Effect of Low and Moderate Recycled Concrete Aggregate Replacement Levels on Concrete Properties

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Task 6: Research Benefits and Implementation Steps

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6.1 Project Summary

This research investigated the effects of incorporating recycled concrete aggregate (RCA) at low replacement levels on the properties of paving concrete. Four different RCA sources were used, each with different aggregate properties. For each source, replacement levels of 5, 10, and 15% were tested and compared to a control group, which had no RCA. Of the four RCA sources investigated, three (Henderson, Aggregate Industries, and MoDOT) had similar levels of absorption capacity and percent fines, while one source (AVR) had higher levels of both of these properties. RCA replaced virgin aggregate of a similar gradation and replacement was on the basis of volume.

Fresh and hardened concrete properties were tested and a statistical analysis was conducted to determine if any observed differences in hardened properties between the test mixes and the control group were statistically significant. This research found that using up to 15% of an RCA with reasonable values of absorption capacity and percent fines would not negatively impact most concrete properties. It also provided an outline for future research to develop a specification to define what constitutes reasonable values of these parameters for future use.

6.2 Research Benefits

Task 1 identified several potential benefits of this research, including construction savings, environmental impacts, reduced risk, and increased technical knowledge. The conclusion that there is likely a way to incorporate up to 15% RCA into new concrete allows these benefits to be realized. While the benefits of using RCA related to construction savings and the environment are smaller for lower levels of aggregate replacement than they would be for 100% RCA concrete, it is important to note that agencies are often not willing to use or able to produce concrete with high RCA levels. Low levels of RCA replacement may also serve as a bridge to higher replacement levels in the future, which will further increase benefits. Quantification of the value of these benefits was outside the scope of this project.

6.2.1 Construction Savings

As quality aggregates become scarcer in major metropolitan areas [1], they will become more expensive. The ability to replace a portion of the virgin aggregates in a concrete paving mix with RCA will reduce the amount of virgin aggregate required, which will in turn reduce costs associated with the material itself. Transportation costs may also be decreased because virgin aggregates will generally need to be transported longer distances from the places where they are still available, while RCA is typically generated within metropolitan areas. This study showed that RCA replacement of up to 15% may be viable, as long as the RCA has reasonable aggregate properties, which could result in a decrease in virgin aggregate consumption of up to 15%. Contractors are also generally reluctant to use untested materials on projects because they often must warranty their work. Increased knowledge related to the use of RCA could result in additional construction savings by reducing risk (discussed in Section 6.2.3).

Quantifying the actual construction savings realized from using RCA would require project specific information, such as if the RCA is being crushed on site, if the concrete is being mixed on site, and haul distances for the RCA and virgin aggregates. Given that an existing concrete pavement generally does not produce enough RCA to be used as both the base and aggregate in a new pavement [2], there may be a need to import additional RCA for the concrete, depending on replacement level.

6.2.2 Environmental Aspects

The use of RCA in concrete to replace virgin aggregates is environmentally friendly because it eliminates both the need to landfill the parent concrete of the RCA and the need to quarry as much virgin aggregate [3]. Using 15% RCA in concrete reduces the use of virgin aggregate by approximately 15%, though the reduction will be slightly different because replacement is based on volume but aggregate is typically measured based on weight. Additionally, transportation distances for RCA are likely to be shorter as virgin aggregates sources closer to metropolitan areas become depleted and virgin aggregates must be sourced from further away; in contrast, most RCA is generated in metropolitan areas. Reduced transportation distances results in reduced emissions from hauling trucks.

Project specific information would be required to fully quantify the environmental benefits of using RCA. Benefits would also depend on where the boundary of the analysis is drawn, for example if cradle-to-gate, cradle-to-grave, or cradle-to-cradle criteria are considered. Additional details needed for an analysis would include haul distances, equipment types, and construction information. One interesting consideration that merits future investigation is how the benefits of carbon sequestration via carbonation change if the RCA is crushed on site and used fairly quickly versus if it sits in a stockpile before being used.

6.2.3 Reduced Risk

One of the main reasons agencies are disinclined to use RCA in paving concrete is the risk associated with using a material that will have unknown effects on the quality and life of the pavement [4]. Previous poor experience with concrete containing RCA has further increased the hesitancy to use RCA [5]. While much research has examined the effects of using high levels of RCA, there is less knowledge regarding the effects of low RCA replacement levels. Additional knowledge specific to these levels of RCA will help agencies make more informed decisions, which results in lower risk that the pavement will not perform as desired. Risk to the contractor is also reduced by both increased knowledge of the effects RCA may or may not have on the pavement.

6.2.4 Technical Outcomes

The main technical outcomes of this project are an increased knowledge of the effect of RCA on concrete properties when used a low replacement levels and guidance for future work that will inform next steps.

Compressive strength was found to decrease for all RCA types and replacement levels and this reduction was generally statistically significant. Surface resistivity was also found to decrease in a statistically significant way, but for the majority of mixes, the decrease was insufficient to change the chloride penetration risk category of the concrete, so these changes may not have practical significance. Flexural strength, Poisson's ratio, 252 day shrinkage, and freeze-thaw durability factor did not experience any statistically significant changes for any of the mixes tested. Elastic modulus and coefficient of thermal expansion were found to decrease only for the mixes containing the AVR aggregate; changes were not statistically significant for any of the other RCA types.

