THE PROFILER

Research Division

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Economics of Mississippi RAP

By: Isaac L. Howard and Jesse D. Doyle
Mississippi State University

What is Reclaimed Asphalt Pavement (RAP) worth? A seemingly simple question until one investigates in greater detail. The answer is it depends on when, where, and in what context the question is asked. Figure 1 shows virgin asphalt prices from the Mississippi Index since 1980 (1) that suggest when the conversation is held makes a significant difference. Values plotted were yearly averages; note that within year spikes frequently occurred.

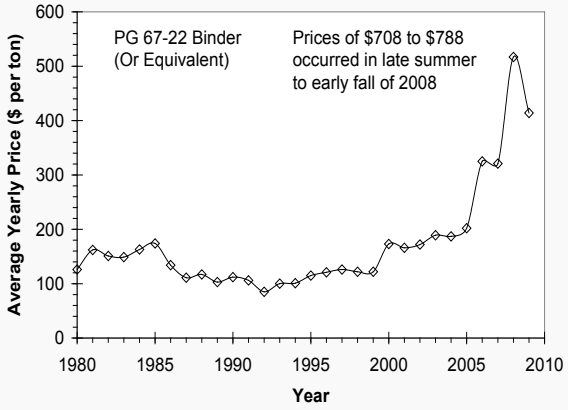

Figure 1. Virgin Asphalt Prices

If the "where" is Mississippi, as it is for this discussion, aggregates in the roadway are predominately gravel with absorption values routinely in excess of 2.5% and occasionally in excess of 4%. To obtain a clearer picture of the aggregate characteristics of Mississippi pavements, Richard Sheffield of Thompson Engineering was consulted, and he revealed that mixes in the 1960's through portions of the 1970's were almost all gravel for large portions of Mississippi. In the late 1970's to late 1980's some crushed stone (e.g., limestone) began to be used to address rutting problems. As gravel crushing became more consistent in the 1990's, many mixes contained all crushed gravel. In the early 2000's, Superpave consensus test requirements led to the use of more crushed stone. RAP comprised largely of gravel aggregates can be used effectively to produce quality pavements, though as with all materials its characteristics must be understood and accounted for.

The context in which the question is asked is the most complicated. The context in this article assumes a high RAP mixture performs the same as current mixes and that performance differences (positive or negative) would have economic implications that are not definable at present. A key context question for Mississippi is how to characterize the aged binder in a given RAP for a given set of conditions.

The authors began research to characterize RAP bituminous material in absence of extraction for a specific set of conditions (2). A new term, AC_{eff}, was defined as the percentage of total RAP bitumen that is useful for compaction under a specific set of conditions. AC_{eff} values of 67 to 87% were found in (2) for three Mississippi RAP sources with Brookfield viscosities of 9 to 53 Pa-s at 275 F, which can be interpreted as 67 to 87 g of bituminous material being effective in adhering particles to one another per 100 g of bituminous material extracted from RAP. It was observed that the lower the Brookfield viscosity, the higher the AC_{eff} in the RAP.

RAP bitumen properties affect behavior at a temperature and the value of the bitumen is affected by temperature, as evidenced in Figure 2 where 100% RAP was heated and compacted without virgin binder. The amount of livening of the aged material was affected by temperature. High RAP warm and hot mixed asphalts will need to be characterized differently, thus affecting the worth of the material.

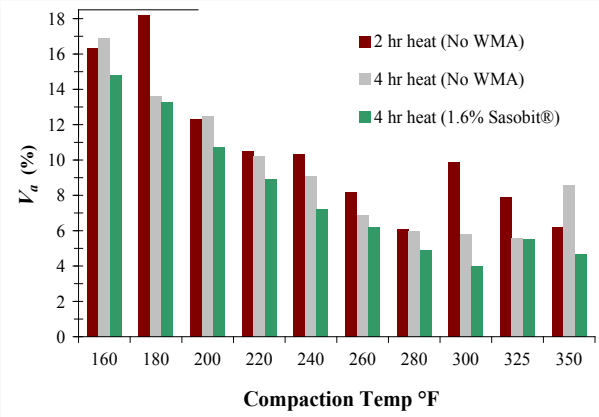

Figure 2. 100% Gyratory Compacted RAP

AC_{eff} furthered characterization principles for RAP bitumen; however, it did not adequately address the context issues for Mississippi RAP. The term was not able to isolate the amount of absorbed bitumen, nor did it account for aggregate characteristics. An advanced technique is under development where select properties of every MDOT-approved asphalt concrete mixture are being used to develop regression equations. The goal is to estimate absorbed and effective bitumen contents with information that would be available in routine practice provided the end use of the RAP was known. If successful, the work which is being performed as part of and with funding through MDOT State Study 212 would conceivably allow moderate amounts of testing to characterize RAP and place value in the context of the mixture's end use. Current value systems for RAP typically account for all the bituminous material when performing savings calculations, which historically have been mostly associated with hot mixed asphalt containing on the order of 10 to 15% RAP. Additionally, RAP is often viewed as a cheaply obtained commodity for economic calculations, though producers contacted during this research would have been reluctant to sell RAP, if they would sell it at all. Adequate use and quantities of milled RAP are an additional issue but are beyond the scope of this document.

