Mechanistic Analysis of Composite Pavement (HMA over PCC) System

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A. Introduction

A newer pavement system technology in the transportation construction industry, called "Composite Pavement", is a combination of either a Portland Cement Concrete (PCC) base and a Hot-Mix Asphalt (HMA) overlay or a PCC base and PCC overlay. This research will take a more in depth look at the specific combination of PCC and HMA. The first part is a review of *Composite Pavement Systems, Volume 1, HMA/PCC Composite Pavements,* created by the SHRP2 (Second Strategic Highway Research Program) (Rao et al. 2013). The second part is a mechanistic analysis of the performance of composite versus traditional pavement.

B. Literature Review of SHRP2 Publication

B.1 Background

One of the advantages of composite pavements is that a safe, smooth, quiet, strong and durable road can be constructed using this method that will require less maintenance than a traditional pavement system. This is because the underlying strength of the PCC slab bears most of the structural load, and can last much longer than an asphalt concrete base, while the high quality HMA surface ensures good friction, drainage, sound control, and surface smoothness. Another advantage is that high quality aggregate does not necessarily need to be used in the PCC, and can even be composed of recycled aggregate. There is also an ease of maintenance with this system, as usually the layer of HMA need only be replaced, and the PCC base can be left in place much longer.

Some of the most common disadvantages cited by various agencies concerning HMA/PCC composite pavement systems are the cost and occurrences of reflection cracking. Reflection cracking occurs when a crack occurs in the surface HMA, which has been transferred from movement at a joint or crack in the underlying PCC. Other disadvantages include industry acceptance issues, lack of experience with this type of construction, lack of long-term data, rehabilitation and characterization of underlying PCC, construction time, and surface durability.

A typical cross section of an HMA/PCC composite pavement system includes a relatively thin but high-quality surface layer of HMA. Underneath this is a thicker, but often lower-quality PCC slab. Recycled concrete is often used in this slab. Underneath the PCC slab is usually a well-graded base coarse; specifications depend on the in-situ soil stability and strength. Subbase or subgrade may just be in-situ soil or an improved graded soil depending on the region and traffic loading requirements. An example of a typical cross-section is shown in Table 1 below, along with Figure 1, a typical cross-section.

Section		Cell 70 HMA/PCC (475 ft [145 m])
HMA	Thickness	3 in. (75 mm) placed in two lifts
	Binder	PG 64-34
	Mix	Superpave wearing course designated SPWEB440F with 0.5 in. (12.5 mm) nominal maximum aggregate size (SP 12.5)
PCC	Thickness	6 in. (150 mm)
	Mix	Low portland cement concrete (~360 lb/yd³) plus 240 lb/yd³ (40%) fly ash, Class C (FAC)
	Coarse	50% RCA, 50% Mn/DOT Class A
	Aggregate	Maximum aggregate size 1.25 in. (32 mm)
Base		8 in. (200 mm) Class 5 unbound
Subgrade		Clay
Joint spacing		15 ft (4.6 m)
Dowels		1.25 in. (32 mm) placed on baskets in driving lane at PCC middepth and nondoweled passing lane
Joints		Saw and seal HMA over PCC joints (except last six joints)

Table 1: Typical Cross Section Composition (*SHRP2*)

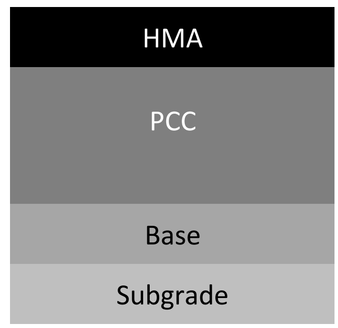


Figure 1: Typical Cross Section Composition

As mentioned, reflection cracking is the most commonly cited type of pavement distress. Another common distress found with these pavements is fatigue cracking, which typically initiates at the bottom of the PCC slab, where the slab is in tension. However, since PCC is significantly stronger than typical bases made of HMA, fatigue cracking is less common in these composite pavements than in typical HMA pavements. Fatigue cracking is virtually non-existent in the HMA of composite pavements because the HMA is almost always in compression. This causes for longer ride quality and reduction in noise because fatigue cracking is eliminated in the wheel path. Fatigue cracking may occur at the bottom or top of the HMA layer if friction has been lost between the HMA and PCC, and fatigue cracking in the PCC may reflect through to the HMA. This loss of interlayer friction is a problem that can also lead to potholes and slippage cracks. Freeze-thaw durability is another factor that is particularly important in the underlying PCC layer, which is designed to be in place for two to three lifetimes of the HMA overlay. Rutting, longitudinal cracking, and low temperature thermal cracking are minor issues that are not as likely to affect HMA/PCC composite pavement systems.