Another technical outcome is providing additional data on fresh testing of concrete containing RCA. There is little information in the literature on test such as the box test [6] or the super air meter (SAM) [7] being used on concrete containing RCA. While this research cannot verify that the box test is valid for concrete containing RCA, it does provide documentation in the literature of using the box test on concrete containing RCA. For the SAM test, good agreement was found between concrete which met the SAM number limit of ≤ 0.2 and concrete which met the freeze-thaw durability factor recommendation of ≥ 70. While several of the SAM tests run in this study were found to have likely been run incorrectly, those that were correctly run did accurately predict freeze-thaw durability. This indicates that the SAM test may be valid for concrete containing RCA at replacement levels up to 15%. However, to definitively say that the SAM test is valid to predict freeze-thaw durability for concrete containing RCA, a larger study that includes some mixes that are not durable would be required.

Linear regression analysis was used to identify how much of the variation between a test mix and the control group could be attributed to aggregate properties of absorption capacity, specific gravity, percent fines, Micro-Deval, and fineness modulus. While this research was not designed to specifically identify aggregate property limits for use in a specification, it can provide a roadmap for future work to produce a specification, as discussed in Section 6.3.

6.3 Implementation Steps

This research serves as a first step towards implementation of RCA a low replacement levels in concrete pavements. For full implementation, a specification for RCA will be required. The results of this research can help define the next research project, which could be used to develop specification criteria.

This research found that RCA replacement levels up to 15% could be used in concrete pavements with the only expected change being a decrease in compressive strength as long as the RCA had reasonable properties. Three of the four RCA sources tested had aggregate properties that would likely be considered reasonable while the fourth RCA source would likely be considered unreasonable due to its high absorption capacity and fines content. This RCA source was also the only one that experienced statistically significant changes in properties other than compressive strength.

While the linear regression analysis identified that absorption capacity, specific gravity, percent fines, and Micro-Deval could all be candidates for a specification limit, some of these parameters may be more useful than others. Changes in absorption capacity between virgin aggregate and RCA are most likely due mainly to the adhered mortar content of the RCA, while the absorption capacity of the parent rock would have a smaller effect. The adhered mortar content of the RCA would also affect the specific gravity, but here the properties of the parent rock may play a larger role in determining overall RCA specific gravity. Because the adhered mortar content is a significant factor in the behavior of the concrete made with RCA, either absorption capacity or specific gravity could be limited as a way to limit adhered mortar content. But limiting absorption capacity makes more sense because the properties of the parent rock will likely have a much smaller impact on absorption capacity than on specific gravity.

A specification limit on percent fines is also recommended because fines in general [8] and RCA fines in particular [8–11] are known to reduce concrete properties. Agency representatives on the technical advisory panel for this project also strongly favored limiting fines or requiring washing of the RCA, which indicates that most agencies would likely feel more comfortable using RCA with such a requirement. Producers supplying RCA for this study were reluctant to wash it but felt that they could meet a specification on fines through other means.

Micro-Deval was also identified as a potentially important aggregate property for certain concrete properties. While the underperforming RCA in this study had a Micro-Deval value similar to that of other RCA sources considered, Micro-Deval may still have value as a specification limit because it could eliminate RCA made from parent concrete with weak or poorly performing aggregate. Any future study to define a specification should include these types of aggregates to determine a limit that would eliminate them.

This work did find that RCA replacement of virgin aggregate from within the same gradation type or close to that type is likely acceptable. This is also the only practical way to control the gradation in RCA substitution without being overly burdensome on the producers. Any future specification should require that RCA substitution replace virgin aggregate of the same gradation type. Requiring a matching gradation would hinder implementation and would likely not result in improved concrete properties.

Future research should explore the effect on concrete properties of RCA sources with a variety of aggregate properties. Ideally, any study would include several aggregates that hold one or more property constant while changing another property. In practice, it would be very difficult to source RCA meeting these requirements. A more practical alternative would be to source a large number of RCA types in the hopes of capturing a wide range of properties. In order to determine specification limits, it would be desirable to have RCA sources with aggregate properties above and below the likely specification limits so that these limits can be determined. Based on this research and the literature, an absorption capacity limit around 5-6% and a limit on percent fines of 1% are recommended starting points. However, the proposed future research will serve to refine these limits. This research was not able to suggest a limit on Micro-Deval, but the Technical Advisory Panel suggested a limit of 22% as a starting point based on their past experience.

In addition to developing a specification, further research is needed to investigate the relationship between compressive strength and the pavement design inputs it is usually used to predict, mainly flexural strength and elastic modulus. Because the use of RCA caused concrete compressive strength to decrease but had no effect on flexural strength or elastic modulus for reasonable RCA sources, using compressive strength to predict these properties may not result in accurate predictions. Similarly, it is unknown if the standard correlations between compressive strength and other properties are valid for concrete made with RCA. In this work, flexural strength was underpredicted by an average of 4% while elastic modulus was overpredicted by an average of 25%. This indicates that the relationship between elastic modulus and compressive strength in particular should be investigated. However, because this research used only a small number of RCA sources, it is recommended that correlations between compressive strength and both flexural strength and elastic modulus be investigated in any larger study with more RCA sources. Concrete specifications could also consider requiring minimum values of flexural strength and elastic modulus rather than simply relying compressive strength as a proxy.

Once a sample specification has been developed, test projects can use this specification to provide field data. Test sections will also help inspire confidence in the sample specification if they perform well.

6.4 References

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