Ternary Blend Concrete with Reclaimed Asphalt Pavement as an Aggregate in Two-Lift Concrete Pavement

Ross A. Bentsen[1], William A. Vavrik[2], Jeffery R. Roesler[3], and Steven L. Gillen[4]

Abstract

The Illinois Tollway, as part of its $12 billion Move Illinois capital program, desires roadway construction to be "greener" than ever before. Reductions to the environmental impact of highway construction are required to meet this goal, and in concrete pavements this translates to requiring the use of byproduct materials, recycled asphalt pavement as a coarse aggregate, and recycled concrete aggregate in ternary blended concrete pavement materials. To develop the standards and specifications for this "black rock" concrete mixture, the Illinois Tollway completed a laboratory and field trial program. The laboratory program investigated the replacement of virgin coarse aggregate in a ternary blend concrete mix (containing cement, slag, and fly ash) with various levels of fractionated recycled asphalt pavement (FRAP). In the laboratory three levels of FRAP as a replacement of coarse aggregate were evaluated: 20 percent, 35 percent, and 50 percent replacement. The results of the laboratory investigation showed that up to 50 percent FRAP as a coarse aggregate component may be feasible in a ternary concrete pavement mix that meets the Illinois Tollway's strength requirements. This paper presents the impacts of the FRAP on the concrete material properties such as slump, unit weight, air content, compressive strength, split tensile strength, flexural strength, and modulus. The construction practices and lessons learned from a 0.7-mile trial interstate reconstruction and widening project of two-lift concrete with FRAP show that this method is a viable way to improve the sustainability of concrete pavements with no anticipated impact to cost or performance. As a result of this research, the Tollway plans to deploy this technology for a program that may include over 3 million square yards of new concrete pavement.

[1]Quigg Engineering Inc., 2351 S. Dirksen Parkway, Springfield, IL 62703; PH 217-245-5675; FAX 217-245-5398; e-mail: rbentsen@quiggengineering.com

[2]Applied Research Associates, Inc., 100 Trade Centre Drive, Suite 200, Champaign, IL 61820; PH 217-356-4500; FAX 217-356-3088; e-mail: wvavrik@ara.com

[3]University of Illinois, Department of Civil and Environmental Engineering, 205 N. Mathews MC-250, Urbana, IL 61801; PH 217-265-0218; e-mail: jroesler@illinois.edu

[4]Illinois State Toll Highway Authority, 2700 Ogden Avenue, Downers Grove, IL 60515; PH 630-241-6800 ext 3944; FAX 630-241-6105; e-mail: sgillen@getipass.com

Introduction

The Illinois Tollway has begun a 15-year, $12 billion Move Illinois capital program to build and rehabilitate major portions of its 286-mile network of interstate highways. One of the efforts in this program is to continue to reduce the environmental impact of roadway construction. The Tollway has successfully researched and implemented numerous recycling initiatives in the construction of the pavement bases and asphalt mixtures, and is moving forward on increasing the sustainability of its concrete mixtures. The Tollway's concrete mixture sustainability research has involved designing ternary-blended concrete mixtures containing coarse fractionated reclaimed asphalt pavement (FRAP) as a substitute for a portion of the virgin coarse aggregate.

The Tollway's successful research conducted on "black rock" in concrete has resulted in the Tollway specifying ternary mixtures containing coarse FRAP for the reconstruction of a 62-mile portion of the Tollway's interstate pavement system. The Tollway is using black rock concrete in two pavement systems. For mainline pavement reconstruction, the black rock concrete is the lower lift of a two-lift composite concrete pavement, with a long-life concrete mixture placed as the upper lift of the composite concrete pavement. For ramp reconstruction, the Tollway is using black rock in the concrete pavement of a "traditional" composite pavement, with the concrete pavement overlaid by a 2-inch-thick asphalt mixture.

