Project Summary
Texas Department of Transportation

0-4826: Use of Crushed Gravel in Concrete Paving

Background

The Texas Department of Transportation (TxDOT) has used siliceous river gravel (SRG) aggregates for many years in the construction of continuously reinforced concrete (CRC) pavement; however, in many instances these pavements have been subject to delamination and spalling distress, and have been very expensive to maintain and repair. Previous TxDOT-funded field studies have confirmed that spalling is a consequence of early-age delaminations.

Delamination occurs when temperature or evaporation-induced differential shrinkage stresses surpass the concrete interfacial shear strength. The delamination crack, the precursor to spall development, is typically oriented parallel to, and at a shallow depth below, the surface of the pavement. Delamination cracking eventually leads to spalls as a result of the presence of incompressible materials preventing expansion, moisture wetting and drying cycles, traffic loading, and other conditions.

The goals of this project were to develop a test protocol to measure the bond strength between coarse aggregate and mortar, to determine measures or practices that can be applied to improve delamination resistance and spalling performance of the gravel concrete in CRC paving, and to provide guidelines and recommendations to minimize early-age delamination in SRG-CRC paving. Solutions to the delamination problem would involve an increase in the strength of the concrete or a reduction in the stress in the concrete, to prevent debonding between the aggregate and the mortar.

What the Researchers Did

A fracture toughness (K_{IC}) test (originally developed at Texas Transportation Institute) was used to represent the interfacial shear strength between aggregate and mortar for a variety of coarse aggregate types and concrete mixtures at early ages. Aggregate crushing and aggregate types were investigated as possible corrective measures to improve the interfacial bonding between gravel aggregate and mortar before selecting the factors and their levels for detailed laboratory investigation.

A fractional factorial design, based on Taguchi's orthogonal array using four factors (i.e., aggregate type, water to cementitious ratio, replacement of ultrafine fly ash, and curing method), was selected to conduct the detailed laboratory study. The significances of each factor to achieve better K_{IC} were determined, and the optimum design combination (a combination of all the four factors with their best levels) was subsequently chosen and validated. The microstructural investigation of the interfacial transition zone was conducted for both laboratory and field specimens. The key material and construction parameters that significantly affect the bond strength of concrete at early ages were identified through the laboratory investigation.

Research Performed by:

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A comprehensive investigation of aggregate properties relative to physical (e.g., absorption capacity percentage), geometric (i.e., shape, texture, and angularity by Aggregate Imaging System), and chemical (surface free energy by Universal Sorption Device) characteristics was conducted. A rating system based on utility theory was applied to evaluate the overall aggregate contribution to the concrete bonding performance and feasibility of design combinations. A fracture mechanics-based approach was proposed with the facilitation of numerical analysis to predict the occurrence of delamination based on the criterion that delamination occurs when K_I exceeds K_{IC}. The relationship between interfacial surface energy and material and construction factors was investigated. A delamination detection protocol using nondestructive testing (NDT) techniques was developed. Test sections for both winter and summer were established to verify the measures and trends relative to the practices and techniques to minimize the development of spall-related delamination in CRC paving.

What They Found

The major finding from this research was that with the appropriate combination of materials and methods, most coarse aggregate deficiencies relative to bonding can improve. The aggregate-paste interfacial bond for a given cement paste was found to be a function of the combined effects of all three aggregate properties (physical, chemical, and geometric).

The application of utility theory to evaluate the overall contribution of aggregate properties to the bonding performance of concrete, combined with feasibility of design, enabled the research team to propose possible construction guidelines, including selecting the best aggregate type, modifying mixtures by blending different aggregates, and optimizing design combinations for concrete paving construction to arrest delamination and spalling distresses. Researchers found that quality control of the curing process may be the most feasible means for minimizing early-age delamination in the field.

What This Means

This project established a potential step-by-step process of selecting construction options for using gravel aggregates in concrete paving, including determining aggregate rating, developing case-sensitive delamination-resistant mix proportions, estimating the probability of delamination, and selecting the method of construction. If the test sections constructed under this project perform well, the validity of this process will still need to be verified. More case studies are needed to calibrate the curve of probability of delamination occurrence as a function of effective wind speed, curing quality, and construction practice (such as better curing practices and early-age sawcutting). The threshold values for different levels of probability of delamination occurrence and the calibration of the curves need to be established through detailed future research.

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