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THE SHEAR STRENGTH OF 50 MPA CONCRETE BEAMS MADE USING RECYCLED CONCRETE COARSE AGGREGATES

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Five 50 MPa longitudinally reinforced beams were loaded in a four-point testing setup to study their shear behavior. The beams were three meters long, and their cross section was 150 mm by 420 mm. The testing region did not contain stirrups. The beams were shallow, with a span to depth ratio of 3. All beams were similar except for the percentages of replacement of natural coarse aggregates with recycled concrete coarse aggregates, which were 0%, 10%, 20%, 35% and 100%. The results have shown that the replacement of natural coarse aggregates with recycled ones had a negligible effect on the ultimate shear strength. However, the results on the modulus of elasticity showed a reduction of less than 10% in beams with the use of recycled aggregates.

Keywords: Recycled Aggregates, Reinforced beams, Modulus of elasticity.

1 INTRODUCTION

The full and partial replacement of the natural coarse and fine aggregates with recycled alternatives has been proven to be a feasible option. Crushed old concrete provides a good source of such recycled materials (Rahal 2007, De Juan *et al.* 2009).

The bulk of research has focused on full and on relatively large percentage of replacement of natural coarse aggregates (NCA) with recycled concrete coarse aggregates (RCA). However, in many countries around the world, there is a large demand on coarse aggregates while the supply of RCA can be limited. In addition, the full replacement or the relatively large percentage of replacement may have a significant effect on the engineering properties of the recycled aggregate concrete (RAC) (Rahal 2007, Etxeberria *et al.* 2007). In many cases, relatively smaller replacement can be of practical value.

The aim of this research is to study the effect of using RCA on the shear strength of longitudinally reinforced concrete beams. The study focuses on the effects of relatively small percentages of replacement.

2 EXPERIMENTAL PROGRAM

Five longitudinally reinforced beams were cast and tested to failure under a four-point loading setup with a shear span to depth ratio of 3. Table 1 and Figure 1 provide the basic details about the specimens. The beams were 150 mm by 420 mm in cross section. The effective depth *d* was 387 mm and the longitudinal reinforcement ratio was about 1.04%. The target compressive strength of the concrete was 50 MPa, and. The main difference between the five specimens was the percentage of replacement of the NCA with RCA, which was 0%, 10%, 20%, 35% and 100%. The table shows that the focus was on relatively low percentages of replacement.

To minimize the possible variation in the test results, the side of the beam opposite to the test region was reinforced with stirrups in order to guarantee failure in the selected test region side.

Table 1. Properties of the beam specimens and summary of results.

Specimen	**RCA (%)**	f_{cu} (MPa)	f_{cy} (MPa)	E_c (MPa)	V_u (kN)	$\frac{v_u}{\sqrt{f_{cu}}}$	**Ratio R**	$\frac{v_u}{\sqrt{f_{cy}}}$
50-A-0-00r	0	52.3	55.5	30150	64.8	0.154	1.00	0.150
50-A-0-10r	10	50.3	47.8	28260	68.7	0.167	1.08	0.171
50-A-0-20	20	47.3	44.9	25600	66.2	0.166	1.07	0.170
50-A-0-35	35	48.2	47.0	23870	69.4	0.172	1.12	0.174
50-A-0-100	100	47.3	44.4	24560	61.2	0.153	0.99	0.158

