capacity and small stiffness of the component [2–4]. Therefore, the use of recycled concrete with low self-heavy weight combined with good-quality steel is applied in construction projects, which not only reduces the overall weight of the structure, but also solves the problem of poor bearing capacity and stiffness. In this way, the advantages of sustainable use of recycled concrete resources have been brought into play, and the design goals for the best use of resources have been achieved.

At present, foreign scholars have relatively little research on steel reinforced recycled concrete. A lot of research results have been made on the bond-slip properties of ordinary concrete for steel sections. However, there are common problems in the study process that have insufficient accuracy of bond-slip tests and affect the final test results [5–9]. Yang et al. [5] and Zheng et al. [6,7] carried out standard steel concrete standard launch tests and solid abdominal steel concrete pull tests. Studies have shown that the concrete strength grade, the length of the embedded steel section, the lateral stirrup ratio, and the thickness of the concrete protective layer are the main factors affecting the bond slip performance. The internal steel strains are exponentially distributed and linearly distributed in the rising stage and the falling stage of the load. According to the experimental derivation of the bond strength calculation method is to meet the structural design accuracy requirements. Zheng et al. [8] carried out the outsourcing steel reinforced concrete launch test. Experiments have found that the concrete strength grade, contact surface state and contact length are the important factors affecting the bond strength. Wang et al. [9] conducted the test of steel-concrete specimens at a constant high temperature. The results show that the ultimate slip load and residual load of the shaped steel concrete are significantly lower than those

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at room temperature, and the decline is fastest at 20 to 200 °C, and the sliding load at 200 °C is gentler.

Scholars from various countries have conducted active research on the bond-slip properties of reinforced recycled concrete. Research found that the bond-slip performance of recycled concrete and steel bars is quite different from ordinary concrete. From this, it can be inferred that the bond-slip performance of shaped steel recycled concrete will be greatly different [10–13]. Prince et al. [14] and Liu et al. [15] conducted tests on the bond-slip properties of recycled aggregate concrete and steel bars. Based on the regression analysis of the experimental data, the empirical bond stress-slip relationship between RCA concrete and deformed rebar is proposed, and the conclusion is drawn that the strength of recycled concrete is higher than the performance and ultimate adhesive stress in the mechanical effect. Bomphe et al. [16] and Eiras-Lopez et al. [17] conducted experiments on the bond-slip performance of recycled concrete with different replacement ratios and water-cement ratios. The study found that the replacement rate of recycled coarse aggregates significantly affects compressive strength and bond performance.

At present, studies on the bond-slip properties of steel reinforced recycled concrete in various countries are rarely reported [18–19], and the research carried out is limited to the bearing capacity performance of steel reinforced recycled concrete. Zhang et al. [20] carried out the bending test under the repeated load of a compressed steel plate reconstituted coarse aggregate concrete composite beam and two steel-pressed steel plate ordinary concrete composite beams. The test results show that the performance of recycled concrete composite beams is inferior to that of ordinary concrete components with the increase of the replacement ratio of recycled coarse aggregates.

In summary, this paper adopts a bond-slip test device with higher measurement accuracy to launch the experimental study of steel reinforced recycled concrete. Based on the main factors of the ratio of recycled coarse aggregates, concrete strength, and steel embedded length, the study on bond slip mechanism and bond strength calculation method for recycled steel reinforced concrete is carried out.

2. Testing situation

2.1. Test material

The test materials used were PC32.5R ordinary portland cement, natural coarse aggregate, recycled coarse aggregate, natural fine aggregate, general fine sand and urban tap water. The recycled coarse aggregate was provided by Shaanxi Jianxin Technology Environmental Protection Co., Ltd. The physical properties of recycled coarse aggregates, natural aggregate and sand are shown in Table 1. The mix ratio of recycled concrete and its measured strength are shown in Table 2. The elastic modulus and strength of the combination H-section steel with No. 10 channel steel and 6 mm thick steel plate are shown in Table 3.

2.2. Specimen design

Twenty-seven standard test specimens were designed using the orthogonal method [21]. The test specimen number and design are shown in Table 4, and the test specimen cross-section is shown in Fig. 1. The test piece mainly analyzes the four major factors (replacement ratio of recycled coarse aggregate *r*, compressive strength of recycled concrete *fc*, thickness of shaped steel protective layer *Css* and length of embedded steel *le*) on the bond-slip performance between section steel and recycled concrete. The combined H-beam is formed by bonding two 10-slot steel and two 6-mm-thick steel plates with epoxy resin.

2.3. Loading scheme

The steel reinforced concrete launch test [22] was carried out on a 500 t pressure testing machine in the structural laboratory of Xi'an University of Architecture and Technology. The loading device is shown in Fig. 2. The experiment was carried out by means of monotonically loaded displacement control. The loading rate was 0.3 mm/min. The lower end of the recycled concrete was fixed on the test bench by the support and the upper end was free. When loading, the test pedestal pushes up the recycled concrete, and the upper end of the shaped steel is fixed with the pressure testing machine so as to bear the load from the test pedestal. Therefore, the upper end of the section steel is the loading end and the lower end is the free end. When the steel is pressed into the recycled concrete in about 30–40 mm, the load is stopped when the recycled concrete at the loading end shows a clear peeling tendency.

2.4. Test measurement

2.4.1. Measurement of bond stress

The resistance strain gauges are distributed at equal intervals at the loading end in order to study the bond-slip stress of the connection between steel section and recycled concrete in the experiment. The distance is 50 mm and the spacing can be increased near the free end. This can ensure that the bonding properties between steel and recycled concrete are not changed and the measurement accuracy of the strain gauge can be ensured. As shown in Fig. 3.

Table 1
Recycled coarse aggregate physical properties.

Aggregate type	Apparent density/kg.m^{-3}	Crushing value/%	Moisture content/%	Water absorption/%	Intact stone/%	Secondary aggregate/%	Mortar block/%	Impurity/%
Recycled coarse aggregate	2458	17.0	1.33	3.83	29.5	51.2	16.0	3.3

Natural aggregate physical properties

Aggregate type	Apparent Relative density/kg.m^{-3}	Relative density/kg.m^{-3}	Water absorption/%	Unit weight/kg.m^{-3}	Moisture content/%
Natural aggregate	2800	1492	1.91	1.65	3.48

Sand physical properties

Type	Apparent density/kg.m^{-3}	Bulk density/kg.m^{-3}	Mud content/%	Mud block content/%
Sand	2580	1440	1.8	1.0