



Guidelines and Implementation Recommendations

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GUIDELINES AND IMPLEMENTATION RECOMMENDATIONS

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GUIDELINES AND IMPLEMENTATION RECOMMENDATIONS

Based on findings from the literature review, laboratory tests, and pavement performance simulations, researchers concluded that the use of reclaimed asphalt pavement (RAP) in Portland cement concrete (PCC) is largely feasible for the pavement application. Despite the fact that RAP-PCC yielded reduced mechanical properties (especially different strengths), a proper utilization of optimized aggregate gradation benefits from using RAP and the use of RAP-PCC as a bottom lift in a two-lift pavement construction can compensate the strength reduction and allow more RAP in the mixture. An even higher amount of aggregates (both coarse and fine) can be replaced to make full use of RAP to make low strength PCC for the other applications such as curbs, gutters, sidewalks, etc. Considering the factors related to strength, materials, construction, and performance, researchers developed the following guidelines.

1.1 GUIDELINES

1.1.1 Material Selections and Mix Design

The properties of RAP vary significantly. To make a RAP-PCC with less strength reduction and adequate durability, a good quality RAP material is needed. The RAP materials characterized by lower asphalt binder content (for a coarse RAP with gap aggregate gradation, <5.0 percent; for a coarse RAP with dense aggregate gradation, <7.0 percent) and lower amount of agglomerated particles are generally considered as good quality RAPs. Asphalt cohesive failure was found to be the main failure mechanism in RAP-PCC. In the cohesive failure, cracks easily pass through the asphalt layer in RAP-PCC. Therefore, the higher the binder content, the higher the chances of occurrence of cohesive failure are. The use of coarse RAP alone satisfies low binder content requirements in general.

Fine RAP (particles passing No. 8 sieve) is not suitable to make RAP-PCC for the pavement application because 1) it contains higher binder content than the coarse RAP and would induce a more significant reduction in workability and strength; and 2) the high amount of asphalt binder in fine RAP can be re-used in the hot-mix asphalt (HMA)/warm-mix asphalt (WMA) industry more economically. Fine RAP can be used along with coarse RAP to make PCC for non-pavement low strength applications in order to maximize RAP usage. The use of fine RAP is very important if there is an excess amount of fine RAP or the fractionation of RAP is an issue.

RAP materials generally contain some amount (amount varies) of intermediate size particles (passing 3/8 in. sieve and retained on #8 sieve) and replacing virgin aggregate with RAP containing adequate amounts of intermediate size particles actually introduces dense aggregate gradation in RAP-PCC mixtures. Therefore, RAP source with adequate amounts of intermediate size (>50 percent) particles is highly preferable to achieve a RAP-PCC mix with dense graded benefits. Coarse RAP materials generally contain intermediate size aggregate particles by default as dense aggregate gradation is commonly used to make HMA mixtures for pavement applications. RAP-PCC mixes with dense aggregate gradation help enhance workability and strength, and compensate higher strength reduction normally observed in absences of dense aggregate gradation.

1.1.2 Meet TxDOT Class P Strength Requirement Criteria for Full-Depth Pavement Application

The asphalt in the RAP is considered the major cause of the strength reduction in a RAP-PCC system. Therefore, the asphalt content (i.e., the RAP replacement level) in the mixture needs to be strictly controlled to ensure that the department of transportation strength requirements are met. The 28-day flexural strength can be selected as strength criteria because: 1) The flexural strength is considered to be an important and relevant parameter related to concrete pavement performance because concrete is weak in tension and its tensile strength should be strictly controlled under traffic and environmental loading. The Texas Department of Transportation (TxDOT) pavement design guide approves use of TxCRCP-ME and the American Association of State Highway and Transportation Officials 1993 to design continuously reinforced concrete pavement and concrete pavement contraction design (joint plain concrete pavement) slab thickness, respectively; both of them require 28-day flexural strength as material input, while the compressive strength is not needed; and 2) The RAP-PCC had slower flexural strength growth over time than that required by the specification, so meeting the 28-day flexural strength requirement may be considered a conservative way to estimate the replacement level. The following procedures are recommended for designing a RAP-PCC that meets TxDOT's Class P strength specification:

