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Field performance of concrete pavement incorporating recycled concrete aggregate

Seyedhamed Sadati [a,*], Kamal H. Khayat [b]

[a] Department of Civil, Architectural and Environmental Engineering, Missouri University of Science and Technology, 204 Engineering Research Laboratory, 500 W. 16th Street, Rolla, MO 65409, United States

[b] Department of Civil, Architectural and Environmental Engineering, Missouri University of Science and Technology, 224 Engineering Research Laboratory, 500 W. 16th St., Rolla, MO 65409-0710, United States

HIGHLIGHTS

- Fine and coarse RCA were used to produce concrete in laboratory.
- Coarse RCA was incorporated for casting pavement sections in field.
- Control specimens and core samples were used to monitor concrete properties.
- Instrumentation was employed for monitoring the in-situ deformations.

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ABSTRACT

This paper reports test results of a field-oriented study carried out to demonstrate the performance of recycled concrete aggregate (RCA) for use in the construction of rigid pavement. Properties of eight concrete mixtures containing RCA were first compared to those of a reference mixture. Two mixtures proportioned with 30% and 40% of coarse RCA along with the reference concrete were then used for field implementation, which involved casting a 300-m long pavement section in St. Louis, Missouri. Samples were taken during slip-form pavement construction. Core samples were extracted at 120 days to determine in-situ properties. Instrumentation was incorporated to monitor the long-term deformation of different pavement sections. Incorporation of 30% and 40% RCA reduced the 91-day compressive strength by 7% and 12%, and the 56-day modulus of elasticity by 22% and 14%, respectively. The 56-day splitting tensile strength and flexural strength values of the two RCA mixtures were similar to those of the reference concrete. Mixtures exhibited similar performance in terms of durability against abrasion, freeze and thaw cycles, and rapid chloride ion permeability. An increase of 100 $\mu\varepsilon$ in shrinkage was observed for the 40% RCA compared to the reference concrete. However, all field investigated mixtures exhibited similar long-term deformation patterns and magnitudes. In-situ deformation of all pavement sections was limited to 150 $\mu\varepsilon$ at sensor locations.

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1. Introduction

Interest for the use of environmentally friendly concrete in the pavement design, materials, construction, and maintenance has grown in recent years [1]. Candidate technologies for sustainable rigid pavement materials include the incorporation of supplementary cementitious materials (SCMs), the incorporation of recycled materials in concrete production, and in particular, recycled concrete aggregate (RCA), as well as the use of highly durable concrete to increase service life. Considering the fact that fine and coarse aggregates occupy about 30% and 40% of the total concrete volume in rigid pavement, respectively, the partial replacement of RCA can be employed to reduce the need to natural resources. Over 900 million tons of construction and demolition waste is produced annually in Europe, the U.S., and Japan [2]. In addition to possible reductions in CO_2 emission due to reduced hauling distances [3], RCA can effectively contribute to reducing the depletion of natural resources (virgin aggregate) and decreasing the need for landfills.

Given the variable characteristics of RCA compared to virgin aggregate, there still exists a conservative approach that limits

* Corresponding author.
E-mail addresses: seyedhamed.sadati@mst.edu (S. Sadati), khayatk@mst.edu (K.H. Khayat).

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the use of RCA in field applications [3]. Therefore, most of the applications of RCA involve the use of RCA as aggregate in base and subbase layers, backfill, embankment, stabilization, erosion control (riprap), and landscaping [4]. According to a survey published by the Federal Highway Administration (FHWA) in 2004 [5], 41 states recycled concrete for use as aggregate in new construction in United States. Thirty-eight of these states allow the use of RCA as aggregate in base layer applications. Of these states, however, only 11 were using RCA in new portland cement concrete production [5].

Use of RCA in construction of rigid pavements started in early 1970's. Most of these pavements have performed well. However, several states in U.S. stopped using RCA in pavement construction due to poor performance of some cases [6], which was associated with: (1) higher shrinkage and thermal deformations of RCA concrete, resulting in distress in mid-panel cracks of jointed reinforced concrete pavement (JRCP); (2) inferior load transfer along with faulting in non-doweled sections due to reduced aggregate interlock; (3) durability issues including delayed D-cracking due to use of RCA obtained from crushing of old concrete proportioned with aggregate that are highly susceptible to frost damage [7]. In 1994 Cuttel et al. [6] investigated the use of RCA for construction of single layer concrete pavements in the 1970's and 1980's in Connecticut (one section), Kansas (one section), Minnesota (four sections), Wisconsin (two sections) and Wyoming (one section). Jointed plain concrete pavements (JPCP), continuously reinforced concrete pavements (CRCP), and JRCPs were investigated. Joint spacing ranged from 3.7 to 12 m, and slab thicknesses varied between 200 and 280 mm. The water-to-cementitious materials ratio (w/cm) of the incorporated mixtures ranged from 0.38 to 0.47. Based on the core sample results, authors reported comparable compressive strength and splitting tensile strength values for the control and RCA sections. Up to 23% increase in coefficient of thermal expansion (CTE) was observed for the RCA-made sections. In addition, investigated sections had similar responses to falling weight deflectometer test. However, inferior load transfer efficiency in the case of RCA sections was observed [6]. The investigation was followed by a second survey in 2006 by Gress et al. [8] on same sections (20- to 22-years old at the time of survey). Based on the field measurements and inspections, the authors reported increase in transverse cracking and transverse joint spalling, increase in length of deteriorated transverse cracks, and decrease (up to 0.8 points out of 5.0) in present serviceability rating (PSR) of the pavement made with RCA.