B.2 Design Process

The typical design process is as follows. The design life, reliability (R), and distress restrictions must be determined. The materials are chosen for the base, PCC slab, and HMA. The base is usually comprised of a course aggregate. PCC is comprised of coarse and fine aggregates, water and Portland cement. Often times lower quality aggregates, even recycled materials, are all that is required for the slab. The slab is what bears most of the loading, so compressive strength is highly important to the design; the modulus of elasticity must also meet the design criteria. The HMA surface is comprised of varied grade of aggregate and asphalt binder. The grain size distribution of the aggregates is designed to fulfill requirements for friction and drainage. The resilient modulus is also taken into account for the HMA. Site conditions must be recorded before design can begin as well. This includes current traffic volume and loading and future growth.

B.3 Construction Techniques

Another advantage of this system is that there is no new technology or equipment that needs to be developed in order to implement it. The basic construction process is as follows. The first step is to prepare the sublayers such as subgrade, subbase and base course. This may consist of a variety of materials including cement- or lime-treated subgrade soils, asphalt- or cement-treated base course, permeable base courses and recycled pavement materials. Drainage features, such as edge drains, may also be included in this part of the construction process. Next the PCC base should be placed, and the shoulder ties should be placed simultaneously if required. Reinforcement should be placed prior to pouring the concrete and should be located at the midpoint of the PCC slab and fastened into the sublayers below the slab.

The PCC layer is placed using a common paver while the concrete is delivered by concrete mixing trucks. The fresh properties of the concrete should also be tested during placement. These include air content and slump tests. The PCC surface should also be textured to create an interlocking mechanism with the HMA and the surface should be cured. The most common form of texturing is longitudinal tining. The curing of the PCC surface prevents rapid surface drying and early-age cracking from rapid moisture loss.

Joints should be sawed transversely into the PCC slab at the location of the dowel bars in order to allow for thermal expansion at these joints. These joints should be marked precisely so that joints can be sawed and sealed in the HMA layer directly above them. The PCC layer should be allowed to reach a sufficient structural strength, as specified by agency requirements, in order to support traffic load and be covered by the HMA layer. Before the HMA layer can be placed, a tack coat must be applied to ensure proper adhesion between the PCC and HMA layers. The HMA should be applied per standard HMA paving practices. The properties should be tested by QA/QC and the pavement surface should be as smooth as possible upon application to ensure a smooth ride for the distant future. The shoulders should also be placed at this time. Finally, the transverse joints should be sawed in the exact location of the underlying joints that were cut in the PCC layer. These joints should extend into or completely across the shoulder.

Two small test sections of composite pavement were recently constructed on the Illinois Tollway on the ramps from I-94 to Milwaukee Avenue near Gurnee, Illinois. These test sections were used to implement several sustainability improvement techniques in road construction. These techniques included RAP, partial replacement of cement with fly ash and use of WMA.

