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Numerical Prediction for Bond Stress-Slip Relationship Between Deformed Steel Rebar and Recycled Coarse Aggregate Concrete

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Abstract

To assess the bond behavior of deformed steel bars in recycled aggregate concretes (RACs), pullout test curves were compared with the curves predicted using the equation proposed by Haraji and Guo. The test curves are well predicted by the numerical manner, which demonstrates that the overall bond stress-slip relationship of deformed steel rebar in RAC could be expressed numerically. For each recycled aggregate replacement level, the value of parameter *a* for the ascending branch is found to lie in a narrow range and does not indicate any particular tendency. However, from the *b*-values of steel rebar at upper part of concrete, it can be inferred that the RAC could exhibit lower energy absorption capacity than conventional concrete.

Keywords: Recycled aggregate concrete, Bond stress-slip relationship, Numerical prediction, Energy absorption capacity

1 Introduction

A great number of waste materials that pollute the environment are produced by the demolition of old buildings. To reduce the impact of concrete construction on the global environmental problems and conserve natural resources, production of concrete using recycled materials has been increasingly promoted for the past decades.

Steel-to-concrete bond is one of the most important factor for structural property of reinforced concrete because the bond is responsible for transfer of axial force between steel rebar and concrete thereby ensuring strain compatibility and their composite action. The bond behavior between the two materials is influenced by chemical adhesion and bearing strength between steel rebar and surrounding concrete. Although bond behavior between normal concrete and steel rebar has been extensively studied [1-3] and numerically predicted in the past [4-5], relatively few analytical investigations on bond between recycled concrete and steel rebar [6-7] have been reported, primarily due to the small experimental data base for steel-to-RAC bond response.

The main objective of this study is to determine the effect of replacing natural coarse aggregates with recycled coarse aggregates (RCAs) on steel-to-concrete bond strength with a deformed steel rebar. In addition, the steel-concrete bond strength at various concrete depths (75 mm and 225 mm) was considered in order to investigate the top-bar effect on the parameters for numerical prediction. This analytical study consists of comparing the bond performance of four RAC mixes designed at different replacement levels at one strength level (specified compressive strength of 27 MPa). The measured bond stress-slip responses of the deformed steel bars [8] were used to determine a numerical bond stress-versus-slip relationship between the RAC and the deformed steel rebar. With the parameters for numerical prediction, the practical usage of RAC in various fields would be increased.

2 Analytical predictions for steel-to-concrete bond-slip relationship

For the analytical predictions of the bond-slip relationship of RAC, the following dimensionless bond stress ($\bar{\tau}$) and slip ($\bar{s}$) parameters of Xiao and Falkner [7] are used:

$$\bar{\tau} = \frac{\tau}{\tau_0}, \qquad \bar{s} = \frac{s}{s_0} \tag{1}$$

where τ_0 is the peak bond stress (i.e., bond strength), and s_0 is theslip corresponding to the τ_0. Based on comparisons with the test results, the normalized bond-slip relationship of RAC can be expressed approximately as;

$$\bar{\tau} = \begin{cases} (\bar{s})^a & \bar{s} \le 1 \\ \dfrac{\bar{s}}{b(\bar{s}-1)^2 + \bar{s}} & \bar{s} > 1 \end{cases} \tag{2}$$

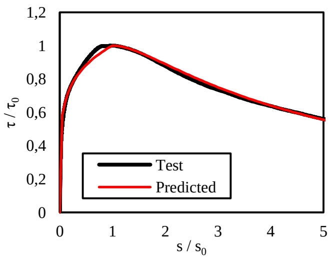
where *a* is a function of the slope of the ascending branch and *b* is related to the area under the descending branch of the stress-strain curve. Equation (2) was proposed by Haraji [4] and Guo [5] for normal concrete. In this study, Equation (2) has been adapted for modeling the bond–slip relationship of RAC by modifying the parameters *a* and *b* on the basis of a regression analysis of the test data [8].

