Performance of High RAP in Flexible Pavements

Illinois Asphalt Pavement Association (IAPA) Scholarship Report

Submitted by

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Table of Contents

Introduction

Reclaimed Asphalt Pavement (RAP) can be defined as the milled materials from previously used pavements containing aggregates and asphalt. There are many economic and environmental benefits to using RAP in new asphalt mixtures. In the production of hot-mix asphalt (HMA), aggregates and asphalt binder are nonrenewable resources. However, with the use of RAP, these nonrenewable resources can be reduced. Using of RAP in HMA promotes sustainable development within the industry of asphalt. The concern for the deterioration of pavement performance, specifically resistance to pavement cracking, stops a large portion of the recycled material used in the pavement mixture. Other issues, including high fines content and aging of asphalt binder, also contribute to the lack of mixtures containing high RAP volumes. This research compiles several different studies on performance tests on different pavement mixtures containing large RAP percentages, up to 50%. It concludes that there are mixtures compared with HMA containing zero percentage RAP, also known as "virgin HMA mix." For some mixes, additives like a recycling agent help in the mix's performance, allowing higher contents to be used.

Objective

The research objective is to understand RAP use in Illinois and neighboring states such as Iowa, Minnesota, and Missouri. This research looks explicitly into the percentages of RAP used in the HMA pavements and mix design performance.

Research

Throughout the Midwest, each state has different specifications regarding how much RAP is allowable in surface course. Table 1 shows a summary of ten midwestern state's max RAP% and volumetric design criteria (Shannon et al., 2016).

Table 1. DOT Standards and Specifications (Shannon et al., 2016)

