Analysis of Crack Propagation in Concrete Containing Recycled Concrete Aggregates

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Research Background

The use of RCA in concrete has thus far been limited mainly to non-structural applications due to concerns related to quality, structural performance, and durability. The purpose of this research is to expand current knowledge on the mechanisms of cracking in concrete made with RCA, and to better understand the effect of RCA properties on the contribution of aggregate interlock to shear capacity.

The main objective of this study is to explore whether any trends may be observed in the propagation of structural cracks in concrete made with various amounts of RCA, and the implications of the aggregate characteristics on the shear strength of large scale reinforced concrete members (Noël et al, 2018).

Applications of Research

The use of recycled concrete aggregates (RCA) has become increasingly attractive as an alternative to conventional natural aggregates for concrete with associated environmental and economic advantages.

Methodology

- Six beams were tested using three mix designs containing 100% RCA, 50% RCA and 0% RCA (conventional)
- Equivalent Mortar Volume method (Fathifazl et al. 2009)
- One beam for each mix was designed to achieve a flexural failure by placing transverse reinforcement along the length of the beam (Noël et al, 2018)
- An additional beam for each mix was designed to force a shear failure to occur on one end of the beam. Stirrups were intentionally removed from one side of the shear beams so that the location of the critical shear crack was known

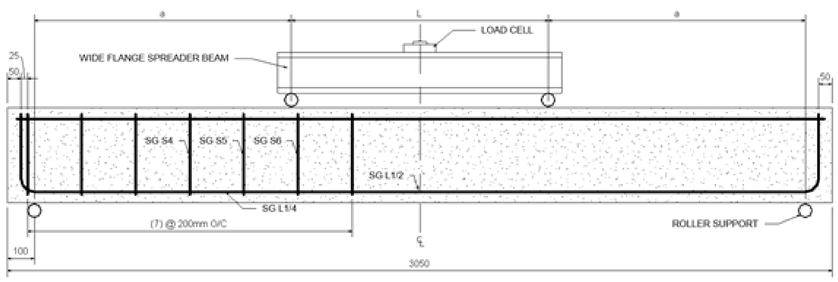


Figure 2: *Beam design*(Noël et al, 2018)

- After loading the beams to failure, cores were extracted from each beam at crack locations for microscopic examination

Before:

After:

- The cores were cut, polished and a grid of 1 cm^2 squares were drawn onto each sample to provide an organized structure for microscopic analysis (7 cm by 6 cm layout)

Results

Preliminary results:

Beam test results

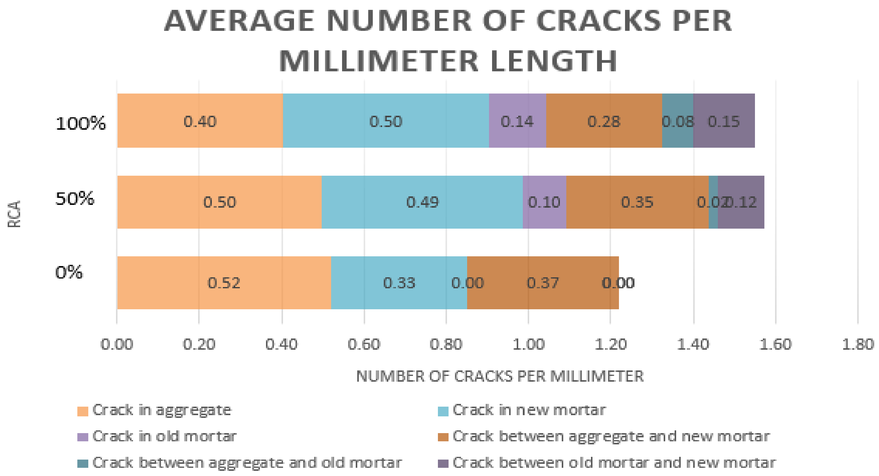
Beam	M_y (kNm)	$\frac{M_y}{M_{pred}}$	Beam	V_u (kN)	$\frac{V_u}{V_{pred}}$
NA-FL	67.1	1.03	NA-S	52.6	1.02
50-FL	68.2	1.04	50-S	65.4	1.25*
100-FL	66.7	1.02	100-S	45.9	0.85

