Evaluation of HMA Modified with Recycled Asphalt Shingles (RAS) Mixtures

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EXECUTIVE SUMMARY

During the summer of 2009, the Tollway made plans to place test sections of hot mix asphalt (HMA) mixtures containing high levels (20% to 45%) of Fractionated Recycled Asphalt Pavement (FRAP) that substituted 5% recycled asphalt shingles (RAS) for a portion of the FRAP materials. Over 8,000 tons of standard FRAP and FRAP/RAS-HMA mixtures were produced and placed on test sections on the outside shoulders of the Jane Addams Memorial Tollway (I-90) westbound between milepost MP 71 and MP 75. In addition, nearly 350 tons of polymer-modified stone matrix asphalt (SMA) surface course containing FRAP/RAS was produced and placed as an overlay test strip on the eastbound I-90 to southbound I-39 exit ramp near MP 62.

The FRAP/RAS-HMA shoulder mixes were sampled and analyzed for performance through a detailed study at Iowa State University and supplemented with additional testing for crack resistance at the University of Illinois. The final report on this study remains to be completed. The FRAP/RAS-SMA surface mix was sampled and tested for performance at the University of Illinois. This report summarizes the results of that study.

The goals of these projects were to explore the following questions:

- What changes to the Illinois Tollway mix design processes (if any) are needed if RAS-HMA/SMA mixtures are to be used?
- What procedures need to be in place to ensure that RAS materials can be used safely in the HMA production and paving processes?
- Is the use of RAS feasible for Tollway contractors, given their equipment and capabilities?
- Are the expected performance characteristics of the mixes the same or better than current FRAP materials?
- What are the limits to replacing virgin liquid asphalt in dense graded HMA or in SMA mixes with recycled asphalt from FRAP and/or RAS sources?
- Can RAS be used in polymerized SMA mixes as a substitute for fiber reinforcement to prevent draindown issues?

The SMA mixture containing recycled asphalt shingles combined with 15% fine portion FRAP showed significantly improved fatigue resistance compared with equivalent SMA mixes containing no recycled material. While fatigue is not a failure mechanism associated with SMA mixtures, this improved fracture resistance translates directly into improved resistance to reflection and thermal cracking. The lower dynamic modulus of the RAS-SMA adds to the improved thermal cracking resistance.

The FRAP/RAS-HMA mixtures placed along the Jane Addams Memorial Tollway in 2009 were a good first step towards the introduction of a potentially valuable new pavement technology into Illinois. While it is still relatively early in the expected service life of these materials and more test data remain to be released, some conclusions can be drawn at this time, including:

- As long as consistent and uniform supplies of RAS materials are available, there are no substantial changes needed to the existing Illinois Tollway mix design procedures to accommodate these new mixture components.
- Because of the potential asbestos hazard associated with collecting, sorting, and processing RAS materials, it will be necessary to train and educate suppliers and

workers dealing with the materials to ensure that safe working conditions are maintained.

- The biggest change needed to contractor equipment to accommodate RAS materials will be a more efficient method of introducing RAS into the mixing process. The RAP feeder used for this demonstration project was adequate for the scale of this limited operation, but a more durable and efficient approach will be needed for full-scale production of FRAP/RAS-HMA mixtures.
- The FRAP/RAS-HMA mixtures showed good fatigue characteristics during laboratory testing, along with lower dynamic modulus values. These results indicate that the material should have improved thermal cracking resistance when used on a limited basis in HMA mixtures.

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INTRODUCTION

Approximately 10 million tons of asphalt shingle roofing are generated in this country each year through the removal of existing roof materials (“tear-offs”). Many of the primary materials used to produce asphalt shingles are similar to materials used in the hot mix asphalt (HMA) paving industry (asphalt cement, sand-sized aggregate, mineral fillers), suggesting a potential recycling opportunity. Material similarities are the primary reason that highway agencies have explored the viability of using what would otherwise become a waste product (asphalt shingles) as a component of HMA paving materials. Agencies investigating this approach have found an environmentally friendly process for keeping waste shingles out of landfills that often reduces the overall price of HMA material production while providing performance as good as, or better than, conventional HMA mixtures.