State	Maximum RAP % in surface	Binder grade change	Volumetric mix design criteria
Illinois (Illinois DOT 2007)	• No specified maximum for high and low ESAL mixes • Engineer can adjust quantity on the basis of test results • Homogeneous and conglomerate are allowed	• RAP > 15% may require softer binder as determined by engineer • RAP not allowed with polymer-modified binder	• % Pass #200: maximum 6/8% (high/low ESAL) • Dust/binder: maximum 1.0 @ design • VMA: minimum 14.0% [12.7 mm (1/2 in.) mix]; VFA: 65–75%
Indiana (Indiana DOT 2010)	• Maximum 15% RAP by weight for surface course mixtures for ESAL ≥ 3 million • Maximum 25% RAP by weight for all other mix	• 15% < RAP < 25% requires reduction of upper and lower PG grade by one level	• % Pass #200: maximum 10% [12.7 mm (1/2 in.) mix size] • Dust/binder: 0.6–1.2 (% pass > PCS ctrl. pt.) • VMA: minimum 14.0% [12.7 mm (1/2 in.) mix]; VFA: 65–78%
Iowa (Iowa DOT 2010)	• Classified RAP maximum 15% by weight in surface for all ESAL levels (at least 70% virgin binder) • Certified RAP: maximum 10% by weight in surface for ESAL ≤ 300K (not allowed for ESAL > 300K)	• RAP > 20% binder replacement requires lower PG grade by one level • RAP > 30% requires blending analysis	• % Pass #200: maximum 10% [12.7 mm (1/2 in.) mix size] • Dust/binder: 0.6–1.4 for all mixtures • VMA: minimum 14.0% [12.7 mm (1/2 in.) mix]; VFA: 70–80% • Film thickness: minimum 8.0 μm
Kansas (Kansas DOT 2007)	• No limit on maximum allowable RAP % (specified in project's contract documents)	• No limit on maximum RAP %	• % Retained #200: maximum 10% [12.7 mm (1/2 in.) mix size] • Dust/binder: 0.6–1.2 [12.7 mm (1/2 in.) A] or 0.8–1.6 [12.7 mm (1/2 in.) B] • VMA: minimum 14.0% [12.7 mm (1/2 in.) mix]
Michigan (Michigan DOT 2012)	• No limit on maximum allowable RAP %	• No limit on maximum RAP %	• Meeting the Superpave mix design through Michigan DOT's bituminous mix design computer program (Michigan DOT 2012)
Minnesota (Minnesota DOT 2005)	• Maximum 30% RAP by weight allowed in surface course for all ESAL levels	• Section 2360.2 G1 gives virgin grade for RAP% • Certain virgin binder not allowed RAP > 20%	• % Pass #200: maximum 7% (all mix size) • Dust/binder: 0.6–1.3 (level 2 wearing course) • VMA: minimum 15.0% [12.7 mm (1/2 in.) mix]; VFA: 65–78%
Missouri (Missouri DOT 2011)	• RAP > 30% allowed provided AASHTO M323 testing ensures PG grade meets contract specification • No limit on maximum allowable RAP %	• Up to 30% RAP by a binder replacement, no change in virgin binder PG grade • RAP > 30% may require binder grade change to meet PG grade specified in contract	• % Pass #200: maximum 10% [12.7 mm (1/2 in.) mix size] • Dust/binder: 0.8–1.6 (all mixtures) • VMA: minimum 14.0% (12.7 mm (1/2 in.) mix]; VFA: 65–78%
Nebraska (Nebraska 2007)	• Maximum 35% RAP allowed (<300K ESAL) • Maximum 25% RAP allowed (300K to 10M ESAL) • Maximum 15% RAP allowed (10M to 30M ESAL)	• Maximum allowable RAP % is exceeded for a given mix design (Table 1028.01) the PG grade must be lowered by one level	• % Pass #200: maximum 10% [12.7 mm (1/2 in.) mix size] • Dust/binder: 0.7–1.7 (all mixtures) • VMA: minimum 14.0% [12.7 mm (1/2 in.) mix]; VFA: 65–78%
South Dakota (South Dakota 2015)	• No limit on maximum RAP %	• No limit on maximum RAP %	• Gyratory mix design submitted to South Dakota DOT Mix Design Lab by a contractor for verification and testing of mineral aggregate and asphalt mixture
Wisconsin (Wisconsin DOT 2010)	• Up to 25% binder replacement by RAP, FRAP combination allowed for surface layer without virgin binder PG grade change • RAP > 25% allowed if binder meets contract specification	• RAP % exceeding maximum allowable specified in Section 460.2.5; virgin asphalt PG grade must be modified so that the resultant binder meets the contract specification	• % Pass #200: maximum 10% [12.7 mm (1/2 in.) mix size] • Dust/binder: 0.6 to 1.2 (all mixtures) • VMA: minimum 14.0% [12.7 mm (1/2 in.) mix]; VFA: 65–78%

Note: VFA = void filled with asphalt; VMA = void in mineral aggregate.

In 2012, the State of Illinois' maximum average for RAP content in high-volume road pavement mixtures was 15% (Al-Qadi et al., 2012). A study conducted by the University of Illinois at Urbana-Champaign (UIUC) and funded by the Illinois Department of Transportation's (IDOT) tested flexible pavement mixtures of up to 50% of RAP to find high performing mixes that are comparable with current roadways. The laboratory data were compared to mixtures with no RAP content. Significant work was done to get representative mixes from RAP stockpiles to ensure that each test result resulted from mix design and different RAP percentages and not volumetric. UIUC research laboratory tested moisture susceptibility, complex modulus, flow numbers, wheel tracking, beam fatigue, and semi-circular bending (SCB) tests. Figures 1 to 4 show flow number test setup, SCB test setup, beam fatigue test setup, and wheel tracking test setup, respectively.

Figure 1. A Specimen in the Flow Number Test (Al-Qadi et al., 2012).

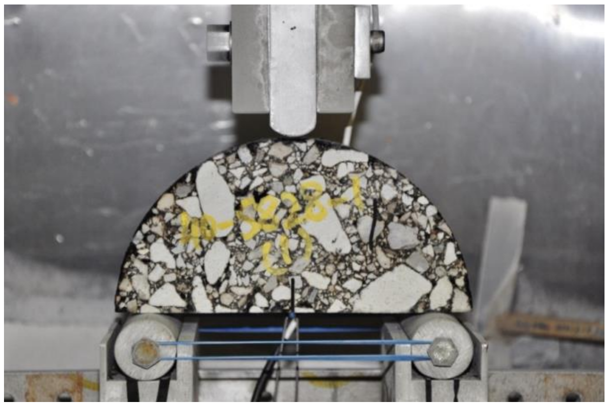

Figure 2. A specimen in the Semi-Circular Bending Test (Al-Qadi et al., 2012).