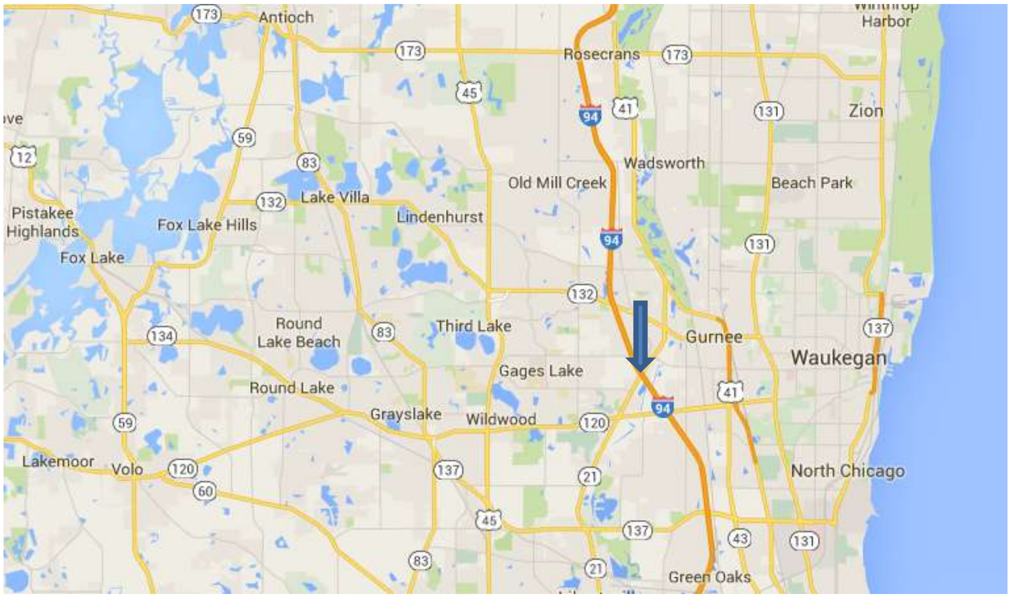


Figure 2: Two test sections near Gurnee, IL

The RAP was used in the course aggregate of the PCC mix, comprising 30% of the total course aggregate. This RAP was required to be fractionated, cleaned and washed. However, all fine aggregates were required to come from virgin sources. RAP was also used in the HMA mix, making up 10% of the aggregates, the rest had to come from local sources. The binder content in the HMA was 5.2%. The process for constructing these test sections followed the standard process that was previously described. QA/QC tests were run on the as-constructed pavements and the results are given in Tables 2 and 3 below.

Property	Value
% Passing 12.5-mm (½-in.) sieve	100.0%
% Passing No. 200 sieve	4.9%
Asphalt binder percentage by weight	5.5%
Voids in mineral aggregate	15.0%
Bulk specific gravity	2.398
Max specific gravity	2.482
Average core density	143.8 lb/ft^3

Property		7 Day	14 Day	28 Day
Entrained air content	4.4%–7.1% (average 5.6%)	na	na	na
Unit weight	146.4 lb/ft^3	na	na	na
Compressive strength	na	4,165 psi	4,430 psi	5,210 psi

Note: na = not applicable.

Tables 2 and 3: Properties of asphalt (2) and concrete (3) in composite pavement test sections. (*SHRP2*)

Additional field sites were also studied within the state of Illinois to cover other types of composite pavement and give more details on long-term performance of these pavement systems. In 2006, a composite pavement comprised of 2-in SMA (Stone Matrix Asphalt) over 2.25-in HMA, all of which was over 8-in CRC was constructed on I-64 near Fairview Heights, Illinois. To give an idea of the type of loading this pavement endured, it was recorded that 1.4 million trucks traveled this road's interior lane in 5 years. The pavement appeared to be in excellent condition as of 2011 and the only distresses were occasional minor mid-lane longitudinal cracks that could have been reflected from the longitudinal joints in the PCC. No rutting has occurred in this pavement.