While the recycling of tear-off asphalt shingles is not yet a well-established industry in Illinois, the Illinois Tollway initiated a project to investigate the viability of incorporating these materials into HMA mixes.

Events Surrounding this Research Project

During the summer of 2009, the Tollway made plans to place test sections of HMA mixtures containing high levels (20% to 45%) of Fractionated Recycled Asphalt Pavement (FRAP) that substituted 5% recycled asphalt shingles (RAS) for a portion of the FRAP materials. Over 8,000 tons of standard FRAP and FRAP/RAS-HMA mixtures were produced and placed on test sections on the outside shoulders of the Jane Addams Memorial Tollway (I-90) westbound between milepost MP 71 and MP 75. In addition, nearly 350 tons of polymer-modified stone matrix asphalt (SMA) surface course containing RAS was produced and placed as an overlay test strip on the eastbound I-90 to southbound I-39 exit ramp near MP 62.

As the experience of Illinois contractors with RAS materials was limited, a Wisconsin-based RAS recycling facility was identified to ensure that the supply of RAS materials was adequate and the quality and consistency of the RAS materials met the Tollway’s needs. To further speed up the learning curve on the use of RAS materials in HMA mixtures, the Illinois Tollway teamed up with Professor Chris Williams of Iowa State University. Professor Williams is the Principal Investigator for the American Association of State Highway and Transportation Officials (AASHTO) Pooled Fund Study, “*Performance of Recycled Asphalt Shingles in Hot Mix Asphalt*,” TPF-5(213). The study was planned and partially funded by the Environmental Protection Agency to explore performance and durability factors of HMA mixes containing RAS.

To further increase the chances that FRAP/RAS mixtures could be used safely throughout Illinois in the future, the expertise gained during this project was used to develop a training course for those interested in setting up asphalt shingle recycling operations. Training materials for suppliers and sorting facility workers were developed by Debra S. Haugen, LLC, in conjunction with this project.

Questions to be Answered

In exploring and evaluating new technologies in pavements, there are a number of questions that need to be answered. The goals of this project were to explore the following questions:

- What changes to the Illinois Tollway mix design processes (if any) are needed if RAS-HMA/SMA mixtures are to be used?
- What procedures need to be in place to ensure that RAS materials can be used safely in the HMA production and paving processes?
- Is the use of RAS feasible for Tollway contractors, given their equipment and capabilities?
- Are the expected performance characteristics of the mixes the same or better than current FRAP materials?
- What are the limits to replacing virgin liquid asphalt in dense graded HMA or in SMA mixes with recycled asphalt from FRAP and/or RAS sources?
- Can RAS be used in polymerized SMA mixes as a substitute for fiber reinforcement to prevent draindown issues?

MATERIAL EVALUATED

Six FRAP/RAS mixtures and three control mixes were included in this project. The volumetric design properties of the mixes, and their placement locations, are shown in table 1.

Table 1. FRAP/RAS and control mixture characteristics.

ID	Mix	Volumetrics	FRAP	RAS	Location
FRAP-RAS Mixes					
RS01	Binder Course	N_{50}@ 3% voids	35%	5%	Shoulder
RS02	Base Course	N_{50}@ 2% voids	35%	5%	Shoulder
RS03	Base Course	N_{50}@ 2% voids	40%	5%	Shoulder
RS04	Base Course	N_{50}@ 2% voids	25%	5%	Shoulder
RS05	Surface	N_{70}@ 4% voids	20%	5%	Shoulder
RS06	Trap Rock SMA	N_{80}@ 3.5% voids	15%	5%	Main Line
Control Mixes					
0907	Base Course	N_{50}@ 2% voids	40%	N/A	Shoulder
0914	Binder Course	N_{50}@ 3% voids	40%	N/A	Shoulder
0823	Surface Mix	N_{70}@ 4% voids	15%	N/A	Shoulder

Mixture RS06 was not part of the original experimental design planned with Iowa State University but was added to evaluate whether the addition of RAS materials would be effective as a draindown preventive additive in polymer-modified SMA mixes. Mixes with high asphalt cement (AC) binder content (such as SMA) are susceptible to draindown during production. Blown-in fibers or rubber modified asphalt cement have been the only effective techniques to date to prevent draindown. For this evaluation, the RS06 included a polymer-modified AC binder but had no fibers. Further evaluations of this mix were performed at the University of Illinois.