This paper discusses the impacts of the FRAP on the concrete material properties such as slump, unit weight, air content, compressive strength, split tensile strength, flexural strength, and modulus. The construction practices and lessons learned from a 0.7-mile trial interstate reconstruction and widening project of two-lift concrete with FRAP show that this method is a viable way to improve the sustainability of concrete pavements with no anticipated impact to cost or performance. And as a result, the Tollway is planning to deploy this technology for a program that may include over 3 million square yards of new concrete pavement.

BLACK ROCK RESEARCH

The Tollway's initial black rock research was conducted in 2010-2011, and reported by the Illinois Center for Transportation (Brand et al., 2012). The research involved conducting initial trial batches with varying levels of ternary cementitious materials and coarse FRAP as a partial replacement of the concrete mixture's coarse aggregate. A typical concrete pavement mix design with 635 pounds of cementitious materials was developed, and coarse FRAP levels ranging from 0 to 50 percent were substituted for a portion of the mixture's coarse aggregate. The study concluded that concrete containing coarse FRAP at up to 50 percent replacement levels can be produced that meets existing Tollway durability and strength performance standards. The evaluation of the fresh concrete properties revealed that, in general, the slump increased, the unit weight decreased, and the air content remained relatively unaffected (although the air content appeared to be somewhat sensitive to FRAP) as the FRAP content increased in the concrete. Additionally, as the FRAP content increased, the strength (compression, split tension, and flexure) and modulus (elastic and dynamic) properties all decreased.

Laboratory investigations reported by Brand et al. (2012) also compared the differences in mixtures containing "washed FRAP" to mixtures containing "dirty FRAP"—that is, FRAP that was simply screened as part of the material processing. The results indicated that FRAP need not be washed to achieve the required workability and strength specification requirements.

Additional research reported by Brand et. al. (2013) involved the testing of large-scale concrete slabs (6 feet square by 6 inches thick) to evaluate the effects of recycled aggregates on the peak flexural load capacity. The slab testing included concrete containing 45 percent FRAP as a coarse aggregate. While laboratory-sized specimens showed typical reductions in strength, the slab-sized results revealed that the presence of the recycled aggregate did not reduce the flexural load capacity as was expected from the results of the laboratory-sized specimens. The fracture energy of the various concretes were found not to be statistically different for the concretes with recycled aggregates relative to the virgin aggregate concrete mixtures. Overall, this meant the failure of the slabs was more controlled by the combined effect of the concrete fracture properties and slab geometry rather than only the concrete strength properties measured from beams.

The Tollway's first field production and placement of black rock concrete was performed in October 2010, as part of the reconstruction of the Milwaukee Avenue ramps on the Tri-State Tollway (I-94). The composite pavement section consisted of a 9-inch-thick concrete with 28 percent washed, coarse FRAP and a 2-inch hot-mix asphalt overlay. The concrete contained 655 lb/yd^3 of cementitious material with 79 percent cement and 21 percent fly ash.

REAGAN TOLLWAY RECONSTRUCTION

The Illinois Tollway continued the field analysis and evaluation of black rock concrete as part of a 0.7-mile reconstruction and widening project on the Ronald Reagan Tollway (I-88). The black rock concrete was included as the lower lift of an 11¼-inch composite concrete pavement, which was constructed in the two-lift concrete construction procedure (Gillen et. al. 2012). The Tollway has developed special provisions for the recycled coarse aggregate allowed for substitution as a portion of the virgin coarse aggregate in the concrete mixture (Illinois Tollway, 2011a), as well as for the ternary concrete mixture containing recycled aggregate (Illinois Tollway, 2011b), and the construction of the two-lift composite concrete pavement (Illinois Tollway, 2011c).

The composite concrete construction special provision requires the contractor to construct the two-lift concrete pavement using two slipform pavers (Illinois Tollway 2011c). However, the special provision allows the contractor to demonstrate the use of an alternate construction method using other equipment and placement methods. For the I-88 project, the contractor chose to construct the pavement using a belt-placer to deposit the concrete in front of a strike-off machine, followed by another belt-placer to deposit the concrete on top of the first concrete layer, followed by a concrete paver/finisher.