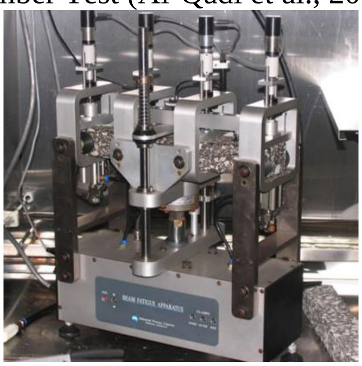

Figure 3. A Specimen in the Beam Fatigue Test (Flexural Fatigue, 2018).

Figure 4. Specimens in the Wheel Tracking Test (Stuart et al., 2001).

The UIUC research team used two sources of aggregate and RAP material. The performance grade asphalt binder PG 64-22 was used in the HMAs. A single-bumped binder PG 58-22 and a double-bumped binder PG 58-28 were used to engineer each sample to that of a softer asphalt binder on the performance of HMA with a considerable amount of RAP. With a too much-aged binder, the pavement's stiffness increases, and there is more potential for thermal cracking. The HMA mix becomes less stiff using a softer PG to mix with the stiffer RAP. The effectiveness of single and double binder-grade bumping was analyzed to determine what level of bumping was needed in the several percentages of RAP mixes to get the mixture to maintain the virgin blend's characteristics. The aggregates were sourced from two IDOT administrative districts, districts 1 and 5. The asphalt binders were from Champaign, IL, and Indiana. Eight mixes were prepared, four from each district, the control virgin HMA mix was provided by IDOT. Researchers achieved required Voids in Mineral Aggregate (VMA) values as a result of disparity in RAP aggregate gradation. Each specimen was required to pass the Tensile Strength Ratio (TSR) minimum requirement to follow IDOT’s moisture susceptibility test. Each mix was designed to meet the IDOT requirements for air voids, VMA, and Voids Filled with Asphalt (VFA)

The study's findings concluded that as RAP content increased, the tensile strength, TSR, and the complex modulus increased. The beam fatigue test resulted in beam fatigue life slightly improving with the addition of RAP. The wheel tracking test results indicated that with a high RAP content, the rutting potential would reduce. The fatigue behavior that was measured by the conventional fatigue curve slope showed that fatigue behavior could improve. Fracture energy was decreased, and the potential for thermal cracking would increase with RAP, which was especially evident for 30% of RAP increase. This, paired with grade bumping, significantly decreased temperature fracture energy, indicating that the two's paring is necessary. Grade bumping proved to be beneficial, and in the higher contents of RAP, double binder grade bumping is best to reduce the thermal cracking in HMA mixtures.

In conclusion to the UIUC's study, a designed HMA of high quality with up to 50% RAP can be made that can meet required volumetric and performance criteria. The performance of high RAP mixes was equal to that of the virgin aggregate mix, and in some cases, it improved. A double-bumped asphalt binder can help reduce the RAP stiff residual asphalt binder and retain original properties to that of the virgin mixture.

Another study by Shannon et al. (2016) used a total of nine high RAP surface mixes were created that accounted for as high as 50% of the virgin binder. Following current Iowa's specifications, "the Iowa DOT specification allows a maximum of 15% classified RAP usage in different pavement layers… limited up to 30% of the virgin binder replacement" (Shannon et al., 2016). Meeting all the volumetric mix design criteria, these mixes of 30%, 40%, and 50% were analyzed against control with two fractionated methods (fractionated RAP and optimum FRAP). The study tested the performance grade of the blended binder and tested to see if the effects of the fractionation methods affected the volumetric properties of the mix.