Figure 1 shows the test section layout for the RAS-HMA mixtures produced for the Iowa State University study.

Illinois Tollway Shingle Research Test Section Layout

PROJECT: I-08-5543 – Jane Addams Memorial Tollway – I-90

LOCATION: Westbound Outside Shoulders

TEST SECTION	1	2	3	4	Bike Trail Bridge	4	5	Burr Oak Bridge	5	6	7	8	N/A
SECTION LENGTH, ft	2345	2214	1926	1990		826	1714		630	1388	2592	2150	
SURFACE MIX NUMBER	90BITRS05	90BIT0823		90BITRS05		90BITRS05				90BIT0823		90BITRS05	
SURFACE MIX TYPE	20% FRAP / 5% RAS N70 SCS	25% FRAP N70 SCS		20/5 RAS N70 SCS		20% FRAP / 5% RAS N70 SCS				25% FRAP N70 SCS		20% FRAP / 5% RAS N70 SCS	
STA #	363+25 MP 71 1/4 – 339+80	339+80 MP 71.7 – 298+40		298+40 MP 72.5	278+50 - 276+00			250+60 - 248+60	242+30	242+30 MP 73.5 – 202+50		202+50 MP 74 1/4 – 168+80	
DATE PLACED	8/10/2009	8/10/2009		8/10/2009						8/10/2009		8/10/2009	
TONNAGE	256.41	616.6		556.51						633.09		532.69	

BASE MIX NUMBER	90BITRS04	90BITRS02	Bike Trail Bridge	90BITRS02	90BITRS03	Burr Oak Bridge	90BITRS03	90BITRS01	MILLED MATERIAL
BASE MIX TYPE	25% FRAP/5% RAS BIT BASE	35% FRAP/5% RAS BIT BASE		35% FRAP/ 5% RAS BIT BASE	45% FRAP/ 5% RAS BIT BASE		45% FRAP/ 5% RAS BIT BASE	35% FRAP/5% RAS N50 BCS	
STA #	363+25 – 317+66	317+66 MP 72.1	278+50 - 276+00	267+74	267+74 MP 73.1	250+60 - 248+60	228+42	228+42 73.8 – 181+00 MP 74.7	
DATE PLACED	7/29/2009	7/29/2009			7/29/2009			7/30/2009	
TONNAGE	1272.96	1295.86			846.23			1314.36	

TEST SECTION LAYOUT

Not to Scale

Test Section Descriptions

1	Shingle Surface over 25 / 5 Base	5	Shingle Surface over 45 / 5 Base
2	Standard Surface over 25/ 5 Base	6	Standard Surface over 45/ 5 Base
3	Standard Surface over 35 / 5 Base	7	Standard Surface over 35 / 5 Binder
4	Shingle Surface over 35/ 5 Base	8	Shingle Surface over 35/ 5 Binder

Figure 1. FRAP/RAS-HMA test section layout.

SUMMARY OF FIELD NOTES

The following notes summarize characteristics of the SMA mixture containing RAS used in this study and were compiled by S.T.A.T.E. Testing through their field observations of the trial mix production and placement. The complete mix design, mix design notes, and quality control (QC) and quality assurance (QA) data are provided in appendix A.

MIX DESIGN

All RAS materials used in this project were produced by 2nd Season Recycling and were tested in March 2009, with the asphalt content and extracted gradation results shown in table 2.

Table 2. RAS gradation information.

Percent Passing	Test ID 001-01	Test ID 002-01
¾ inch	100.0	100.0
½ inch	99.8	99.6
3/8 inch	99.7	98.7
No. 4	97.1	94.1
No. 8	94.3	90.5
No. 16	77.1	73.8
No. 30	55.6	54.3
No. 50	48.0	46.5
No. 100	38.8	35.5
No. 200	26.9	25.5
Percent AC	24.6	23.1

PRODUCTION NOTES

The processed RAS was added to the mixes via a RAP feeder. While this solution worked well enough for the scale of production needed for this project, the production team believed that a more efficient method of adding RAS materials should be investigated to improve the consistency of the mixing process when these materials are used at higher production levels.