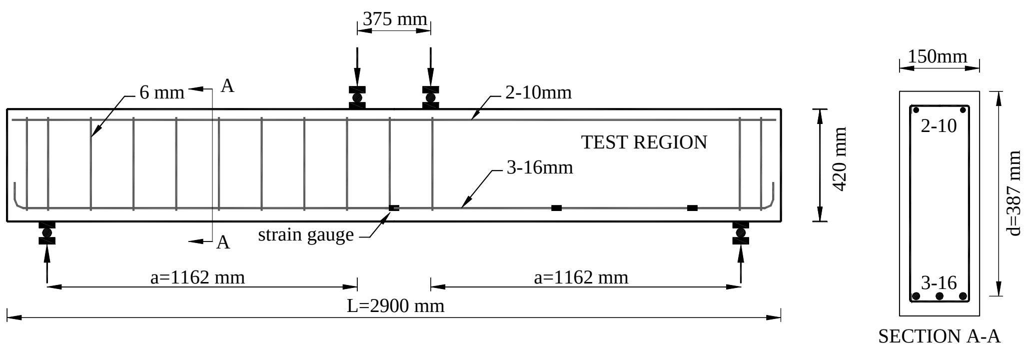

Figure 1. Details of the beam specimens and test setup.

2.1 Concrete and Steel Materials

The concrete proportions included 410 kg of cement, 705 kg of sand and 1100 kg of coarse aggregates in a cubic meter. The water cement ratio ranged from 0.35 for the 100% RCA concrete to 0.4 for the NCA concrete. A high range superplasticizer was added to obtain a slump suitable for the ease of casting. The coarse aggregate grades were 9.5 mm, 12.5 mm and 19 mm. When NCA were replaced by RCA at a certain percent of replacement, the replacement affected the quantities of the three grades equally.

Standard cylinders and 150 mm cubes were cast from the same concrete batch as the beams. All concrete was cast in the laboratory and was compacted using an electrical vibrator. After casting, the steel molds were covered with wet burlap and plastic sheets to control the moisture. The specimens were de-molded after 24 hours, but their moist curing continued till the age of 7 days. After that, the moist curing was discontinued and the concrete specimens were stored in lab conditions waiting testing. Samples from the 16-mm bars longitudinal steel were tested and the average yield strength was 565 MPa and the average ultimate strength was 668 MPa.

2.2 Instrumentation and Testing

Strain gauges were installed on the reinforcing steel bars at locations shown in Figure 1. During testing, the vertical deflections at midspan of the beam specimens were measured. The load was applied at a rate of 0.15 kN/s. The loading was paused at every 10 kN of loading in order to record the measurements and mark the cracks.

3 RESULTS

Table 1 provides a summary of the experimental results, while Figures 2 and 3 provide further details of the effects of the replacement on the various properties of the concrete.

3.1 Modulus of Elasticity

The modulus of elasticity E_c was measured in the standard cylinders which were cast from the same concrete as the beams. Table 1 gives the average values. Figure 2 plots the results of the modulus of elasticity tests, normalized with respect to the square root of the cylinder compressive strength. It is shown that the use of recycled aggregates causes a reduction in the modulus of elasticity that reached 14%.

Typically, the modulus of elasticity is related to the square root of the compressive strength of the cylinder. For example, the ACI building code (ACI 2011) recommends calculating the modulus of elasticity of normal strength concrete using Eq. (1).

$$E_c = 4700\sqrt{f'_c} \tag{1}$$

Figure 2 also plots the calculations of this equation. It is shown that for the materials used to produce the concrete for this study, this equation over-estimates the modulus of elasticity.

3.2 Ultimate Shearing Strength

Figure 3 plots the ultimate shearing strength v_u normalized with respect to the concrete strengths (both the cube and the cylinder strengths). The figure shows that the use of RCA did not cause any detrimental effect on the shearing stresses. In fact, the normalized strengths of beams with partial use of recycled aggregates were in general larger than that of the control test, and the difference ranged from 7% to 12%. The control specimen was stronger than the specimen with 100% replacement by a marginal difference. However, these results need to be carefully interpreted, with due considerations to the typical variations encountered in testing for the shear strength of concrete (Yu *et al.* 2015, Rahal 2006), especially concrete not reinforced in the transverse direction.