As required by the contract, all means and methods of two-lift concrete placement have to be demonstrated in a test strip, and the contractor successfully demonstrated their process in an off-site test strip that coincided with the construction of another concrete pavement project. The lessons learned from the contractor's process are discussed in the analysis section of this paper.

Mix Design

The Tollway's special provision for black rock mixes is a performance-related specification that provides specific performance requirements for the mix design, but it does not provide prescriptive requirements, such as the minimum amount of cementitious materials (Illinois Tollway, 2011a). These are the performance requirements in the special provision:

- Compressive Strength (AASHTO T22):
  - Interim strength (5 days, opening to construction traffic): 19.7 MPa (2850 psi)
  - Ultimate strength (opening to traffic): 24 MPa (3500 psi)
- Flexural Strength (AASHTO T97, third point loading):
  - Interim strength (5 days, opening to construction traffic): 3.1 MPa (450 psi)
  - Final strength (14 days): 4.0 MPa (575 psi)
  - Ultimate strength (28 days): 4.5 MPa (650 psi)
- Plastic Air Content (AASHTO T152): 5.0 to 8.0 percent
- Slump (AASHTO T119): As needed for slip-form paving
- Hardened Air Content: Air void system has these characteristics as determined by ASTM C 457:
  - Spacing factor not exceeding 0.20 mm (0.008 in.)
  - Specific surface not less than 25 mm^2/mm^3 (630 in^2/in^3)
  - Total air content not less than 4.0 percent

The Tollway is including flexural strength in its specification to get a further understanding of that key component to pavement thickness design. In the evaluation of two-lift concrete construction, the ultimate flexural strength requirement at 28 days will ensure that the Tollway's inputs into the American Association of State Highway and Transportation Officials (AASHTO) Pavement ME Design software are adequate to support the design traffic throughout the Tollway system.

Since the mix design requirements are performance-based, the producer does not need to report the various proportions of the mixture ingredients, but rather simply the source of the ingredients, to ensure that the source requirements for the materials are met. The special provision does require that the concrete is a ternary blend of cementitious materials, meaning that the concrete must contain at least two supplementary cementitious materials (SCMs), such as fly ash or ground granulated blast furnace slag.

The SCM levels must range for 35 to 50 percent of the total cementitious material in the mix design.

The mix design components for the black rock concrete used for the bottom lift of the two-lift composite concrete pavement are shown in Table 1.

Table 1. Black Rock Mix Design for I-88 Reconstruction

<table>
<tr><th>Material</th><th>Proportion</th></tr>
<tr><td>Portland Cement, Type I</td><td rowspan="3">Fly Ash and Slag Cement are 35 percent of total cementitious</td></tr>
<tr><td>Class C Fly Ash</td></tr>
<tr><td>Slag Cement</td></tr>
<tr><td>Crushed limestone (IDOT CM-11 gradation)</td><td rowspan="2">“Black Rock” is 21 percent of total coarse aggregate</td></tr>
<tr><td>Coarse Fractionated RAP</td></tr>
<tr><td>Natural Sand (IDOT FM-02 gradation)</td><td></td></tr>
<tr><td>Water</td><td></td></tr>
<tr><td>Air Entraining Admixture (ASTM C260)</td><td>As needed</td></tr>
<tr><td>Water Reducing Admixture (ASTM C494)</td><td>As needed</td></tr>
</table>

The mix components for the Illinois Department of Transportation (IDOT) standard Class PV mix design used for the upper lift of the two-lift composite concrete pavement are shown in Table 2.