The polymer modified SMA mix containing 5% RAS and 15% FRAP (RS06) was produced on October 7, 2009.

Placement and production of the SMA mixture containing RAS went well. Some of the RAS fibers were initially visible as a “five o’clock shadow” on the pavement surface, but this was a temporary and harmless effect.

The production volumetric results were acceptable and well within expectations for small quantities and frequent plant proportioning adjustments. In addition, the draindown experiment (RS06) was successful, giving the Tollway another option for producing SMA mixtures without the need for virgin fiber reinforcement. The use of ground tire rubber (GTR) modified asphalt in SMA mixes is the other option.

PERFORMANCE EVALUATION METHODOLOGY

One of the goals of this project was to verify through a laboratory testing program whether the FRAP/RAS-SMA materials showed similar pavement performance to currently specified SMA mixes. One means of determining this was to evaluate material properties as they relate to pavement design.

The design of full-depth HMA pavements, with or without RAS, relies on two primary material properties: the fatigue performance curve and the HMA dynamic modulus (stiffness). The dynamic modulus determines how much the pavement section flexes under traffic loads, resulting in strain in the asphalt layer. This strain is then evaluated against the fatigue performance curve, which relates strain to the allowable loads that a pavement section can carry.

Other HMA material properties that are of concern include resistance to rutting and resistance to weathering. Relative rutting resistance is indicated by the dynamic modulus test, which is included in this testing program, and is controlled for most projects primarily through the mix design process and by the selection of raw materials. While rutting resistance is mainly due to the aggregate structure in the mixture, added stiffness from the binder (from RAS materials) can further enhance rutting resistance.

OBSERVED FIELD PERFORMANCE TO DATE

The RAS test sections were observed as part of the two most recent annual pavement surveys conducted on September 1, 2009, and July 26, 2010. As of the most recent survey, no cracks were observed in either the FRAP/RAS or the control mixtures. Continued field monitoring will provide the additional information necessary to identify any performance differences that may develop between the FRAP/RAS and the control mixtures.

ASPHALT MIXTURE PERFORMANCE TESTS

Fatigue and dynamic modulus tests were performed for the RS06 mixture on material samples collected at the plant during construction. Samples were sent to the Illinois Center for Transportation (ICT) in Rantoul, Illinois, for testing.

PERFORMANCE TEST DATA

DYNAMIC MODULUS TESTING

Dynamic modulus specimens were compacted to 7% and 4% air voids. The dynamic modulus tests were conducted at -4°, 10°, and 29°C to allow for construction of the master curve.

The dynamic modulus master curve for the 7% air voids specimens is given in figure 2, and the curve for the 4% specimens is shown in figure 3. The time-temperature shift factors resulting from the construction of the master curve are shown in figure 4. There is nothing unusual in these curves by themselves.