Shannon et al. (2016) concluded that the Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR) () tests found that a single virgin asphalt binder performance grade modification was efficient in alleviating the aged RAP binder's negative effect. The study used the beam fatigue test, and the results performed well, showing no significant change in fatigue life as more RAP was used. The optimal binder content was not dependent on RAP contents. The binder PG 64-22 underwent DSR testing and bending beam rheometer testing. With the BBR testing, the stiffness did not increase as the binder increased to 40%, but it increased to 50%. The fatigue test results indicated no significant change in fatigue life as RAP materials increased to 50%. The study concluded that for higher amounts of RAP to be used in mixes, the volumetric properties must be improved so that the designs can meet specifications. To analyze the distribution of aggregates and binders of RAP materials, it was concluded that “asphalt amount in RAP depended on the size of RAP materials, and fine aggregates were difficult to remove from RAP stockpile” (Shannon et al., 2016). The fractionation method created an increase in film thickness and a decrease in the dust-binder ratio. Solely the fractionated RAP mixture with 30% RAP had all the mix design criteria.

A study was done by the Minnesota Department of Transportation (MnDOT) in 2013 tested field performance and laboratory tests with mixes of high RAP mixtures of 30% or more. Similar to the mixes in the Illinois study, this research used the PG 58-28 binder as it was concluded that it was the most used asphalt binder in Minnesota; the other binder used was PG 58-34. The study included indirect tensile strength testing, semi-circular bending testing to measure fracture energy and roughness.

MnDOT study found that with an increased RAP came an increased stiffness as well as higher strength values. When comparing creep stiffness, keeping the RAP percentage between 25-40% gave a better performance. With the PG 58-34 binder and increased RAP, the critical temperature increased, which predicted a lower crack resistance. The addition of RAP lowered fracture energy from the semi-circular bending test, and the fracture toughness increased. In low temperatures, in particular, the highest RAP content created destructive fracture properties. This data set concluded that none of the mixes met recommend levels for fracture toughness nor energy. In conclusion, the study reported that there weren’t satisfactory results to constitute mixes above 25% RAP.

In a field study done near Harrisonville, Missouri, conducted by Tran et al. (2016), studies comparing RAP contents up to 40% concluded that such mixes could achieve similar quality and performance as the leading mixes. Three mixes, 25% with a PG 64-22 binder, 30% with a PG 70-22 binder, and 40% RAP with a PG 70-22 binder, underwent laboratory performance testing and early field performance testing. The study also used a recycling agent, Hydrogreen, to test the performance. The mixes were tested for tensile strength ratio, dynamic modulus test, overlay test, indirect tensile test, and early field performance testing for rutting and cracking.

In conclusion, all three sections performed well after 10 months of the early field performance testing, none showing measurable rutting. When it came to cracking, the three test sections showed low-severity transverse cracking, which looked reflective. The mixes of 30 and 40% RAP had less cracking than the control 25% RAP mix. The wheel tracking test observed no stripping for the mixes, which indicated the resistance to moisture damage was adequate. The dynamic modulus test concluded that the stiffness of 40% was close to 30%, but the differences were not statistically significant. The research conducted in Missouri concluded that the three mixes could achieve performance and construction quality similar to the control. The recycling agent proved to help the higher RAP content mixes to achieve the same performance as leading mixes.

Conclusion

There is a wide range of performance based on high RAP in reviewing all four state's research. While Illinois gave no maximum RAP percentage in mixes, it was concluded that mix designs up to 50% could perform just as well as the current mixes. Similar results were concluded with research done in Missouri, mixes with higher contents up to 40% RAP performed up to the state’s standards with the use of a recycling agent. However, in Minnesota and Iowa’s reports, it was concluded or unclear if the design mixes were adequate. The discrepancy between the state’s conclusions depended on a variety of controls. Further research is recommended for the mixes to test long-term performance, and it is recommended that because of the high amount of fine aggregates made through milling and processing operations of recycled aggregate, it affects the high amount of RAP that can be used because there is difficulty in meeting the volumetric properties. While there has been a significant process made to increase the amount of recycled asphalt pavement into the state’s standards and specifications, more research needs to be conducted to ensure long-term field performance.

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