Table 2. IDOT Class PV Mix Design for I-88 Reconstruction

Material	Proportion, kg per m^3 (lbs per yd^3)
Portland Cement, Type I	273 (460)
Class C Fly Ash	86 (145)
Crushed limestone (IDOT CM-11 gradation)	1087 (1832)
Natural Sand (IDOT FM-02 gradation)	711 (1198)
Water	153 (258)
Air Entraining Admixture (ASTM C260)	As needed
Water Reducing Admixture (ASTM C494)	As needed

I-88 Concrete Test Results

Figure 1 summarizes the compressive strengths for the first 3 days of two-lift concrete pavement construction. The data shown were taken from both the quality control (QC) testing conducted by the contractor and the quality assurance (QA) testing conducted by the Tollway. The solid lines illustrate the results for the top-lift, “standard” IDOT Class PV concrete mixture, while the dashed lines illustrate the results for the lower-lift, black rock concrete mixture.

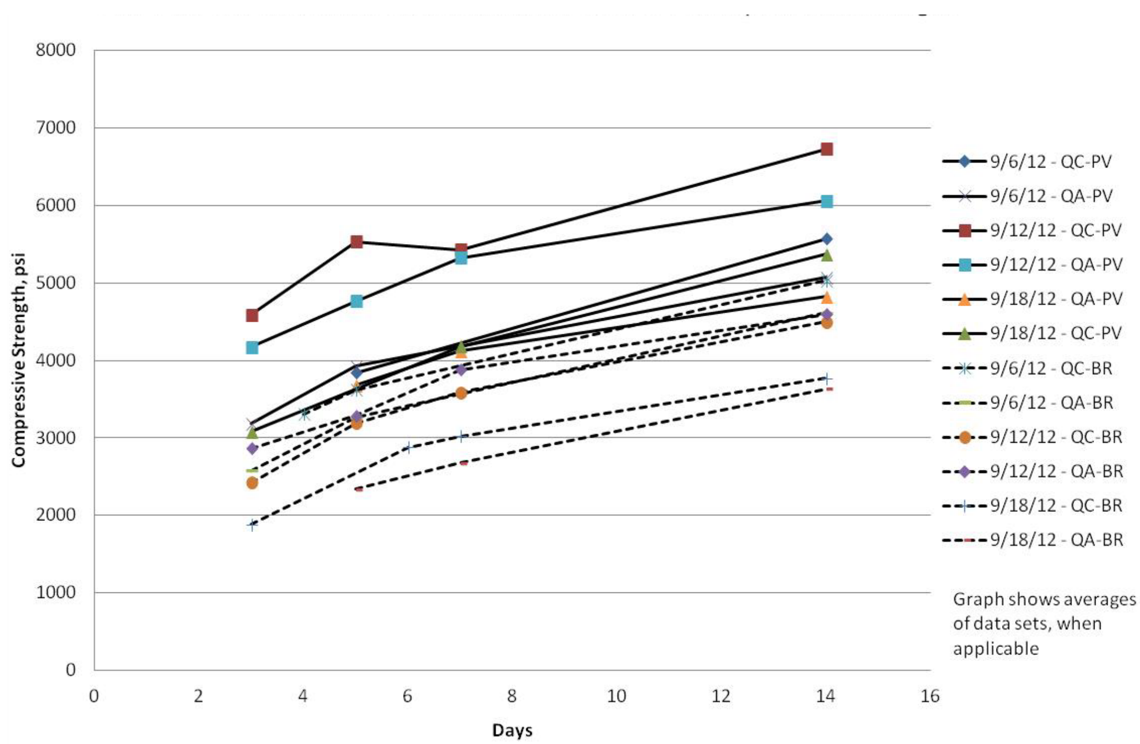

Figure 1. I-88 Two-Lift Pavement: Black Rock and IDOT PV Concrete Compressive Strength

Figure 2 summarizes the flexural strengths (third-point loading) for the first 3 days of two-lift concrete pavement construction. Again, both QC and QA results are shown. The solid lines illustrate the results for the top-lift, IDOT Class PV concrete mixture, while the dashed lines illustrate the results for the lower-lift, black rock concrete mixture.