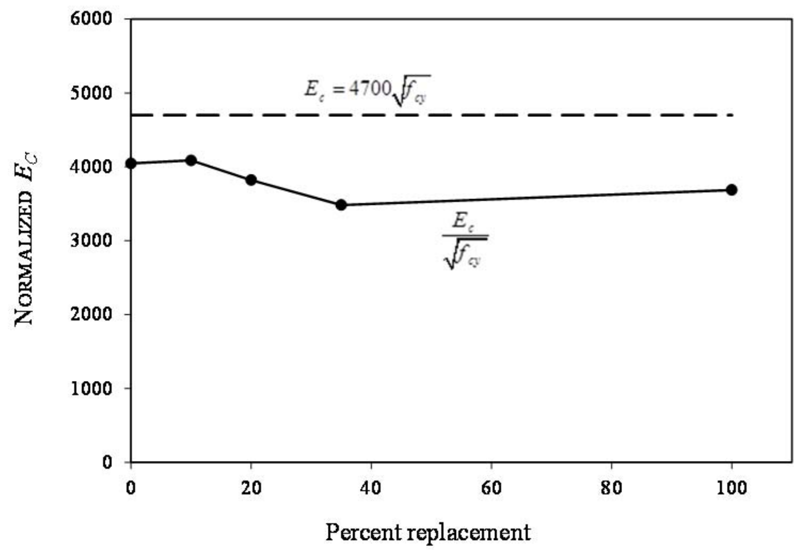

Figure 2. Results on the Modulus of Elasticity of concrete.

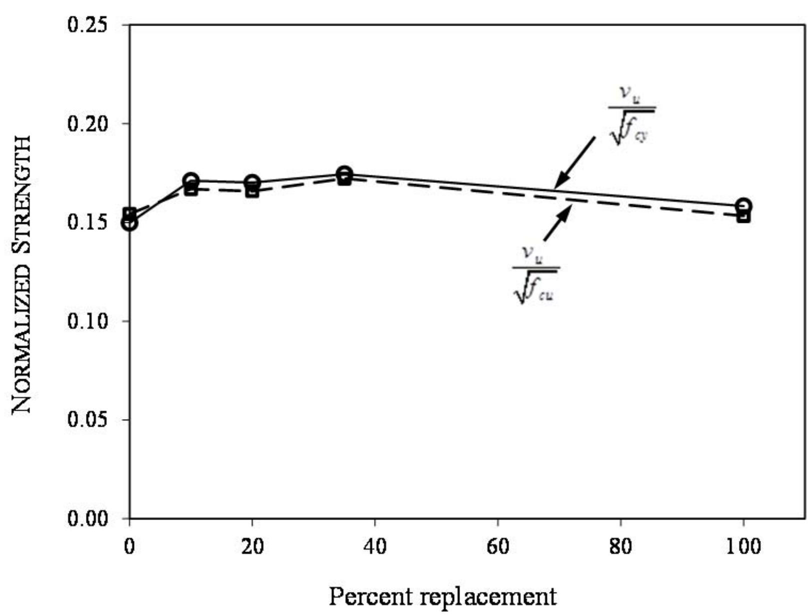

Figure 3. Normalized ultimate shearing strength.

It is to be noted that in a previous study (Rahal and Alrefaei 2015) on longitudinally reinforced beams of similar dimensions but lower concrete strength (35 MPa), the tests have shown a more obvious effect on the shearing strength. A 20% replacement caused a 17.5% decrease in shearing strength, and an obvious effect on the shear deformation in the beams.

4 CONCLUSIONS

A series of five beams with various percentages of replacement of natural coarse aggregates with recycled coarse aggregates were cast and tested to failure in shear. The percentages ranged from 0% to 100%, with emphasis on relatively lower values.

The replacement of NCA with RCA caused a slight reduction in the modulus of elasticity of concrete reaching about 14%.

The replacement caused no significant reduction in the shearing strength. In fact, the beams with partial use of recycled aggregates resisted shearing strengths which were slightly stronger than the control beam by 7 to 12%. However, this result needs to be carefully interpreted especially given the normal variations encountered in shear testing.

Acknowledgments

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