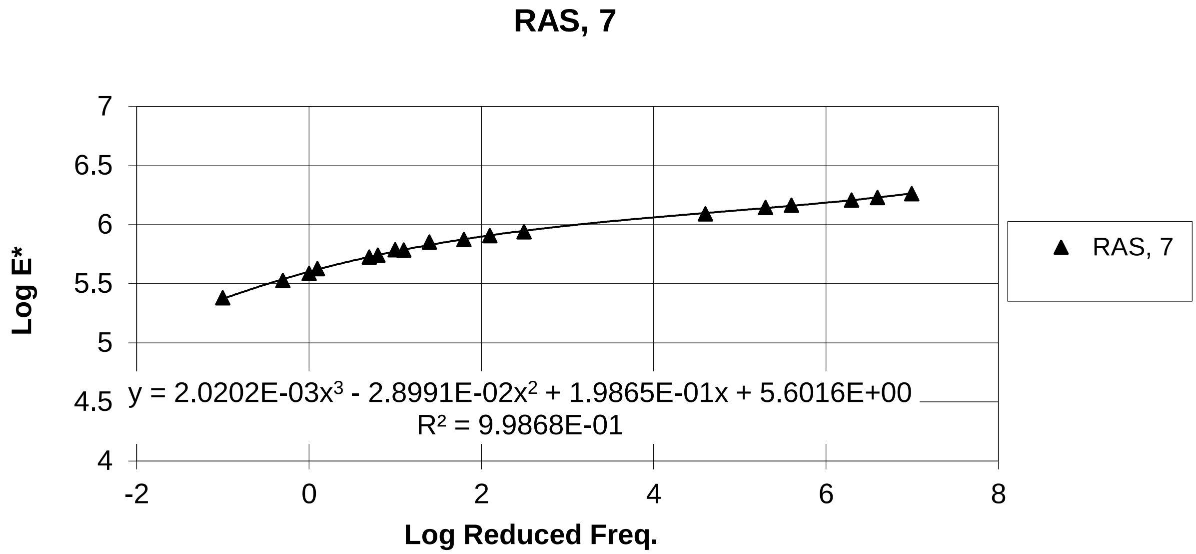

Figure 2. Dynamic modulus master curve for 7% air void samples.

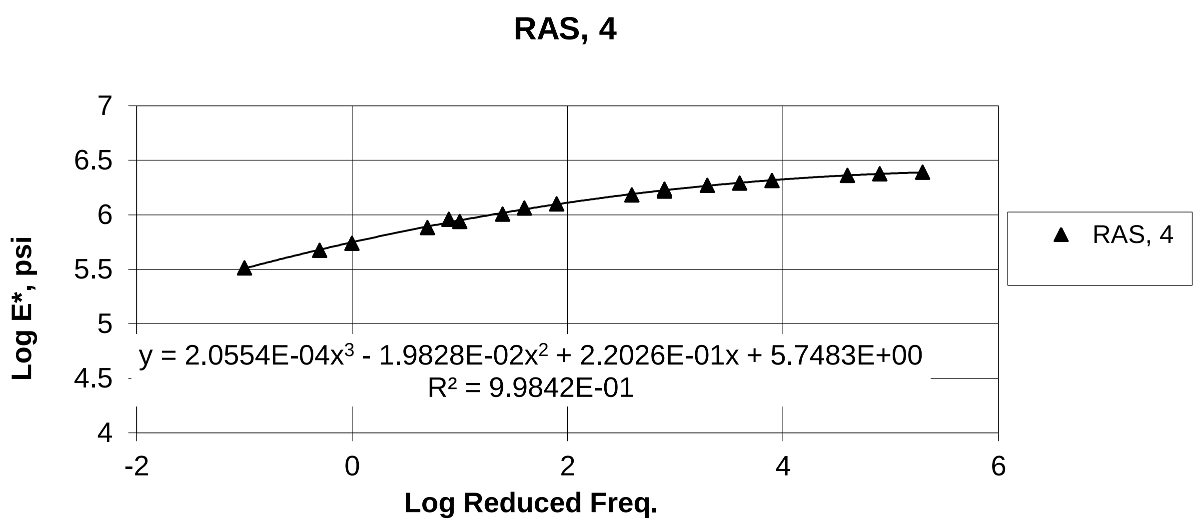

Figure 3. Dynamic modulus curve for 4% air void samples.

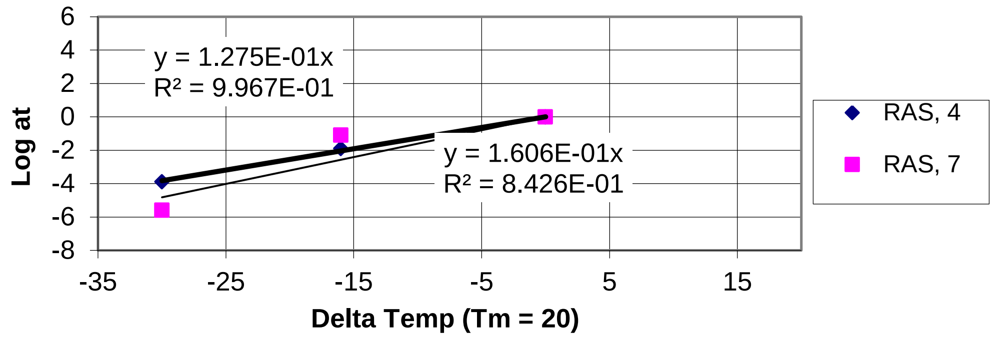

Figure 4. Time-temperature superposition shift factors.