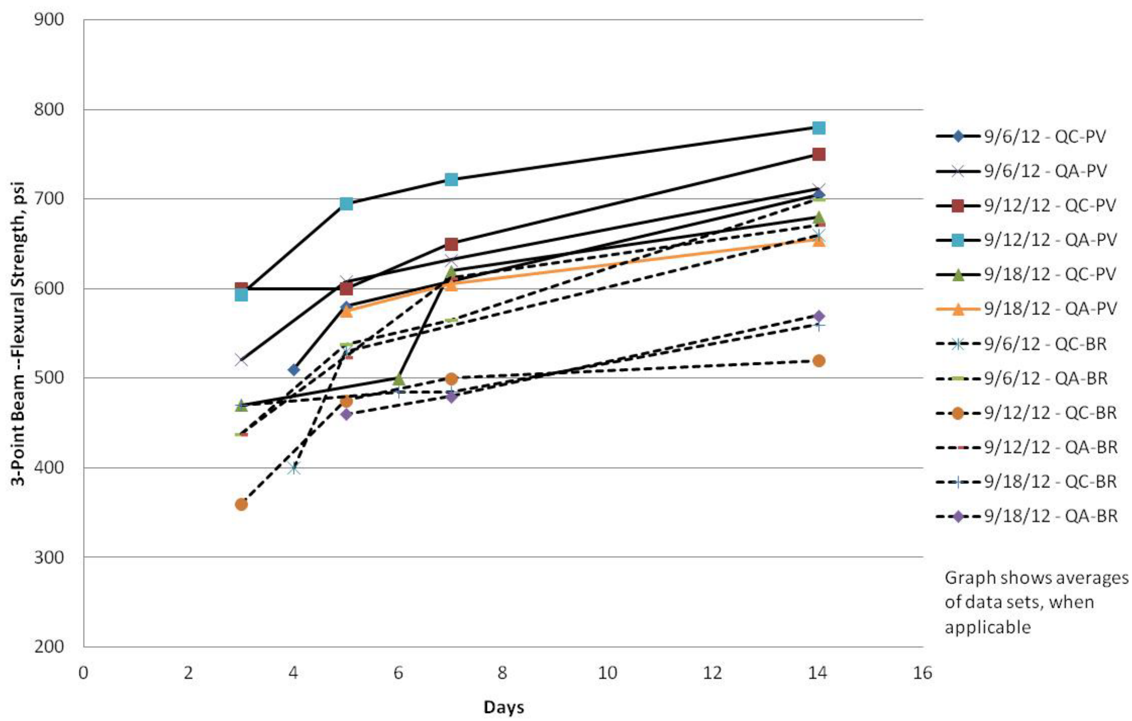

Figure 2. I-88 Two-Lift Concrete: Black Rock and IDOT PV Flexural Strength

As can be noted in Figures 1 and 2, the strengths of the black rock concrete (dashed lines) were generally less than those of the standard paving concrete mix (solid lines). However, all mixtures achieved the 14-day compressive strength requirements in the contract specifications noted above. Additional review of the strength data is included in the analysis section of this paper.

Coefficient of Thermal Expansion

The coefficient of thermal expansion (CTE) is an important concrete pavement material property that has a direct impact on the performance of jointed concrete pavements. CTE is defined as the change in unit length per degree of temperature change. Measurements of CTE can have a relatively wide range.

CTE is important in pavement design because it affects both slab stresses and joint openings. The magnitude of the curling stresses (caused by differences in temperature from the top to the bottom of the slab) is very sensitive to the CTE. The CTE plays an important role in optimizing jointed concrete joint design and in accurately determining the pavement stresses over the design life that are critical to cracking and faulting.

The CTE is strongly influenced by the aggregate type (geology) as well as the cement paste content and other concrete mix factors. Because CTE can be estimated from the weighted average of the mix components, the aggregates have the largest impact on CTE, as they make up 70 to 80 percent of the portland cement concrete volume.