1. Select a good quality of coarse RAP material and test asphalt binder content for the selected RAP according to ASTM D 6307. A RAP material with greater amounts of intermediate size particles (to achieve dense graded gradation) and lower ranges of asphalt binder content (to ensure higher RAP replacement level) is desirable. Coarse RAP materials with ideal gradation range requirements to make RAP-PCC mixes for pavement applications is generated. It is recommended that contractors generate RAP stockpile materials satisfying the gradation requirements.
2. Design RAP-PCC mixtures by replacing 20 percent coarse RAP and 40 percent coarse RAP, respectively. If possible, adding one more point (30 percent) is highly recommended.
3. Cast and cure RAP-PCC samples as well as the reference sample designed in step 2; test samples' mechanical properties at 28 days. It is recommended to test 28-day flexural strength. If the flexural strength test is not applicable, testing compressive strength is allowed.
4. Construct a regression relationship between the 28-day flexural strength (or compressive strength if it was tested in step 3) and the global asphalt binder volumetric fraction (GABVF).
5. Determine the optimum GABVF in accordance with the target flexural strength. For TxDOT Class P specification, the 28-day flexural strength requirement is 570 psi. If 28-day compressive strength is tested in step 3, the target compressive strength requirement can be set as 3906 psi (determined by using the modified American Concrete Institute correlation equation developed). Back-calculate the optimum RAP replacement level using mix design information.

1.1.3 Meet TxDOT Different Strength Requirement Criteria for Low-Strength Applications

Although the production of RAP-PCC for full-depth pavement application is restricted to coarse RAP replacement alone at this point, the use of fine RAP (alone or combined with coarse RAP) for low-strength PCC applications is allowable. This use of fine RAP in PCC can maximize RAP usage if excess fine RAP is available or the RAP fractionation becomes an issue. The guidelines for making RAP-PCC mixes that meet lower strength requirements (class A, B, C, E, S, and SS) are presented below.

If time and expense permit, a robust method to determine the optimum RAP replacement level is always encouraged. This approach, performed through a case by case experimental study, can ensure better accuracy in determining RAP replacement. The following procedures are recommended:

1. Select a RAP material and test asphalt binder content for the selected RAP according to ASTM D 6307.
2. Design RAP-PCC mixtures by introducing RAP at various replacement levels covering the entire range (e.g., 0, 20 percent, 40 percent, 70 percent, and 100 percent). If both of the coarse and fine RAPs are used, replace virgin coarse aggregate with coarse RAP and replace virgin fine aggregate with fine RAP at designed replacement levels, respectively. If only coarse RAP or fine RAP is used, replace the corresponding virgin aggregate at designed replacement levels.
3. Cast and cure RAP-PCC samples as well as the reference sample designed in step 2; test samples' 56-day compressive strength.
4. Construct a regression relationship between the 56-day compressive strength and GABVF.
5. Select the best regression equation for describing the compressive strength and binder fraction relationship. If the maximum GABVF for the tested RAP-PCC is smaller than 3.5, a linear relationship might be valid. Otherwise, a logarithmic relationship might be more suitable.
6. Determine the optimum GABVF in accordance with the target 56-day compressive strength specified by different concrete class in Item 421 (i.e., 2000 psi for Class B, 3000 psi for Class A and E, 3600 psi for Class C and Class SS, and 4000 psi for Class S). Back calculate the optimum RAP replacement level using mix design information.

The following procedures provide an approach for designing RAP-PCC mixtures that meet TxDOT's different strength specifications in a less robust way, provided the time and expense are limited or the strength requirement is less crucial:

1. Select a RAP material and test asphalt binder content for the selected RAP according to ASTM D 6307.
2. Determine the mix design for the reference PCC and test its 56-day compressive strength.
3. Select the target 56-day compressive strength requirement based on the different class requirement; calculate the allowable percent reduction between the reference PCC compressive strength and the target one.

4. Using the generalized correlation equation: $\%red = 26.455 \times \ln(\theta) + 6.2264$ to estimate the allowable GABVF.
5. Back-calculate the optimum RAP replacement level using mix design information.

Due to fact that the RAP properties can vary with time and sample selection, it is highly recommended to cast and test RAP-PCC with designed RAP replacement according to the procedures that are described above to verify the mixture has the specified strength.

1.1.4 Selection of RAP-PCC Pavement Type

A significant amount of further work is needed in order to develop procedures for better selection of a RAP-PCC structure that satisfies the requirements of mechanical performance and sustainability (i.e., ensuring the positive effects on economics, environment, and human life). Based on the findings to date from this study, the following recommendations are made.

If the designed RAP-PCC can satisfy the requirements of adequate surface characteristics and mechanical properties, a full-depth pavement containing a RAP-PCC slab might be feasible. To satisfy the requirements of adequate surface characteristics, a RAP-PCC mixture needs to meet the requirements of abrasion resistance/skid resistance, noise reduction, and ride quality. A detailed study on determining these properties followed by performance prediction matching with field conditions is an important area of further research. Suitable mechanical properties (e.g., modulus of rupture, coefficient of thermal expansion) can be controlled by replacing an adequate amounts of RAP in PCC with the design approaches described in the previous section. It is still recommended to use TxDOT approved design tools to determine the RAP-PCC pavement thickness. However, it is important to validate through lab and field tests that a RAP-PCC slab of the same thickness can show an equivalent performance as a plain PCC slab. Although an increase in pavement thickness will lead to higher cost, which might be compensated by the materials savings in using existing recycled material, the positive impacts on the environment and public safety due to consuming fewer natural stones, and removing RAP stockpiles may still make the project beneficial.