3 Analysis Results and Discussions

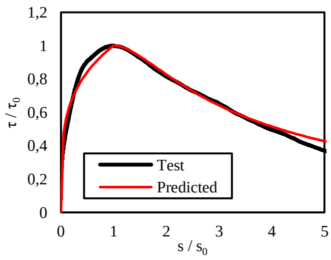
Figure 1 presents the average test curves and the curves predicted analytically using the equation (2) for pullout test specimens, and the values of regression parameters *a* and *b* are reported in Table 1. It was found that the test curves are well predicted by the equation (2), which demonstrates that the equation (2) can be applied to predict numerically the overall bond behavior of RAC with deformed steel rebar. Because of the similarity in the ascending portions of the measured bond-slip curves of the pullout specimens, the parameter *a* was found to lie in a narrow range for each of the RCA replacement level. The parameter *a* for the ascending branch does not indicate any particular tendency as reported in other research [6-7].

As listed in Table 1, parameter *b* of HB series slightly higher than that of V series. And it is found from the parameter *b* related to the area under the descending branch that the energy absorption capacities of the RAC pullout specimens are not significantly different from those of the normal concrete when deformed steel rebar is located in the lower part of the concrete member (V or HB series).

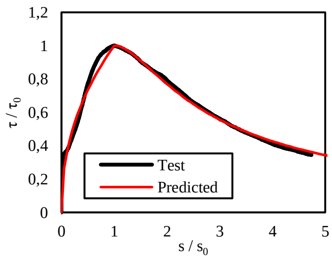
However, from the variation of the *b*-values in the case of deformed steel rebar located in the upper part of the member (HT series), it can be inferred that the energy absorption capacity of the RAC-30 is higher than that of the normal concrete.