The measured CTE values for the I-88 construction are shown in Table 3. These values are consistent with other mixes using the same aggregate sources, are consistent among the various days of production, and are consistent with the CTE used in pavement design. There are no anticipated issues or impacts on CTE using black rock in two-lift concrete pavements.

Table 3. CTE Test Results

Mix Type	CTE (in/in/ºF)	CTE Average of Set (in/in/ºF)
Black Rock	4.798E-06	4.794E-06
	4.888E-06	
	4.695E-06	
Black Rock	4.793E-06	4.824E-06
	4.870E-06	
	4.810E-06	
Black Rock	4.878E-06	4.840E-06
	4.860E-06	
	4.783E-06	
Top Concrete	4.444E-06	4.442E-06
	4.430E-06	
	4.452E-06	
Top Concrete	4.486E-06	4.522E-06
	4.643E-06	
	4.437E-06	
Top Concrete	4.622E-06	4.604E-06
	4.615E-06	
	4.575E-06	

DATA ANALYSIS

Strength

Concrete containing coarse FRAP has shown to have lower compressive and flexural strength than the same concrete mixture with all virgin aggregate (Brand et al., 2012), and the experience on the I-88 project is no different. However, the comparison of the two concrete mixtures isn't strictly possible, since the black rock mix design didn't simply replace virgin coarse aggregate with coarse FRAP. Most obviously, the quantity of portland cement that was replaced by supplementary cementitious materials (fly ash and slag cement) was much higher for the black rock mix than for the standard mix (35 percent versus 24 percent).

The strength and modulus properties of concrete materials are key to the long-term performance. Flexural strength (MR) is the maximum tensile stress at rupture at the bottom of a simply supported concrete beam during a flexural test. Like all measures of concrete strength, MR is heavily influenced by the concrete mix design and the curing. The aggregate properties are important to the strength and modulus because of their relatively high modulus (compared to that of cement paste) and their control of the volumetric stability of the concrete material. The strength, angularity and surface texture of the aggregate impacts crack development and propagation in concrete materials. A high-strength matrix and low-strength aggregate will tend to fail at the interface or by fracturing the aggregate. A low-strength matrix and a high-strength aggregate will fail at the bond interface or by cracks in the matrix. Because the interface with Black Rock is a potential weakness in the concrete materials, it is essential to understand the strength and modulus properties of the concrete mixtures.

The MR has a significant impact effect on the fatigue cracking potential of the slabs under repeated slab bending. Because of this primary impact, the MR needs to be characterized with great care in concrete pavement design. It is further important to understand how the MR changes over time as it relates directly to the pavement performance.

One comparison that can be made is between the compressive and flexural strengths of the concrete. An equation typically used is:

$$MR = k\ x\ \sqrt{F'c} \qquad \text{Equation 1}$$

Where MR = Modulus of rupture (third-point flexural strength)
k = factor
F'c = compressive strength

The researchers analyzed all of the I-88 strength results for the black rock and standard concrete that had a comparable result (e.g., a 28-day strength for each test) when samples were cast from the same batch. The results of the analysis are in Table 4, where the k factor is solved for using Equation 1.

Table 4. Comparison of I-88 Strength Results

	k Factor (inch-pound units)	
	Standard Mix	**Black Rock Mix**
Average	9.4	9.1
High	10.3	11.0
Low	8	7.0
Standard Deviation	0.7	1.2

The k factor for non-high-performance concrete mixtures typically ranges between 7.5 and 10 inch-pound (Kosmatka, 1985). The k factor relationships for the standard and black rock mixes are generally the same. Therefore, the assumption of flexural strength that is often made for use of MR in pavement design is appropriate for the black rock concrete mixes.