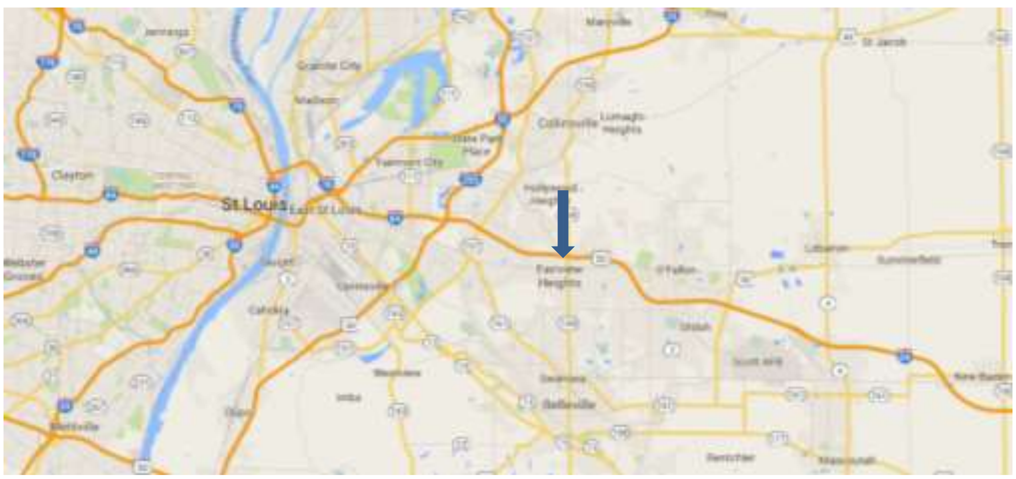


Figure 3: Test section near Fairview, IL

In 1992, a composite pavement was constructed on I-294 in Chicago, Illinois. This pavement was made of a 3.5-in layer of HMA over a 12.5-in JPC layer. In 2000, the layer of HMA was milled and a new 3.0-in layer of HMA was placed. In 2010, the pavement was reviewed for performance, after an estimated 30 million trucks had traveled the outer lane in the 19 years since its creation. It was noted there was reflection cracking only at the transverse joints in the JPC (Joined Plain Concrete). These reflection cracks have caused some roughness from their deterioration, and additional roughness has occurred from slight raveling. There was 0.2 inches of rutting in the wheel path.

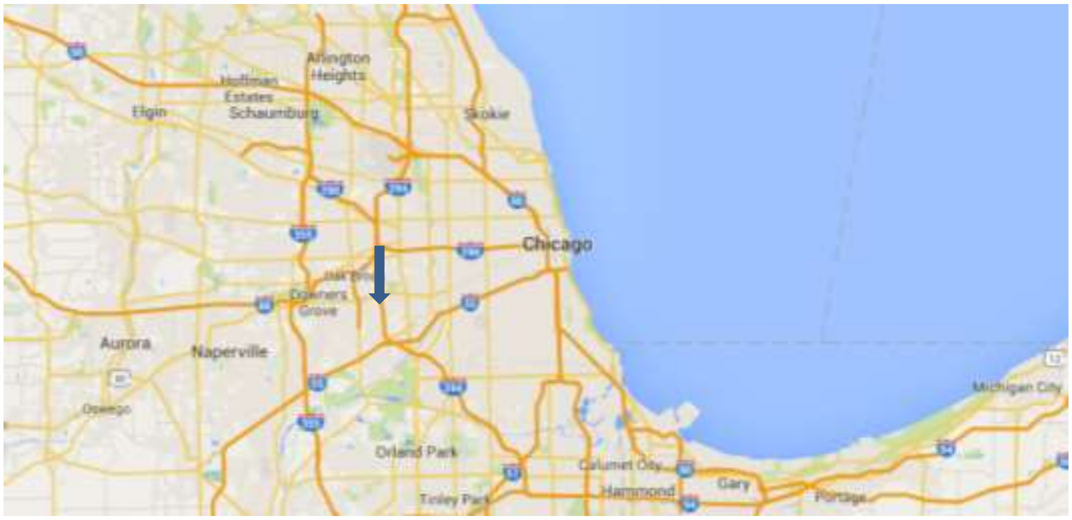


Figure 4: Test section on I-294

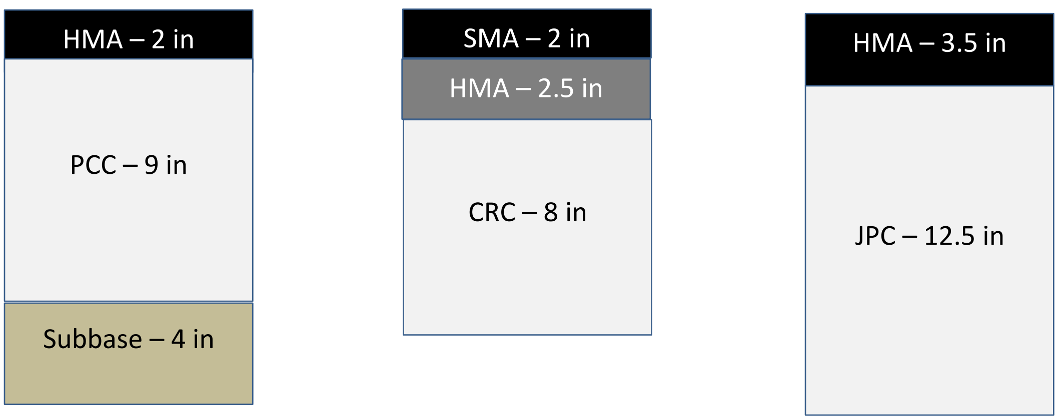


Figure 5. Cross-section of test pavements on the following interstates in Illinois: I-94 near Gurnee, I-64 near Fairview Heights, and I-294 in Chicago respectively.

