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

Task 1: Initial Memorandum on Expected Research Benefits and Potential Implementation Steps

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1.1 Research Project Introduction and Objectives

Recycled concrete aggregate (RCA) has been extensively researched as a way to improve the sustainability of concrete, eliminate construction waste, and address looming shortages of virgin coarse aggregates. When used as a replacement for coarse aggregate in concrete, RCA is known to effect many of the properties of concern for pavement design and construction. RCA has much higher absorption capacity than virgin aggregate, which results in increased water demand and/or decrease workability. Flexural, compressive, and tensile strengths can all be decreased, as can modulus of elasticity. Creep and shrinkage may increase, while durability can be lower. The degree of severity of these effects depends on the characteristics of the RCA, the mix design, and the amount of RCA used [1].

Many of the studies on RCA investigate either complete replacement of the coarse aggregate or look at 50 and 100% replacement. In reality, many agencies do not have access to enough RCA to use high replacement levels because RCA is in high demand for other applications, such as granular bases [2]. Additionally, many agencies are reluctant to explore high replacement levels because of known concerns with the use of high replacement levels of RCA. Previous projects built with RCA during the 1970’s – 1990’s resulted in some failures and state bans on the use of RCA in pavements [3,4] and institutional memory further contributes to the reluctance to return to using high RCA levels in concrete. The combination of inadequate supply and agency concerns over high replacement levels make lower RCA replacement levels a feasible alternative, but these have not been investigated extensively.

The goal of this research is to investigate the effect of replacing virgin coarse aggregate with coarse RCA at low and moderate replacement levels in concrete for paving applications. Low and moderate replacement levels are most likely to be implemented because they do not require as much RCA and they may be perceived to have less risk to owners. Therefore it is important to understand how these replacement levels will affect the mechanical and non-mechanical properties of the concrete. This research will investigate the effect of up to three different RCA coarse aggregate types at various low and moderate replacement levels (10-50%). Tests conducted will measure properties that are often used in performance specifications, as given in AASHTO PP 84-19 [5].

1.2 Expected Research Benefits

1.2.1 Benefits to Taxpayers of NRRA Member States

The main benefit of this project will be a better understanding of how the use of recycled concrete aggregate (RCA) as a partial replacement for virgin coarse aggregate affects the properties of a concrete mix at low and moderate replacement levels. These levels are much more realistic in terms of what agencies are likely to use, due to both material availability and concerns related to performance. A better understanding of the replacement levels at which RCA begins to have a non-negligible impact on various concrete properties will help state agencies determine the level of RCA to use and if any pavement design modifications or specification changes are required to account for changes in the concrete properties.

The ability to use RCA in concrete with confidence will benefit the taxpayers of NRRA member states by reducing both the costs and environmental impacts of paving projects. As viable virgin aggregate sources are depleted around more major metropolitan areas, aggregates will need to be sourced from further away [6]. The longer haul distances associated with these aggregates will increase costs and emissions associated with transportation. If a portion of the virgin aggregate in the concrete can be replaced with RCA, this will both delay the exhaustion of local virgin aggregate supplies and reduce the amount of aggregate that must be imported once local aggregate is no longer available. Additionally, using RCA will reduce the amount of virgin aggregate that must be mined and eliminate the need to landfill the parent concrete from which the RCA is derived.

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 DOTs are often not willing to use or able to produce concrete with high RCA levels. By investigating replacement levels that agencies may actually use, these benefits can be realized.

1.2.2 Initial Projection of Expected Benefits

The following benefits in specific areas of interest to agencies have been identified:

- **Construction Savings** – as quality aggregates become more scarce in major metropolitan areas [6], 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.

- **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 [7]. 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.

- **Reduce Risk –** one of the main reasons agencies are reluctant 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 [8]. While much research has examined the effects of using high levels of RCA, there is much less knowledge regarding the effects of low and moderate RCA replacement levels. Additional knowledge specific to these levels of RCA will help agencies make more informed decisions, which results in lower risk.

1.2.3 Expected Technical Outcomes

The expected technical outcome of this work is additional knowledge that will help to agencies better understand the expected properties of concrete made with low to moderate RCA replacement levels. While RCA has been extensively research in the literature, most projects have focused on complete replacement of the coarse aggregate. Those that examined multiple replacement levels often skew towards higher replacement levels. This research will specifically address low replacement levels.