FATIGUE TESTING

The fatigue samples were compacted to 7% air voids. The fatigue testing was conducted at 20°C at a frequency of 10 Hz. Repeated loads for a preset strain level were repeated until failure, which was defined as a decrease in modulus of 50%.

The fatigue curve is given in figure 5. Two test points are not shown, as these tests were conducted on an older machine that was experiencing mechanical difficulties. The low strain test conducted at 300 micro strain is shown, but it is not included in developing the fatigue equation. This is because the test was not carried to completion due to the extended fatigue resistance exhibited by these mixtures that was amplified at the low strain. The data point for the low strain test is shown with an arrow, indicating that failure is projected to occur at a much higher number of load repetitions. The fatigue equation for this mixture is:

$$N_f = 3.719\text{ E-24 } (1/\varepsilon)^{8.890}$$

INTERPRETATION OF PERFORMANCE TEST RESULTS

DYNAMIC MODULUS

The dynamic modulus values for the Tollway FRAP/RAS-SMA mixture are lower than what would be considered typical. The effect of the shingle asphalt is to provide a lower compressive stiffness. Figure 6 is the master curve for an Illinois Department of Transportation (IDOT) District 1 SMA mixture with polymer and fiber added. This IDOT SMA mixture is significantly stiffer at the higher frequency (lower temperature). The stiffness values are closer to each other at the higher temperature (lower frequency).

The fatigue equation for the IDOT District 1 SMA with polymer and fibers and with no recycled materials is:

$$N_f = 5.83\text{ E-13 } (1/\varepsilon)^{5.507}$$

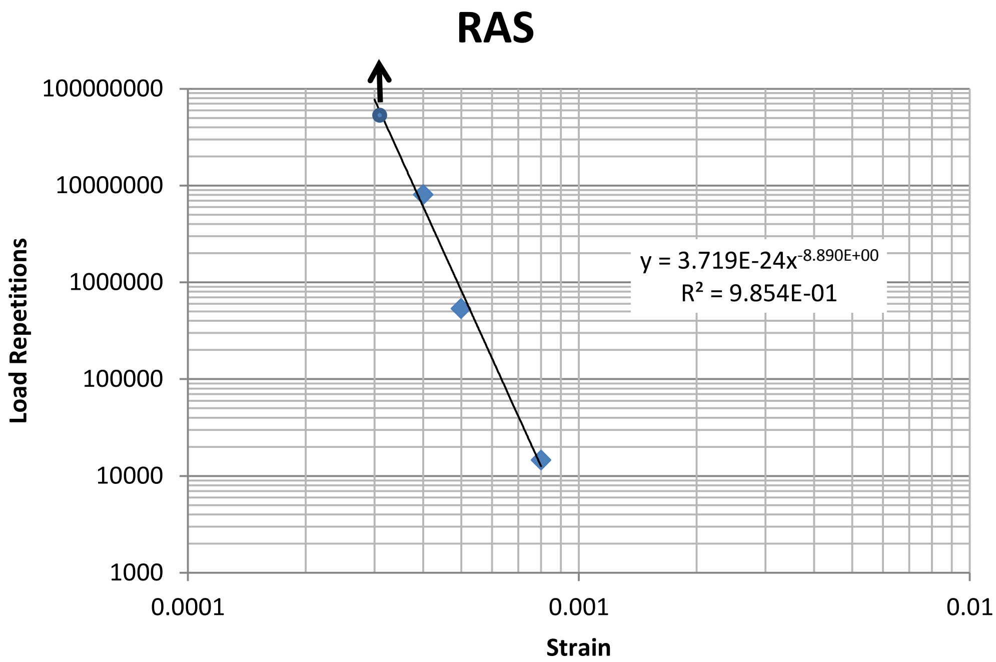

Figure 5. Fatigue curve for FRAP/RAS-SMA mixture.