The results of the performance of the test sections have shown that composite pavement implementation has resulted in a satisfactory fulfillment of the purpose and goals of this system. The following section delves further into the performance of this pavement system.

C. Mechanistic Analysis of Composite Pavements Using AASHTOWare

When comparing the performance of conventional HMA pavements to those of composite HMA/PCC pavements, a ME (Mechanistic-Empirical) Design software called AASHTOWare is used, which simulates the performance of various pavements under a variety of loadings and environmental strategies.

In order to find a composite pavement that has an equivalent strength, a conventional HMA pavement over a granular base and a composite pavement with a two-inch HMA overlay over a PCC slab are taken. Both of these pavements were over the same subbase and subgrade. A 6 inch HMA pavement over a 10 inch base and a 2 inch HMA over lay over a PCC slab of undetermined depth are assumed. To determine this depth the modulus of elasticity of each material is used to find the transformed depth of the HMA pavement if it were PCC. A modulus of elasticity of 475 ksi for the HMA and 30 ksi for the granular base are assumed. According to the American Concrete Institute, the modulus of elasticity is found by the formula $5700\sqrt{f'c}$, where f'_c is typically 4 ksi for design purposes. This yields a modulus of elasticity of 3605 ksi.

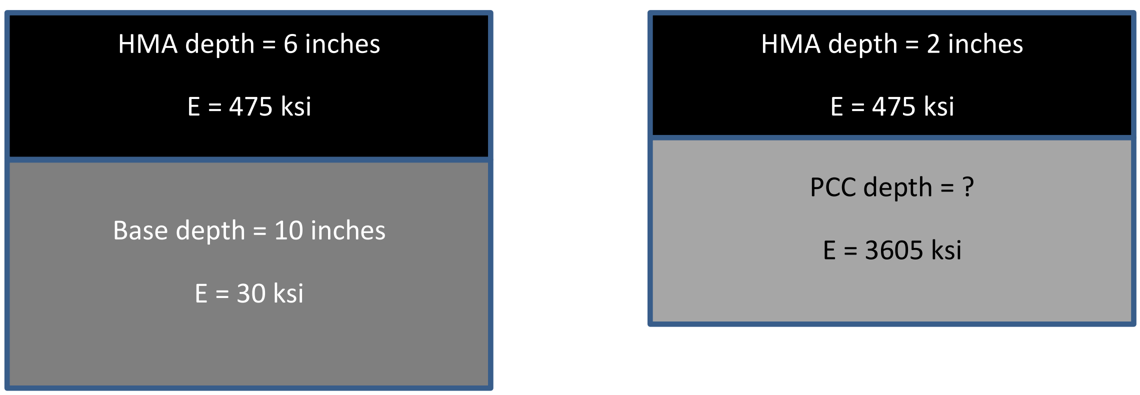


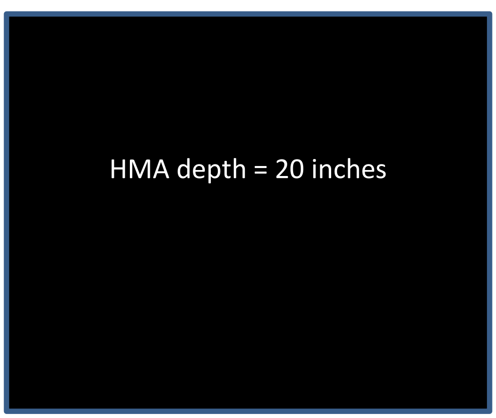
Figure 6. Equivalent depths of HMA and composite pavements.

The following equality shows the relationship that exists between the two pavements.

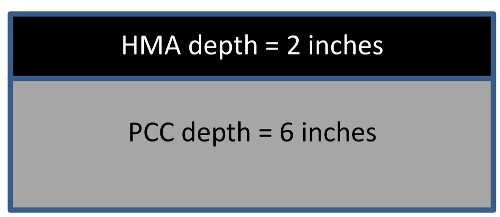
(6 in HMA)(475 ksi) + (10 in base)(30 ksi) = (2 in HMA)(475 ksi) + (depth of PCC)(3605 ksi)

Solving for this equation yields a PCC depth of 0.6 inches. When this value is entered into the performance software, it incurs an error that states the PCC slab must have a minimum thickness of 6 inches in order to be evaluated. This minimum thickness is consistent with design and construction practice in most districts. The reason is that 0.6 inches of PCC may have a theoretical strength that is equal to 6 inches of HMA, but the brittleness and marginal weakness of the concrete does not allow it to develop its full strength in this thin of a layer. Plus reinforcement cannot be placed in concrete slabs that are too shallow.