Virgin aggregate prices at the plant were obtained in October 2008 from 10 asphalt plants representing every district in Mississippi. Gravel (GR) prices ranged from $13 to $26, limestone (LS) ranged from $15 to $38, and sand prices ranged from $3 to $14. Two mix combinations common to Mississippi and their composite aggregate price are shown in Figure 3. The price of PG 67-22 was $708 per ton in October 2008 which for the example mixes results in the virgin asphalt prices shown in absence of RAP.

Milling, hauling, and handling estimates for RAP were obtained at the same time as Figure 3 data; upper end cost was $15 per ton. The data in Figure 3 shows that the value of the aggregates easily offsets the cost of milling, hauling, and handling. In some cases, some investment remains in the aggregates (e.g. District 3), but this is difficult to quantify in specific terms and is left for the producers as the relative quality of RAP aggregates to virgin aggregates will also play a role.

Viewing RAP as an investment with a cash out fee equal to milling, hauling, and handling costs allows any effective bitumen to be valued at market price, while ineffective bitumen is valued as aggregate. A logical manner to view the value of the bituminous material in the RAP is to assign market value to the amount of virgin binder that was not needed as a

result of RAP inclusion. This method is enhanced when the material is viewed as an investment that is maximized when collected at the right time and used for the right application.

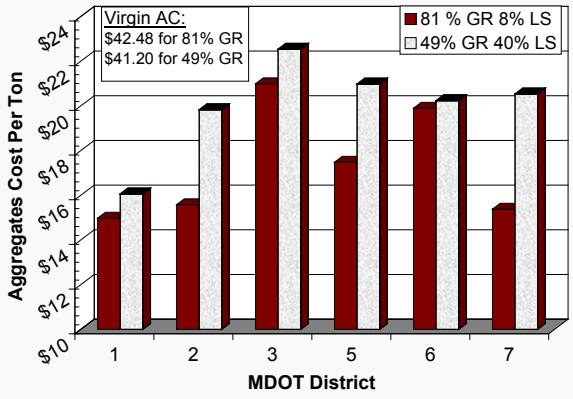

Figure 3. Virgin Material Costs (Oct 2008)

The higher the absorption of the RAP aggregate relative to the absorption of virgin aggregate, the less valuable a portion of the RAP bitumen becomes. A zero absorption aggregate is valuable, but an aggregate that has 0.9% absorbed bitumen has no more value than an equivalently sized and shaped aggregate with 0.7% absorbed bitumen, even though it was more expensive to attain the 0.9% absorbed asphalt aggregate in the original use of the material. The extra 0.2% bitumen could be viewed as an expended investment. Absorbed bitumen value in RAP is difficult to fully quantify. One approach with potential is to take the market asphalt price and multiply by the asphalt absorption of the virgin aggregate that the RAP aggregate would replace in the mixture.

Stockpile moisture content will affect RAP economics. Based on samples taken by the authors and numerous samples taken by Mississippi asphalt producers at locations throughout the state, RAP stockpile moisture contents can easily exceed 5% and were measured up to 8%.

Production costs could be one of the primary factors affecting economics of high RAP mixes (especially warm mixes). Reduction in mix production rates would drastically affect economics due largely to fixed costs. Production rates of elevated RAP mixtures aren't well defined for Mississippi materials and will require future field monitoring. Pre-heating devices for RAP may be useful to offset production issues.

According to Jeremy Robinson of the MDOT Materials Division, the goals of the 45% RAP mixture on the NCAT test track were to determine if such a mix could be designed with current MDOT specifications and materials and if the mixture could be produced; mixture was produced in July 2009. The design asphalt content was 5.6%, consisting of 2.28% RAP asphalt (45% RAP with 5.06% total asphalt or 0.45*5.06% = 2.28%) and 3.32% virgin asphalt. Conceptually this mix design approach assigns full value to all RAP bituminous material. The ongoing question is how the mixture will perform under traffic and environmental conditions over a period of time. As of February 2010 the section had negligible rutting, no cracking problems, and overall good performance.

In concise terms, economic implications of high RAP mixtures needs additional investigation of three items: 1) characterization methods to provide a reasonable estimate of the amount of the total bituminous material that will behave as binder in the new mixture; 2) a method to estimate and value absorbed bituminous material in RAP; and 3) a high RAP mix design approach that uses the aforementioned characterization philosophy.

Proven mix designs with high RAP contents could have significant economic implications provided they were ready for implementation when virgin asphalt prices spike (e.g. 2008). An investor would have no reservation in agreeing to purchase virgin asphalt for average yearly prices of $85 to $126 per ton between 1989 and 1999, using it for the financially beneficial purpose of carrying traffic, and then selling it at an advantageous time in the market. If inflation is taken as 3%, the investor would have paid the equivalent of $111 to $221 per ton for the material between 1989 and 1999 if purchased with October 2008 dollars, when PG 67-22 cost $708 per ton, requiring only 31% of the RAP bitumen to be effective in the new mixture (highly achievable based on previous research by the authors in MDOT State Study 200) for a return on the investment to occur.