With the increasing interest in the use of sustainable concrete made with RCA, more information regarding the performance of such materials in field applications is required. The research presented here contributes to the evaluation of properties of pavement concrete proportioned with partial replacement of RCA. The results presented should be of interest to owner agencies and engineers considering the design and use of eco-friendly concrete for transportation infrastructure.

The objective of the study reported in this paper is to investigate the material properties and performance of the rigid pavement cast with RCA. The investigation is divided in two phases. The first phase investigates the properties of concrete mixtures produced with fine and coarse RCA for pavement application. Several concrete mixtures proportioned with different fly ash replacement levels, fine and coarse RCA contents, and w/cm were investigated in the laboratory. The mixtures were tested to determine mechanical properties, durability, and shrinkage. Two mixtures produced with 30% and 40% coarse RCA replacement and a reference concrete proportioned without any RCA were employed at second phase for the construction of a pavement section in St. Louis, Missouri. Sampling was conducted at the job site, and core samples were extracted to evaluate in-situ properties of the sustainable concrete. Instrumentation was also employed to monitor early age and long-term deformation of different pavement sections.

2. Experimental program

2.1. Material properties

The investigated concrete was proportioned with binary cement containing Type I/II portland cement and Class C fly ash. Crushed limestone with a maximum size of 25 mm was used for the virgin aggregate. Well-graded siliceous river-bed sand was used. Coarse and fine RCA procured from a commercial recycling center were employed as a partial replacement of the virgin aggregate. The RCA (both fine and coarse) were produced by recycling old concrete available at Lambert International Airport area in St. Louis, Missouri. Table 1 presents the physical properties of the fine and coarse aggregates. The residual mortar content of the RCA was determined by a combination of thermal stress and chemical degradation testing as suggested by Abbas et al. [9]. RCA was soaked in a saturated solution of sodium sulfate and subjected to cycles of freezing and thawing to detach the adhered mortar from the old virgin aggregate particles [9].

2.2. Mixture proportions

An initial laboratory investigation was conducted at phase I to evaluate the performance of candidate mixtures. A mixture recommended by the Missouri Department of Transportation (MoDOT) for rigid pavement applications was used as a reference concrete. This concrete was prepared with 323 kg/m^3 of cementitious materials that included 25% Class C fly ash, by mass, a w/cm of 0.40, and virgin aggregate. The initial laboratory investigation involved the variation of w/cm, fly ash, and fine RCA content. Class C fly ash was incorporated at a replacement rate of 25% to 40%, by mass of cementitious materials. The w/cm varied from 0.37 to 0.42. Fine RCA replacement ranged from 0 to 20%, by volume, and coarse RCA replacement was fixed at 30%. This was carried out to evaluate engineering properties and durability of concrete containing fine RCA and to investigate the feasibility of producing an environmentally friendly, yet durable, pavement material.

Table 2 summarizes the mixture proportions and fresh properties of the concrete developed and evaluated in phase I. All mixtures were proportioned with sand-to-aggregate ratio (S/A) of 40% (by volume) and total cementitious material content of 323 kg/m^3, except for the equivalent mortar volume (EMV) mixture [10]. The EMV mix design method requires that the total mortar content in the reference concrete produced with virgin aggregate is equal to the total mortar content of the RCA-made concrete [10]. The total mortar of the RCA-made concrete is considered as the summation of residual mortar content attached to the RCA particles and the fresh mortar of the new mixture. The second condition of the EMV method is that the total virgin coarse aggregate content in the reference concrete should be equal to the total virgin coarse aggregate content of the RCA-concrete, i.e. the summation of the old coarse aggregate available in RCA particles and virgin aggregate of the RCA-made concrete [10].

A lignum-based water reducing admixture (WRA) with specific gravity of 1.2 and 40% solid content, and an air-entraining admixture (AEA) were incorporated to secure an initial slump value of 50 ± 15 mm and an air content of 6% ± 1%, respectively. A coding system was developed for labeling the different mixtures. The codes are composed of three numbers indicating the fly ash content, fine RCA content, and w/cm. As an example, code "25-15-40" refers to a mixture made with 25% of fly ash, 15% of fine RCA, and w/cm of 0.40.

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