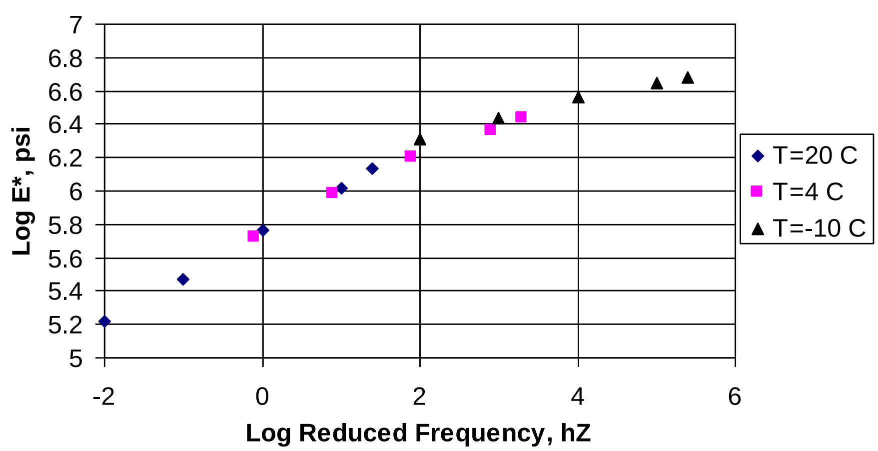

Figure 6. Dynamic modulus curve for IDOT District 1 SMA, 7% air voids.

The important point of comparison is the exponent of each fatigue equation. The recycled mixture (RS06) has an exponent of 8.890 compared to the value of 5.507 for the IDOT SMA. The value for the IDOT SMA is typical of mixtures tested. The value of 8.890 is exceptionally high, and the higher this exponent, the greater the fatigue resistance of the mixture. The Tollway FRAP/RAS-SMA mixture has shown very fatigue-resistant behavior. As shown in figure 7, the value for the FRAP/RAS-SMA mixture is also substantially higher than values for other SMA mixtures placed on the Tollway in 2007, which had values ranging from 5.00 to 5.45.

