

JOINT TRANSPORTATION RESEARCH PROGRAM

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Using Recycled Concrete as Aggregate in Concrete Pavements to Reduce Materials Cost

Introduction

The main objective of this project was to evaluate the effects of using aggregate produced from crushed concrete pavement as a replacement for natural (virgin) coarse aggregate in new pavement mixtures. A total of ten different concrete mixtures containing recycled concrete aggregate (RCA) were designed to meet the requirements of the Indiana Department of Transportation (INDOT) specifications. These mixtures included three different RCA replacement levels of 30%, 50%, and 100% (by weight of the natural coarse aggregate) and two different cementitious systems (plain system—Type I Portland cement only and fly ash system—80% of Type I Portland cement and 20% of ASTM C 618 Class C fly ash). The scope of the project included the evaluation and comparison of several properties of RCA and natural aggregates, and evaluation and analysis of the effects of RCA on concrete properties.

All mixtures were first produced in the laboratory (trial batches), then subsequently reproduced in a commercial ready-mixed concrete plant. Each mixture produced in the ready-mixed plant was used to prepare several types of specimens for laboratory testing. The tests performed on fresh concrete included determination of slump and air content. The mechanical properties of the hardened concrete were assessed by conducting compressive strength, flexural strength, modulus of elasticity, and Poisson's ratio tests.

Concrete durability was assessed using a wide array of measurements, including: rapid chloride permeability (RCP), rapid chloride migration (RCM), electrical impedance spectroscopy (EIS), surface resistivity, free shrinkage, water absorption, freeze-thaw resistance, and scaling resistance tests.

After the ten concrete mixtures were tested, the original gradation was modified and six additional concrete

mixtures were developed and produced in the laboratory. The original aggregate gradation was modified by adjusting the fine-to-coarse aggregate ratio and adding a mid-size #11 aggregate ($D_{max} = \frac{1}{2}$ in.). A mid-sized RCA coarse aggregate was introduced that was crushed from mixed-use concrete debris. These mixtures were used to study whether different sizes and proportions of virgin and RCA aggregates could be used to produce an "optimized blend" that improved one or more concrete characteristics, and to examine the influence of using a non-pavement concrete as RCA in new concrete mixtures.

Findings

Test results indicated that the properties of plain (no fly ash) concrete mixtures with 30% RCA as coarse aggregate were very comparable to, and in some cases even better than those of the control concrete (0% RCA). Plain concrete mixtures with 50% RCA and 100% RCA showed a reduction in durability and mechanical properties; however, they still passed all of INDOT's specifications requirements. The one exception was for the 100% RCA and no fly ash mixture in which the w/cm was increased to 0.47 to achieve workability (exceeding <0.45 w/cm target).

The use of fly ash improved the strength and durability of RCA concrete, especially at later ages. In particular, the properties of concrete with 50% RCA coarse aggregate were similar to the properties of the control concrete. Similarly, the mechanical and durability properties of the mixture with 100% RCA coarse aggregate and 20% fly ash were better than those of a similar mixture prepared without fly ash. Even though, when compared to the fly ash concrete with 100% virgin aggregate, the mechanical and durability properties of the 100% RCA concrete were lower, it still met minimum requirements imposed by INDOT's specifications.

The test results obtained from the six additional modified mixtures indicated that modifying the aggregate gradation with a mid-size RCA made from mixed-use concrete did not benefit either compressive or flexural strength values. The failure to improve concrete strength with these modified aggregate gradations may have been due, at least in part, to the quality of the mid-sized RCA aggregate used to modify the gradation.

The interactive benefit-cost analysis (BCA) developed under this project showed that using RCA can reduce aggregate costs, resulting in measureable project-wide savings. Cost savings, or lack of savings, related to using RCA can be readily identified using either project-specific inputs or general estimates.

In conclusion, this project demonstrated that quality, durable concrete that contains some level of RCA coarse aggregate made from old concrete pavements can be used in new concrete pavement structures. This practice can lead to good resource management, quality concrete pavements, and potential cost savings.

Implementation

Considering the limited scope of this study (only one source of RCA, one Class C fly ash, and two natural aggregate sources), and potential variability in RCA characteristics, it is recommended that the amount of RCA coarse aggregate be limited to 30% in plain concrete and 50% in fly ash concrete to ensure adequate quality of the pavement concrete.

The field trials demonstrated that RCA as 30% and 50% of the coarse aggregate in a concrete mixture without fly ash can be successfully produced and placed in slip-form paving using standard INDOT practices by traditional paving equipment. Future use should explore higher percentages of RCA replacement in shoulders and non-highway construction until confidence and experience is developed using RCA.

The benefit-cost analysis developed under this project is a useful tool to examine the costs of using RCA compared to natural aggregate in pavement structures. The BCA can identify cost savings and provide information valuable to users in resource management decisions.

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