If the designed RAP-PCC has undesirable surface characteristics for serving as a top layer, a two-lift pavement might be a good option. Since there is no specification on the two-lift pavement in terms of material properties, mix design and structure design, two-lift pavement construction is considered as an option in the United States and requires future work before it can be implemented in the field. From the case study of exiting two-lift pavements, a 2–3 inch top layer and a 6–10 inch bottom layer are within the normal ranges. The RAP-PCC shall be used to construct the bottom layer; the procedure to design the RAP-PCC material for a bottom lift can be established once the material specification for two-lift pavement comes out. It is anticipated to use a RAP-PCC material with low cementitious content and a high RAP replacement level for the bottom lift, which can be a more economical and environmentally friendly option for future pavement construction.

1.2 IMPLEMENTATION AND FUTURE WORK

Based on the above-mentioned guidelines, researchers presented an implementation plan with proposed further research work in order to further evaluate the RAP-PCC properties and carry out the guidelines in field applications:

- Test additional RAP materials covering a wide range of materials representing different geographic locations:
 - Generate RAP satisfying the gradation requirements; the current study actually used the RAP materials from the existing stockpiles in HMA plants to make PCC. It is important to work with the industry to develop effective procedures to make RAP materials with the required gradation from the reclaimed asphalt materials to make PCC.
 - Develop better RAP characterization techniques to help select RAP and to better predict RAP-PCC properties. Significant efforts need to be made to investigate the effect of RAP quality and mix design strategy on RAP-PCC properties. Specifically, research needs to be done to correlate or interpret the factors that affect the rate of deterioration k , which is a parameter representing how significant the negative effect of RAP on PCC properties. As an example, other than the binder content and RAP gradation, it is highly recommended to introduce the degree of RAP agglomeration. The degree of RAP agglomeration can be quantified using petrographic methods.
- Additional mechanical tests:
 - Creep test: The addition of the RAP is anticipated to cause more creep for PCC because of the viscoelastic nature of asphalt material. This assertion needs to be verified and the effect of increased creep caused by the RAP on PCC pavement performance should be investigated through finite element method simulation.
 - Fracture toughness and fatigue tests: The criteria to judge the feasibility of the use of RAP in PCC in this study was the material strength criteria. According to Bažant and Oh,¹ “when the structure is relatively large, the crack band is relatively narrow and the fracture process zone is negligibly small, which satisfies the assumption of linear fracture mechanics. The strength limit does not matter since it can always be exceeded, in view of the stress concentration at crack front, and so only fracture energy matters.” This theory appeared to be true because both the large scale slab tests and the field section tests from the previous published studies showed RAP-PCC pavement indicated equivalent performance, despite the fact that RAP-PCC had reduced strengths. Hence, the fracture properties of RAP-PCC need to be comprehensively evaluated.
- Durability tests: This study mainly focused on the mechanical properties test of PCC containing different types of RAP. While some of the preliminary durability test results were presented, more detailed and systemic research needs to be conducted to verify RAP-PCC has no durability issues. Those durability tests include but are not limited to:
 - Restricted shrinkage test: The conventional ring test for testing restricted shrinkage (ASTM C1581/C1581M) performed in this study showed no cracking in both reference PCC samples and the RAP-PCC samples within 28 days of curing. In order to get a more significant result, a shrinkage test under more severe conditions such as dual ring test is preferable.

¹ Bažant, Z. P., and Oh, B. H. (1983). “Crack band theory for fracture of concrete.” *Materials and structures*, 16(3), 155-177.