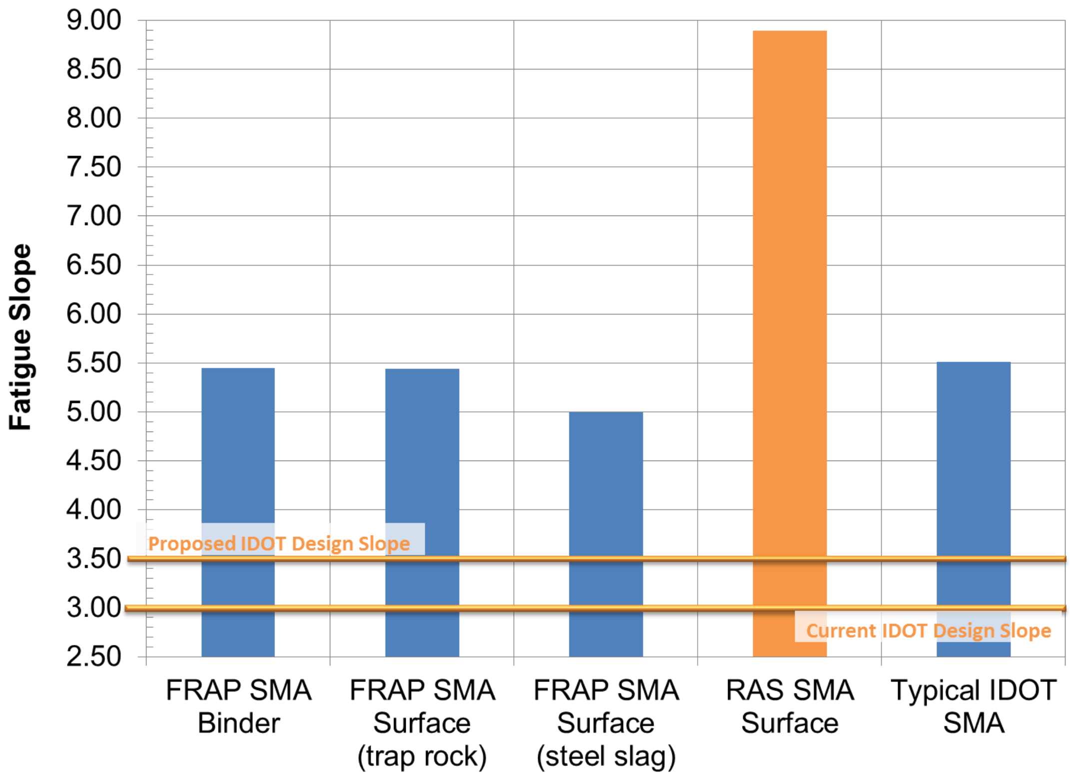

Figure 7. Fatigue slope comparison

Flexural Behavior

Normally, a stiffer mixture will have higher fatigue resistance when tested in the laboratory, as has been done here. To see such a striking difference in fatigue resistance indicates that some other material property is being altered by the recycling operation and/or the material used in the recycling operation. The differences can be seen in a comparison of the compressive dynamic modulus test and the flexural fatigue test.

The compressive dynamic modulus test accentuates the stone on stone aggregate structure as the aggregate particles are forced together with each load. The flexural fatigue test places the mixture into tension, pulling the aggregate particles apart, emphasizing the behavior of the asphalt binder.

In previous testing where fatigue and dynamic modulus testing has been conducted on the same mixture at the same 7% air voids, there is a consistent relationship between the dynamic and flexural modulus. The flexural modulus is between 0.5 and 0.6 of the dynamic modulus in mixtures tested to date. The recycled shingle mixture has a dynamic modulus of 4,350 MPa at 20°C and a frequency of 10 Hz. For these recycled mixtures to follow the behavior noted in other mixtures, the flexural modulus would be between 2,175 MPa, and 2,610 MPa. The average flexural modulus for the FRAP/RAS-SMA mixture is 3,000 MPa, which is significantly higher than that found for standard mixtures tested.

The stiffer mixture in flexure will exhibit an increased fatigue resistance, since it is the modulus in flexure, not the compressive modulus, which most closely relates to fatigue behavior. The recycling operation may produce a lower compressive modulus because of aggregate structure, but it produces a proportionately higher flexural modulus in comparison to typical mixtures. The modifying properties of the shingle asphalt appear to provide an increased level of elasticity and toughness that cannot be discerned in a compressive modulus test, but requires a tensile failure test.

LABORATORY TESTING CONCLUSIONS

The mixture containing recycled asphalt shingles shows significantly improved fatigue resistance. While fatigue is not a failure mechanism associated with SMA mixtures, this improved fracture resistance translates directly into improved resistance to reflection thermal cracking. The lower dynamic modulus of the RAS-SMA adds to the thermal cracking resistance.

CONCLUSION

The RAS-HMA mixtures placed along the Jane Addams Memorial Tollway in 2009 were a good first step towards the introduction of a potentially valuable new pavement technology into Illinois. While it is still relatively early in the expected service life of these materials, some conclusions can be drawn at this time, including:

- As long as consistent and uniform supplies of RAS materials are available, there are no substantial changes needed to the existing Illinois Tollway mix design procedures to accommodate these new mixture components.
- Because of the potential asbestos hazard associated with collecting, sorting, and processing RAS materials, it will be necessary to train and educate suppliers and workers dealing with the materials to ensure that safe working conditions are maintained.
- The biggest change needed to contractor equipment to accommodate RAS materials will be a more efficient method of introducing RAS into the mixing process. The RAP feeder used for this demonstration project was adequate for the scale of this limited operation, but a more durable and efficient approach will be needed for full-scale production of FRAP/RAS-HMA mixtures.
- The FRAP/RAS-HMA mixtures showed good fatigue characteristics during laboratory testing, along with lower dynamic modulus values. These results indicate that the material should have improved thermal cracking resistance.

While these materials have shown good performance to date, additional monitoring of field performance is recommended. In addition, a study of the costs associated with using RAS materials is needed to determine whether the implementation of FRAP/RAS-HMA mixtures is in the best long-term interests of the Illinois Tollway.