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Discussion of "Bond of Reinforcement in Concrete Incorporating Recycled Concrete Aggregates" by Liam J. Butler, Jeffrey S. West, and Susan L. Tighe

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In view of the increasing interest in using recycled concrete aggregates (RCAs) as coarse aggregate for structural concrete, and considering the need for identifying the key aggregate properties that may be used as indicators of their potential performance in structural concrete, the discussed paper pinpoints the RCA and RCAconcrete properties that have the greatest influence on the bond of reinforcing steel to concrete. We would like to compliment the authors for having carried out such a thorough experimental research leading to valuable findings and useful information for providing guidance on the evaluation and impact of several RCA sources on the bond of reinforcement in structural concrete. The discussers would like to contribute the following comments and questions for their consideration and response, mainly about bond testing and statistical evaluation of bond results.

The authors have tested a total of 48 beam-end specimens to measure the bond strength and slip properties of several concretemixes. Although beam-end specimens are intended to recreate the concrete and reinforcing steel stress states present at the end of a reinforced concrete flexural member, the authors have introduced some boundary conditions, as follows: (a) bond breakers were installed at the specimen surface in order to prevent conical failure at the loaded end; (b) two 20M bars were placed in the same plane of the bar being pulled out to provide adequate reinforcement against crushing of concrete; and (c) shear reinforcement was placed in the same plane as the longitudinal reinforcement so as not to intercept any longitudinal splitting crack resulting from bond failure. Regarding these three conditions, the discussers would to point out the following. (a) As shown in Fig. 3 of the discussed paper, two PVC bond breakers were placed at both ends (loaded end and free end) of the bar to be pulled out. However, it seems that the bonded length of the bar test and the lengths of the PVC bond breakers present some inconsistencies. Should not the bonded length be centered longitudinally, instead of being closer to one end than the other? Why do the two PVC bond breakers have different lengths? We suppose that the longer bond breaker corresponds to the free end of the specimen and that its length is determined by the compressive reactions plate (Fig. 4). However, this is not clearly stated and, furthermore, the local stress state generated may affect the bonded length as well. In addition to that, the relative positions of the different bonded lengths tested (125, 375, and 450 mm) with respect to the stirrups is not clear from the figures and data provided in the paper. (b) The two 20M bars have a higher cross-sectional area than the test bar, whereas the authors detailed that the 20M bars provided one half of the cross-sectional area of the test. (c) Stirrups are commonly used to provide confinement, and they are placed around the longitudinal reinforcement. However, stirrups were placed in a particular manner: in the same plane as the longitudinal reinforcement and without longitudinal reinforcement in their corners. In these conditions, it seems that the stirrups do not contribute to confinement and therefore could be eliminated. In order to offer a better understanding of the test setup, can the authors provide additional details on these topics?

The authors have not explained why they eliminated the contribution of confining effects to bond strength in their test. In this way, splitting failures have occurred in all cases reported, as expected, because the cover: diameter ratio is always less than 2.5—the minimum reference value that ACI 318-11 code (ACI 2011) establishes to prevent splitting failures. Since splitting failure can occur before bond stresses have been activated along the entire embedded length, it is not possible to know the length of rebar that is actually bonded to concrete. Perhaps this represents a problem for the analysis of experimental results, because bonded length is one of the main variables included in the experimental program, but its real value remains unknown. The authors used three linear variable differential transformers (LVDTs) to measure slip, one of them at the bottom of the specimen to measure free-end slip. However, the discussers have not found sufficient information in the paper to understand how the measured slips at both ends were considered in the analyses of test results. A displacement rate of 0.3 mm/min was used to monitor the behavior after slip for each specimen, and to ensure that slip or other failure did not occur less than 3 min after the start of the test.Was this displacement rate applied to the loaded end or to the free end of the test bar? Has the elastic strain of the rebar been considered to calculate the slips at both ends? Finally on this topic, it is noteworthy that a splitting failure implies a premature end of the complete bond potential. Then, the yield strength of the test bar (467 MPa for the 25M test reinforcing bars used) may be not achieved. By way of example from data included in Table 4, the maximum bond force values (T_b) of 70, 170, and 190 kN can be assumed as representative for the three groups of specimens based on bonded length of 125, 375, and 450 mm, and the corresponding tensile stresses in the tested bar are 140, 340, and 380 MPa, respectively, all of them less than the yield strength of the tested bar (467 MPa), which requires a T_b of 233.5 kN.