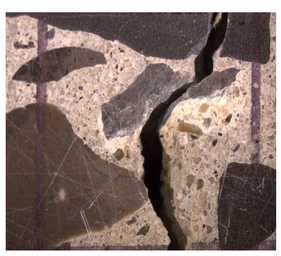
*This beam experienced a flexural failure, and not a shear failure as predicted

Table 2: *Beam test results* (Noël et al, 2018)

The control beam failed in shear as expected with an experimental-to-predicted load ratio of 1.02. On the other hand, the beam with 50% RCA exceeded the predicted shear capacity by 25% and ultimately exhibited a flexural failure mode with yielding of the longitudinal steel reinforcement followed by concrete crushing. Finally, the beam with 100% RCA failed at only 85% of the predicted shear strength. This suggests that the shear capacity of beams with RCA is linked to the microstructure and spacing of the aggregates which affects the tortuosity of the crack path (Noël et al, 2018).

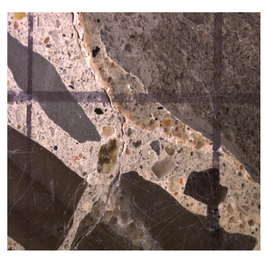
Secondary results (invalid):



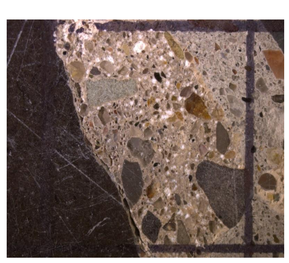


Open crack, caused by loading; crack propagates through two aggregates as well as the new mortar

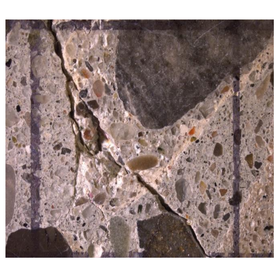
Residual mortar was easily distinguished from new mortar due to the difference of hue and texture



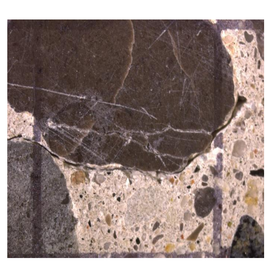
Crack propagates through the interfacial transition zone (ITZ) between the residual and new mortar



The rare occurrence of cracks propagating thought the ITZ between the residual mortar and aggregate suggests residual mortar tend to behave like an aggregate particle as opposed to the new mortar



The crack splits into a fork within the residual mortar



Closed crack, crack fork within the virgin aggregate and another crack propagating through the ITZ between the aggregate and the new mortar

*All these images were taken at 16x magnification

Tertiary results (invalid):

An estimation of tortuosity was estimated by dividing the true crack length (to a certain degree of accuracy) by the distance between the ends of it. This measurement of tortuosity could then be used to explain the magnitude of aggregate interlock within each sample. Although the results correspond with the preliminary results, each core was extracted arbitrarily from their respective beam thus rendering this data invalid.

Tortuosity

Mix design	Actual length/Straight length (mm/mm)
100%	1.08
50%	1.14
0%	1.11

Conclusion

This research is based upon the expansion of the preliminary results. Evidently the secondary results do not correspond upon these results. In conventional concrete, empirical evidence suggest cracks are more likely to occur through the ITZ between the new mortar and aggregates as opposed to through a virgin aggregate particle (Noël et al, 2018). As shown in the bar graph, the value for "crack in aggregate" is 0.52 cracks per millimeter, the highest of three designs which in theory should be the lowest. It has been suggested that closed cracks are to be excluded from the count.

Future Considerations

Majority of the time was allocated towards the polishing process of the concrete samples. This was a highly time consuming process resulting in time being compensated from the forensic analysis and review. The concept behind polishing technology is rather straight-forward and future upgrades can serve as topics of investigation. My recommendation would entail equipping the frame of the machine with an adjustable solid arm – much like the arm of a record player, strong enough to hold the weight of a concrete sample and withstand constant force of the rotating plate.

References and Acknowledgements

Fathifazl, G., Abbas, A., Razaqpur, A. G., Isgor, O. B., Fournier, B., and Foo, S., "New Mixture Proportioning Method for Concrete Made with Coarse Recycled Concrete Aggregate," Journal of Materials in Civil Engineering, vol. 21, no. 10, 2009, pp. 601–611.

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