I-88 Construction Operations

Two-lift concrete construction operations have often included two vibratory paving machines when casting the concrete. The Tollway allows the contractor to use other equipment options by demonstrating the effective placement of the two-lift pavement during the construction of a test strip. In the I-88 work, the contractor demonstrated effective placement operations using a placer/spreader to deposit the mix onto the pavement and then strike-off the lower lift to line and grade. The second lift was then placed on the unconsolidated first lift (Figure 3), and then both lifts were consolidated together by the slipform paver/finisher. The interface location between the two-lifts was not perfectly straight (Figure 4), as referenced by the red dye in relationship to the plan location of the lift boundary. However, with additional coring and a complete analysis of the pavement consolidation, the effective placement and consolidation demonstrated using this equipment and construction method satisfied the Tollway's requirements.

Figure 3. Top Lift Being Placed on the Unconsolidated Lower Lift

Figure 4. Illustration of the Two Lifts in the Composite Concrete Pavement

One purpose for two paving machines may be to prevent commingling of the two mixtures when drastically different mixture types are used in the pavement construction. For instance, a two-lift concrete construction project for the Kansas DOT (Fick, 2009) involved a standard concrete mixture on the bottom and a high-friction, low-noise, small aggregate mixture in the top lift. It is beneficial to keep the highly engineered, upper lift separated from the lower lift, and therefore, two paver/finishers were used in the construction of the Kansas two-lift pavement.

The Tollway's two-lift concrete pavement design targets increased recycling and sustainability in the lower lift, with a standard, long-term performance paving mix for the top lift. The ingredients in the two mixtures are similar enough that a minor amount of intermixing at the two-lift interface is not detrimental. A concern with any concrete pavement construction process is the consolidation of the concrete. An additional concern with two-lift construction is the possible separation or debonding between the two lifts.

One "lesson learned" from the I-88 construction is the time limitation that exists between the two lifts of unconsolidated pavement. Some specifications allow up to 90 minutes between the two lifts, but the I-88 construction determined that effective consolidation of the entire pavement section was more difficult when the two lifts are placed on top of each other more than 45 minutes apart.

Additionally, on the I-88 reconstruction project the black rock concrete showed higher demand for the air-entraining admixture (AEA) to achieve the in-place requirements for the concrete mixture. The producer was using a typically AEA and concluded that a "concentrated" AEA may be needed for future black rock concrete production.

CONCLUSIONS

The construction practices and lessons learned from a 0.7-mile trial interstate reconstruction and widening project of two-lift concrete with FRAP show that this method is a viable way to improve the sustainability of concrete pavements. Increasing the sustainability of the concrete pavement with increased secondary cementitious materials such as fly ash and slag cement was also proven viable, with the strength requirements achievable within an acceptable timeframe applicable to interstate pavement reconstruction.

REFERENCES

Brand, A.S., J.R. Roesler, I.L. Al-Qadi, and P. Shangguan. *Fractionated Reclaimed Asphalt Pavement (FRAP) as a Coarse Aggregate Replacement in a Ternary Blended Concrete Pavement*, Illinois Center for Transportation Report No. ICT-12-008, 2012.

Brand, A.S., A. N. Amirkhanian,, J.R. Roesler. *Flexural Capacity of Rigid Pavement Concrete Slabs with Recycled Aggregates*, Illinois Center for Transportation Report No. ICT-13-XXX, 2013.

Fick, G. *Two-Lift Concrete Paving in Salina/Abieine, Kansas— Interstate 70*, Trinity Construction Management, Inc., December 2009.

Gillen, S.L., A.S. Brand, J.R. Roesler, and W.R. Vavrik. "Sustainable Long-Life Composite Concrete Pavement for the Illinois Tollway," International Conference on Long-Life Concrete Pavement, Seattle, Washington, 2012.

Illinois Tollway. *Coarse Aggregate for Composite Portland Cement Concrete Pavement,* Special Provision, 2012a.

Illinois Tollway. *Composite Portland Cement Concrete Pavements*, Special Provision, 2012c.

Illinois Tollway. *Performance Related Special Provision for Ternary Concrete Mix Designs for Composite Pavements*, 2012b.

Kosmatka, S.H. "Compressive versus Flexural Strength for Quality Control of Pavements," *Concrete Technology Today*, December 1985, 6(4): 4-5.