Using high RAP mix designs during times of high virgin asphalt prices is logical. Not only does it drastically decrease the total cost for virgin materials per ton of mixture, but it also lessens the demand on virgin materials, which in turn should lower their unit price. The challenge is to get the entire materi-

als engineering community thinking as many already do about RAP. RAP is a highly valued material with variable properties that first must be understood and second used in a mix design procedure that rationally accounts for the effect of RAP in high quantities.

The challenge is formidable but achievable and will have a positive impact in Mississippi. The calendar year of 2008 brought record high material prices, 2009 through 2010 brought severe budget shortages; future years are uncertain but promise to bring notable challenges. The State of Texas (3) reported material costs could be reduced up to $15 per ton in some cases in an article where a perspective of RAP, substitute binders, and asphalt shingles was provided. High RAP mixtures are something Mississippi simply cannot afford to live without.

1. Howard, I.L., Cooley, L.A., and Doyle, J.D. (2009). Laboratory Testing and Economic Analysis of High RAP Warm Mixed Asphalt. Final Report FHWA/MS-DOT-RD-09-200.

2. Doyle, J.D., and Howard, I.L. (2010). "Compactability and Bitumen Utilization of 100% Warm Mixed RAP," Transportation Research Board 89th Annual Meeting.

3. Rand, D.A. (2009). "High Price of HMA Going the Way of the Cave Man?," Texas Asphalt-An Official Publication of the Texas Asphalt Pavement Association, Winter 2009, pp. 18-19.

For more information contact Isaac L. Howard at ilhoward@cee.msstate.edu

Pooled Fund Projects with 100% Federal Funding for FY 2011	
Study Title	**Sponsor**
Technology Transfer Intelligent Compaction Consortium	Iowa Department of Transportation
ITS Pooled Fund Program (ENTERPRISE)	Michigan Department of Transportation
Continued Advancements in Load and Resistance Factor Design (LRFD) for Foundations, Substructures and Other Geotechnical Features	Federal Highway Administration
Accelerating Innovation Implementation Across State Boundaries	California Department of Transportation
Improving the Quality of Pavement Profilers	Federal Highway Administration
Bridge Pier Scour Research	Federal Highway Administration
Transportation Library Connectivity	Missouri DOT

Work Program

On August 9, 2010, the MDOT Research Division met with the MDOT Research Advisory Committee and FHWA to discuss and approve the budget for FY 2011. Nine new projects were added to the 80% / 20% program. The entire FY 2011 work program can be found at:
http://www.gomdot.com/Divisions/Highways/Resources/Research/pdf/Reports/WorkProgram/2011FY.pdf

State Study	Study Title	Start Date	Completion Date	Principal Investigator
234	Evaluation of Short Statured Species for Rapid Establishment on Mississippi Roadsides	10/1/2010	6/30/2013	Gregg Munshaw
235	Triple-Bottom Line Assessment of Future Mississippi Intermodal Facility	10/1/2010	6/30/2013	Tulio Sulbaran
236	Expansive Soil (Yazoo Clay) Characterization	10/1/2010	6/30/2013	Landris T. Lee
237	Development of Sustainable Highway Construction Rating System	10/1/2010	6/30/2013	Lin Li
238	Evaluation of Crushed Concrete Base Strength	10/1/2010	6/30/2013	L. Allen Cooley, Jr.
239	Cement Influences on Gravel Aggregate Concrete Strength	10/1/2010	6/30/2013	Robert Varner
240	Evaluation of Fertility Practices During Roadside Establishment in MS to Minimize Nonpoint Source Pollutants	10/1/2010	6/30/2013	Gregg Munshaw
241	SAFE Alert System Pilot Project	10/1/2010	12/31/2012	Mark Herak
242	Collection and Evaluation of Core Data for the MEPDG for Overlayed and New Pavements	10/1/2010	12/31/2011	L. Allen Cooley, Jr.

Calendar of Events		
October 25-27, 2010	Pavement Evaluation 2010 RPUG http://www.cpe.vt.edu/pavementevaluation/index.html	Roanoke, VA
October 28 to November 2, 2010	2010 AASHTO Annual Meeting http://www.transportation.org/meetings/224.aspx	Biloxi, MS
December 6-9, 2010	Southeastern Asphalt User (SEAUPG) Meeting http://www.seaupg.org/events-current.shtml	Oklahoma City, OK
January 23-27, 2011	Transportation Research Board 90th Annual meeting TRB http://trb.org/AnnualMeeting2011/Public/AnnualMeeting2011.aspx	Washington, D.C.
February 3-4, 2011	Mississippi Quality Asphalt Conference	Ridgeland, MS

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Mississippi Department of Transportation
Research Division
Post Office 1850
Jackosn MS, 39215