- Rapid chloride permeability test: The resistivity values of all the studied RAP-PCC mixtures and reference PCC mixtures were determined in this study. Based on the measured resistivity values, all the studied RAP-PCC mixtures showed resistivity values similar to the reference PCC sample. The well-established relationship between resistivity and rapid chloride permeability (RCP) for PCC with virgin aggregates was used to convert the measured resistivity values to RCP values for the studied RAP-PCC mixtures. However, the RAP-PCC is a new composite whose properties might differ from the conventional PCC. Therefore, it is important to perform the rapid chloride permeability test to safely verify that RAP-PCC also has adequate chloride resistance.
- Chemical durability test: Suitable tests need to be performed to verify any issues related chemical durability. The presence of an asphalt layer in aggregate may reduce the chances of an alkali silica reaction (ASR). However, the aggregate in RAP may be reactive sometimes, so detailed ASR testing is an important future durability test.
- Pavement surface characteristics: To have desirable surface characteristics (good abrasion resistance, good skid resistance, good riding quality, and low noise production) is another aspect to determine the feasibility of using RAP-PCC concrete for full-depth application, which is barely investigated in this study. A future study on this aspect is highly needed.
- Field section tests: Field sections using RAP-PCC material shall be built up in Texas as an implementation plan for this study:
 - Full-depth pavement construction: plain PCC full-depth pavement and RAP-PCC full-depth pavements shall be constructed. The determination of the thickness of the plain PCC shall follow the procedures in the TxDOT pavement design manual. The RAP-PCC material shall have desirable surface characteristics; its thickness can be as same as the reference case (plain PCC full-depth). This can verify whether RAP-PCC slab has equivalent performance as the plain PCC equivalent so that the thickness increase is not necessary. Another RAP-PCC full-depth pavement with slab thickness designed according to the design manual can be constructed for comparison purposes. This RAP-PCC full-depth pavement should have a thicker slab than the reference pavement.
 - Two-lift pavement construction: two-lift pavement construction shall be implemented after the necessary future research work is completed. This future work includes:
 - A robust approach to design two-lift pavement needs to be established.
 - The material properties for both top and bottom layers shall be specified.
 - The effect of bonding between top and bottom layer on pavement performance needs to be further studied.
 - Other practical issues on two-lift pavement construction.

After the above-mentioned contents are clear and specified, two-lift pavement that meets the specifications can be constructed. Its performance after a specific time period can be compared to the reference pavement. Figure 1 shows a presentation of the future research work and the implementation plan.

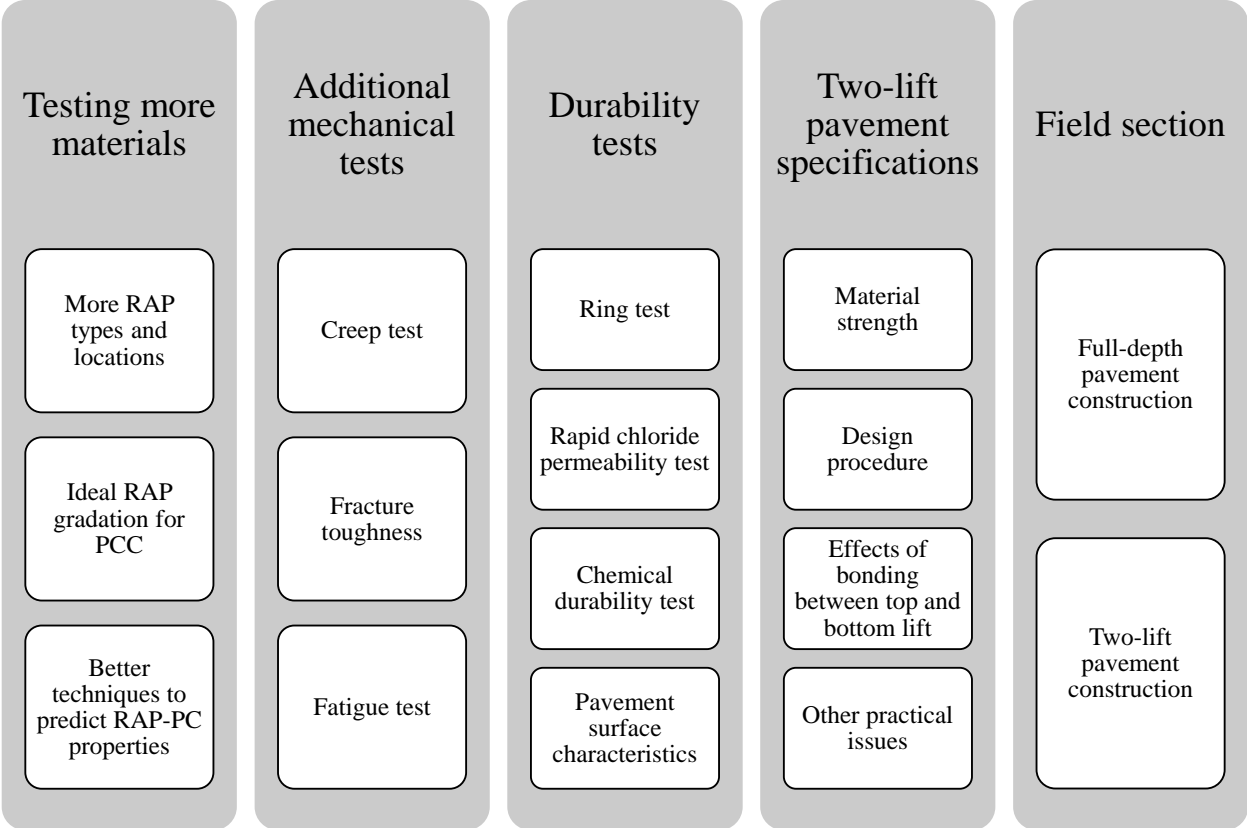


Figure 1. Future Work and Implementation Plan.