The abstract points out that 14 separate concrete mixtures were evaluated, but from Tables 2 to 4 it seems that the reported results comprise 12 concrete mixtures at 4 compressive strength levels each. For this reason, the authors have used normalized T_b values with respect to $(f_c')^{1/4}$ when comparing experimental results between them and to predictive bond equations. However, as discussed in the previous paragraph, these T_b values are probably not consistent regarding the following circumstances determining bond phenomena: length along which bond stresses are activated, whether the yield strength of steel is reached or not, and the end-slip values measured. The authors detail that an excellent correlation (R^2=0.98) between the maximum bond force and the bonded length was found. The authors state that this fact can be explained based on an increased surface area—over which the reinforcing bar is bonded to concrete—as the bonded length increases, which reduces the average bond stress between the bar and the surrounding concrete. It is worth mentioning that R^2=0.97 (less than 0.98) between the normalized maximum bond force and the bonded length implies that the normalization applied does not improve correlation. However, as shown in Fig. 1 in this discussion, R^2=0.57 is obtained between the normalized average bond stress—based on the equilibrium of forces and the uniform bond stress distribution hypothesis along the entire bonded length, which is generally accepted—and the bonded length. In this case, R^2=0.54 (less than 0.57 as expected) when unnormalized average bond stress values are used.

Figs. 9 to 11 (of the discussed paper) present comparisons between experimental and predicted normalized maximum bond force by using Eqs. (5)–(7), respectively. These equations are based on bonded length. Fig. 9 does not include an R^2 value, which is 0.994; an R^2=0.981 is included in Fig. 10 (it seems that some data are missing); and R^2=0.972 is shown in Fig. 11. However, the R^2=0.984 is obtained in Fig. 12 when the ACV parameter is considered in addition to the bonded length. Therefore, it seems that bonded length is a main parameter, whereas ACV remains as a secondary parameter. Perhaps this fact is related to the poor correlations obtained for the relations between normalized maximum bond force and concrete properties, as shown in Figs. 6 to 8 (of the discussed paper).

In light of the interest of this topic, it is suggested to carry out a similar study on specimens that do not experience splitting failures. To this end, imposing good confinement conditions to prevent concrete splitting, such as concrete cover values not less than 5 times the reinforcing bar diameter (FIB 2010; García-Taengua et al. 2011), is suggested for future research.

References

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Figures

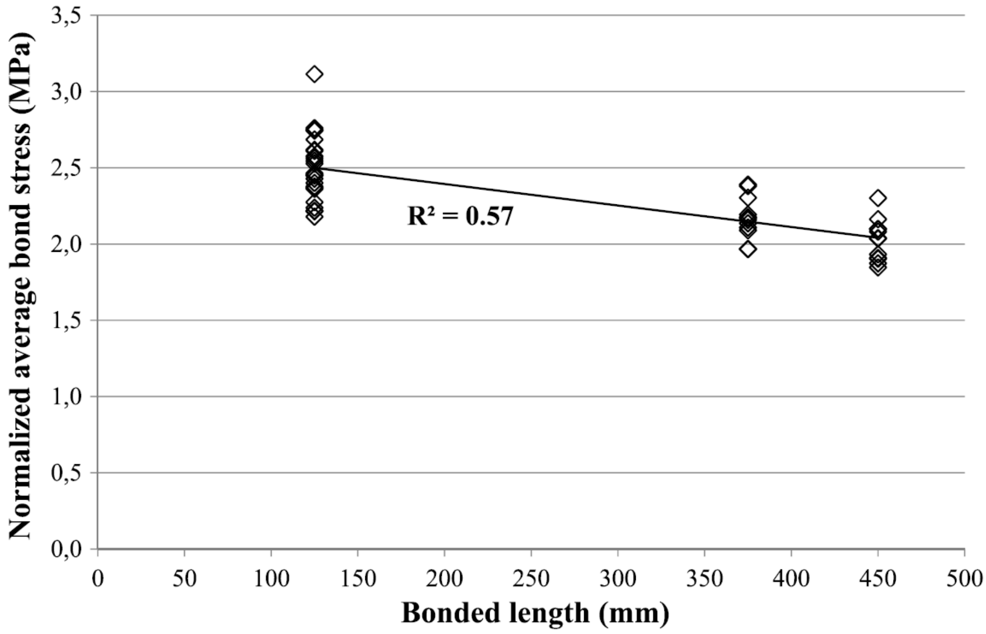

Figure 1. Relationship between normalized average bond stress and bonded length.