(a) RAC-0V



(b) RAC-0HB



(c) RAC-0HT

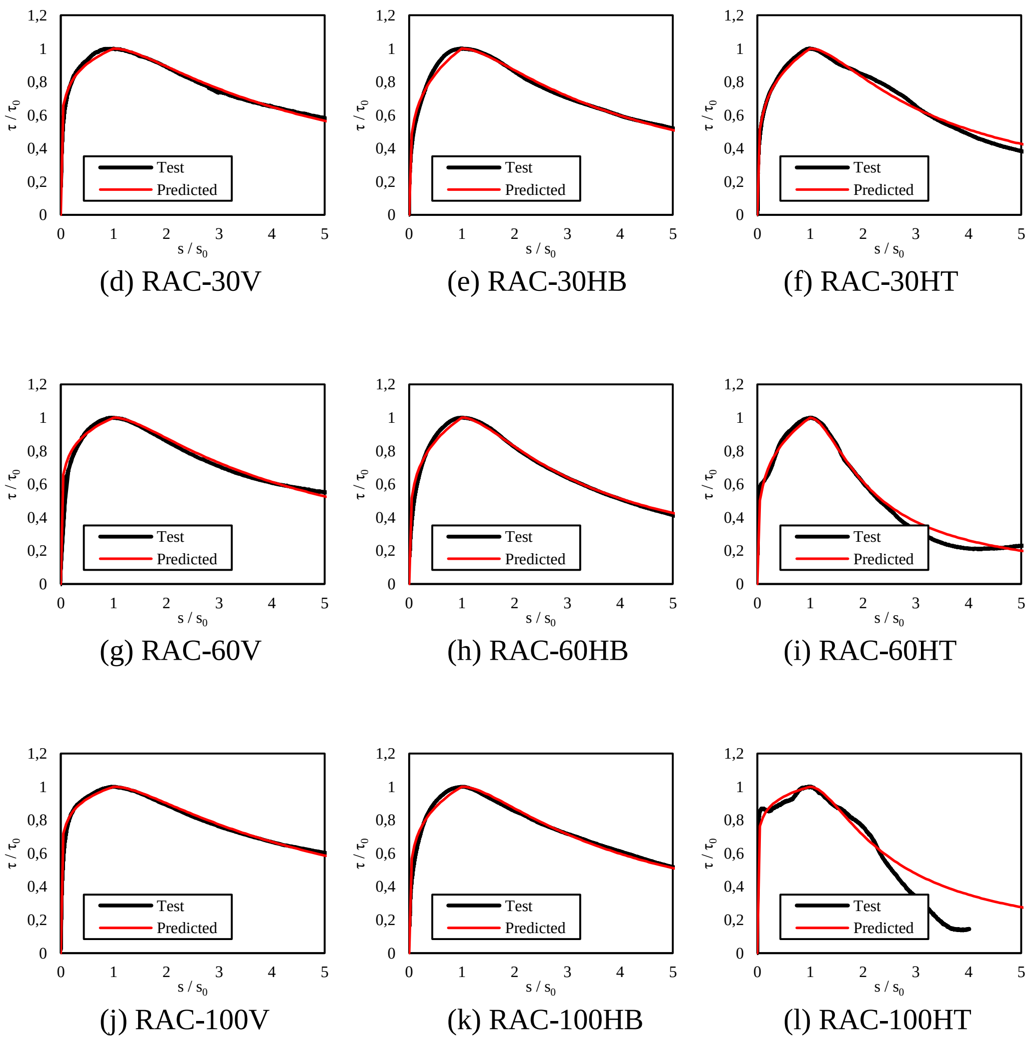
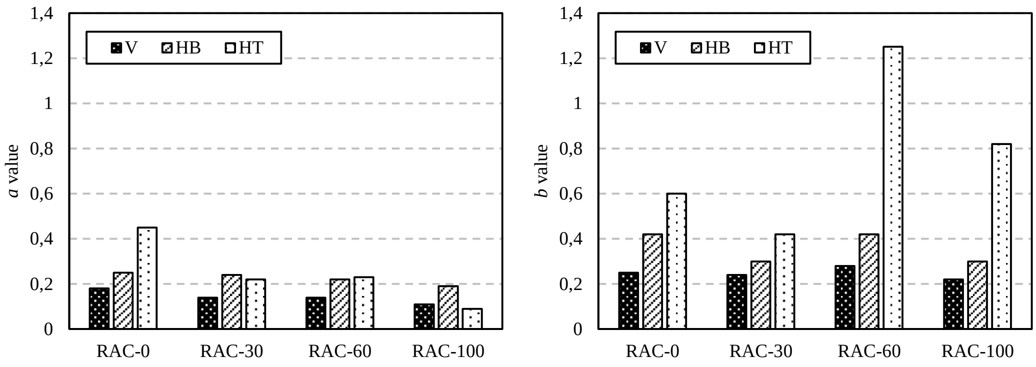


Figure 1. Typical comparisons of predicted bond behavior and test results

As shown in Figure 2, it can also be seen that the energy absorption capacity increases up to 30% of RCA replacement level. However, for 60% and 100% of RCA replacement level, the energy absorption capacity significantly decreases. In particular, the decrement is much more serious for the deformed steel rebar located in the upper part of the member. This means that the top-bar effect coefficient suggested by the ACI and CSA code provisions [9-10] are valid for the development and splice length of steel rebar embedded in RAC.



(a) Parameter *a* (b) Parameter *b*

Figure 2. Comparison of parameters

Table 1. Regression parameter *a* and b

Specimen	Parameter *a*			Parameter *b*		
	V	HB	HT	V	HB	HT
RAC-0	0.18	0.25	0.45	0.25	0.42	0.60
RAC-30	0.14	0.24	0.22	0.24	0.30	0.42
RAC-60	0.14	0.22	0.23	0.28	0.42	1.25
RAC-100	0.11	0.19	0.09	0.22	0.30	0.82

4 Conclusion

The following conclusions can be drawn on the basis of the analytical results.

1) The bond-slip relationships of the RCA concretes were accurately predicted by modifying the parameters *a* and *b*.

2) The parameter *a* for the ascending portions of the measured bond-slip curves of the pullout specimens was found to have the similarity for each of the RCA replacement level.

3) While the energy absorption capacity increases up to 30% of RCA replacement level, those significantly decreases for 60% and 100% of RCA replacement level. From this results, it can be inferred that longer development and splice length of steel rebar would be required for ensuring strain compatibility and their composite action between steel rebar and RAC.

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