Additionally, this work will focus on properties used by state agencies to design the pavement or produce construction specifications. Some tests used to establish performance specifications, such as the box test and super air meter, are not well represented in the literature on RCA. By understanding how lower levels of RCA affect concrete properties like these that are specifically of interest to an agency establishing a performance specification, this research will help agencies like state departments of transportation to make more informed decisions on RCA policy and pavement design.

1.3 Project Steps

1.3.1 Summary of Research Methods (Scope)

This research will investigate the effect of replacing a low to moderate percentage of virgin coarse aggregate in concrete with RCA. Aggregates tested will include a virgin coarse aggregate and coarse RCA from up to three different sources as identified by the technical advisory panel (TAP). All aggregates will be obtained from local aggregate sources and will be aggregates typically used in the production of ready-mix paving concrete.

Properties to be measured and compared in this work are those required AASHTO PP 84-19 for a performance specification [5]. Tests on the fresh properties include air content [9], SAM number [10], and the box test [5]. Tests on hardened properties include compressive strength [11] and flexural strength [12] tested with time to determine how blending affects both ultimate strength and the rate of strength gain, elastic modulus and Poisson's ratio [13], coefficient of thermal expansion [14], freeze thaw durability [15], surface resistivity [16], and shrinkage [17]. These properties were selected because they align with the properties considered in the development of performance specifications and/or are properties used in pavement design per mechanistic-empirical design methods.

3D Digital image correlation (DIC) will also be used to map the strain fields in the concrete during the compressive strength test. DIC is a non-contact, full field optical imaging technique. A speckle pattern applied to a surface of the concrete is photographed using high speed cameras during loading. Software tracks the displacements recorded in the images to provide measurements of displacements. A surface is fit across this field of displacement from which strains are then approximated. The software is capable of analyzing in-plane strains on planar or three-dimensional surfaces (such as a concrete cylinder) and has been used by previous researchers to analyze concrete [ex. 18]. In the proposed work, DIC will be used to examine changes in the global field (including mean values, standard deviations, etc.) due to the use of different RCA levels. Additionally, the strain field at specific regions can be measured during post processing to track strains across specific linear paths. Strain fields measured just prior to fracture will also be studied to help understand microstructural effects of using different RCA levels.

Once testing is complete, the results of each test will be compared to RCA replacement level. Plots will be generated to show if/how each property investigated varies with the percent of RCA. A statistical analysis will be conducted to determine the significance of the results. Based on the results, a level of RCA that can be used in concrete pavements without adverse effects will be suggested. States could then allow this level of RCA similar to how low levels of recycled asphalt pavement (RAP) are often allowed in new asphalt pavements.

1.3.2 Research Process

This work will be broken into several tasks, each with its own deliverable, as summarized below.

- Task 2: Literature Review – in this task, the current state of knowledge on using recycled aggregates and identify gaps in research associated with testing RCA at lower replacement levels and the effects of RCA on properties commonly used in performance specifications and/or pavement design. The results of this literature review will help inform the reminder of the research and will also be a resource for agencies looking to increase their knowledge on RCA.

- Task 3: Materials Acquisition and Mix Design Development – in this task, materials will be acquired for the project and characterized. Mix designs will also be developed for use in testing.

- Task 4: Concrete Mixing and Testing – in this task, fresh and hardened testing will be conducted. The testing regime is determined based on the tests required for performance engineered mixtures. Fresh properties to be tested include air content, SAM number, and the box test. Hardened property tests will include compressive and flexural strength gain with time, elastic modulus, Poisson's ratio, coefficient of thermal expansion, surface resistivity, shrinkage, freeze-thaw durability, and digital image correlation. The results of these tests will be analyzed in subsequent tasks.

- Task 5: Data Analysis – in this task, test results will be compared to determine the effects of using different RCA replacement levels. A statistical analysis will be conducted to determine the significance of the results. This task will show how the use of RCA at various low replacement levels changes the properties of the concrete. Such knowledge is essential for incorporating RCA into concrete pavements while **reducing the risk** of failure associated with using the wrong material properties in design.

- Task 6: Final Memorandum on Research Benefits and Implementation Steps – this task will produce a memo outlining conclusions of the research, their benefits, and the steps required for implementation of the research results. Incorporating low levels of RCA into concrete is expected to result in both **construction savings** and **reduced environmental impact** of concrete paving compared to pavements made with virgin aggregates. The actual savings will likely vary by project due to economies of scale and if RCA is produced on site or hauled.

- Task 7: Final Report – this task will produce a final report describing the results and recommendations stemming from this research. This report will help transportation agencies to implement the findings of this work.

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