It is therefore necessary to set a standard PCC depth of 6 inches and work backwards to find the equivalent HMA depth, all other things being held constant. This calculation yields that a composite pavement of 6 inches of PCC and 2 inches of HMA is equivalent to 46.9 inches of HMA over 10 inches of base material. We can see from this that having an underlying PCC slab in a composite pavement creates a much stronger pavement overall, and is more economical. The performance software cannot evaluate any asphalt pavement thicker than 20 inches either. Therefor an analysis will be run on composite pavement having the minimum PCC thickness of 6 inches and an analysis will be run on traditional pavement with the maximum asphalt thickness of 20 inches. Both of these pavements are assumed to be over the default base and subgrade, so these factors will not vary in the analysis. A diagram of a 20 in AC pavement and a 6 inch PCC pavement with a 2 inch HMA overlay is shown below in Figures 7 and 8 respectively, followed by the analysis of each pavement in Figures 9 and 10 respectively.



Figures 7. 20 inch AC pavement



Figures 8. 6 inch PCC with a 2 inch overlay composite pavement

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	137.79	90.00	99.35	Pass
Permanent deformation - total pavement (in.)	0.75	0.38	90.00	100.00	Pass
AC bottom-up fatigue cracking (percent)	25.00	1.45	90.00	100.00	Pass
AC thermal cracking (ft/mile)	1000.00	26.22	90.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	2000.00	332.00	90.00	100.00	Pass
Permanent deformation - AC only (in.)	0.25	0.21	90.00	98.38	Pass

Figure 9. Distress Prediction Summary of 20 inch AC pavement

Distress Type	Distress @ Specified Reliability		Reliability (%)		Criterion Satisfied?
	Target	Predicted	Target	Achieved	
Terminal IRI (in./mile)	172.00	114.06	90.00	99.99	Pass
Permanent deformation - total pavement (in.)	0.75	0.20	90.00	100.00	Pass
Total Cracking (Reflective + Alligator) (percent)	15	6.67	-	-	Pass
AC thermal cracking (ft/mile)	1000.00	218.81	90.00	100.00	Pass
JPCP transverse cracking (percent slabs)	15.00	3.83	90.00	100.00	Pass
AC bottom-up fatigue cracking (percent)	25.00	1.45	90.00	100.00	Pass
AC top-down fatigue cracking (ft/mile)	2000.00	256.84	90.00	100.00	Pass
Permanent deformation - AC only (in.)	0.25	0.20	90.00	98.86	Pass

Figure 10. Distress Prediction Summary of 6 inch PCC with a 2 inch AC overlay composite pavement

It can be seen from these analyses that the permanent deformation in the total pavement and the AC pavement, and the AC top-down fatigue cracking are less in the composite pavement. However, the AC thermal cracking is significantly greater in the composite pavement. The AC bottom-up fatigue cracking and terminal IRI remain the same between these pavements. This analysis also compares the maximum traditional pavement thickness that can be analyzed to the minimum PCC thickness in composite pavement that can be analyzed, and the composite pavement still performed better. It can be concluded that the composite pavement performs the same or better in most of the criteria. It is also important to note that the overall pavement thickness was much less in the composite pavement than in the HMA pavement, and using fewer materials would have great economic benefits.

D. Conclusion

This new technology is still spreading and adapting to industry standards. There are limitations to this technology, and it should only be used in appropriate situations. The benefits, however, are clear. This technology allows for strong performance, and still provides the benefits of smoothness and sound control that a full HMA pavement has. It is also easier to maintain and allows for more recycled products to be used in the PCC base. It will likely be a technology that society will see implemented more and more in the future.

Reference:

Rao, S., Darter, M., Tompkins, D., Vancura, M., Khazanovch, L., Signore, J., Coleri, E., Wu, R., Harvey, J., and Vandenbossche, J. (2013). *SHRP 2 Report No: S2-R21-RR-2: Composite Pavement Systems-Volume 1: HMA/PCC Composite Pavements*. Washington, D.C., USA.