Developing a Quality Assurance Measure for the Use of Reclaimed Asphalt Pavement in Construction Projects

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The use of reclaimed asphalt pavement (RAP) as a component in new mixes has several environmental and economic benefits. It is usually mixed with specified amounts of traditional aggregates to create new pavements. RAP use is strongly supported by the construction industry, since it presents an opportunity for the contractor to use a lower price ingredient as a significant percentage of the new material. With the wide spread use of that material, there is an increased need for construction quality assurance tests and measures to ensure that the contractors use only the specified amounts of RAP. Currently however, the Illinois Department of Transportation (IDOT) does not have an established quality assurance procedure to guarantee that RAP percentages are not exceeded in post-production mixes. The overall goal of the study presented in this paper was to assist DOTs in identifying and developing methods for quality assurance (QA) of post-production hot-mix asphalt (HMA) containing reclaimed asphalt pavement (RAP). The procedure described in this paper uses the results of simple standard laboratory tests available to most DOTs to calculate the amount of RAP by means of numerical analysis. The procedure allows for on-site quality control/quality assurance (QA/QC) professionals to verify the amount of RAP used by means of simple tests. The procedure was validated using sets of blind field samples, where the design RAP amount was not originally disclosed to the researchers. The positive results obtained in the blind testing program suggest that it would be feasible to immediately use the proposed RAP detection methods presented in this paper. In addition, a computer program was developed by the author to automate the calculation process. The use of the procedure is expected to enhance the overall quality of paving projects that use RAP by ensuring that the correct percentage of aggregates is used. Furthermore, the developed procedure can be used as a pay factor in end result specifications.

Keywords: Reclaimed asphalt pavement, roadway construction, computation, construction engineering, information technology

INTRODUCTION

Reclaimed asphalt pavement (RAP) is the term given to removed and/or reprocessed pavement materials containing asphalt and aggregates, from existing roadways. This material is recycled in limited amounts and used in the construction of new pavements. Therefore, the use of this material as a component in new mixes is strongly supported by the construction industry. The use of RAP has obvious economic benefits. This is mainly due to the lower cost of RAP compared to traditional aggregates and the wide spread availability of the material, even in areas where good aggregates may not be readily available. Industry and Government estimates are as high as 100 million tons of Hot Mix Asphalt (HMA) are recycled annually. According to a recent report issued by the Federal Highway Administration and the EPA, 80 percent of the asphalt pavement that is removed each year during roadway repair and replacement projects is reused as part of new roads, roadbeds, shoulders and embankments (Flynn 1992, Lee et al 2001). Some professionals (Norris 2007) mention that on 10000 tons at $350 per ton for binder, a savings of $33250 can be realized on the binder alone (this is in addition to the savings on the aggregates).

In addition to the economic benefits, the use of RAP has several environmental and economic benefits. Mixes with RAP will use less virgin material, which take pressure off limited quarry reserves. This also results in less material being dumped into the shrinking landfill space. Furthermore, by avoiding trips to the landfill, there are cost savings in trucking and fuel as well as savings in trucking extra loads of liquid asphalt binder for the various projects. Given the construction industry support and the economic benefits, the amount of RAP used in the United States is considerable and continually increasing.

Deviations from target RAP amounts may also cause other deviations from mixture design targets, such as gradation, voids, and asphalt content, which can decrease pavement performance. Currently there are very few methods to determine the quantity of RAP in an asphalt mix from constructed pavements (Buttler et. al. 2004). The developed procedure should take into account the variability in the RAP due to the different sources, as well as be applicable to for all RAP percentages. The procedure should be simple enough to be performed at the asphalt plant laboratories. It should also be quick enough to identify the amount of RAP in a mix so that the hot mix asphalt production may be modified as quickly as possible without a lot of wasted material.

Consequently, it is crucial to have a method to control and determine the quantity of RAP in asphalt mixtures. To address this problem the Illinois Department of Transportation funded a study to develop a procedure to determine the quantity of RAP in asphalt mixtures. This paper presents a procedure that can identify the presence and determine the quantity (%) of RAP in hot mix asphalt during production and from in service pavements. The procedure was validated using the results obtained from the IDOT study. The developed procedure can be used to in two ways; firstly as a quality assurance measure and secondly, as a pay factor in end result specifications. A computerized tool was developed to automate the procedure. The developed tool was verified using actual samples from the IDOT study and the results show that it can be used practically in the field. This paper firstly discusses the advantages of the procedure and the benefits of RAP use. This is followed by description and verification of the developed procedure. Then the developed computer tool, which can be used to perform the proposed numerical analysis, is discussed. Finally, conclusions and recommendations for future development are presented.

CONTRIBUTION AND BENEFITS OF THE RESEARCH

Similar to several other states, the Illinois Department of Transportation (IDOT) does not have quality assurance procedures to guarantee that RAP percentages are not exceeded in post-production mixes. The procedure described in this paper uses the results of simple standard laboratory tests available to most DOTs to calculate the amount of RAP by means of numerical analysis. The problem of trying to determine the amount of RAP from the results of ignition oven and sieve tests is formulated and solved using numerical analysis.

Tests for RAP detection and quantification can be classified into two kinds. Firstly, there are rapid tests that could be carried out quickly to test the presence of RAP and/or to determine approximate amount used. Secondly there are rigorous tests that could predict RAP presence and amount with greater accuracy. The procedure suggested here lies in the first category in that is it uses existing and established laboratory test methods that could be carried out quickly to determine the amount of RAP in post-production mixes or from in-service pavements. The procedure also is simplified due to the fact that many DOTs have limited in-house testing capabilities available to them. As such the procedure represents a novel methodology that uses the results from basic laboratory tests to identify and determine the quantities of RAP used in a mix.

A procedure that can verify the amount of RAP used in a specific pavement will be an invaluable quality assurance tool for any DOT. The procedure however has to be simple, i.e. it cannot involve any specialized or expensive testing and has to be carried out using readily available equipment. In the procedure presented here, an ignition oven is the only testing equipment needed and this is available at most DOTs' labs. The other potential application of such a procedure is in end result specifications. Method-type specifications penalize a competent asphalt-paving contractor by requiring the contractor to use prescribed equipment and methods to construct a particular pavement. End-result specifications, on the other hand, allow the contractor to use his available resources to accomplish the required end product in the manner of his own preference. A suggested contractor pay factor would therefore be the difference between the design RAP percentage and the actual constructed value. The use of the procedure is expected to enhance the overall quality of paving projects that use RAP by ensuring that the correct percentage of aggregates is used.

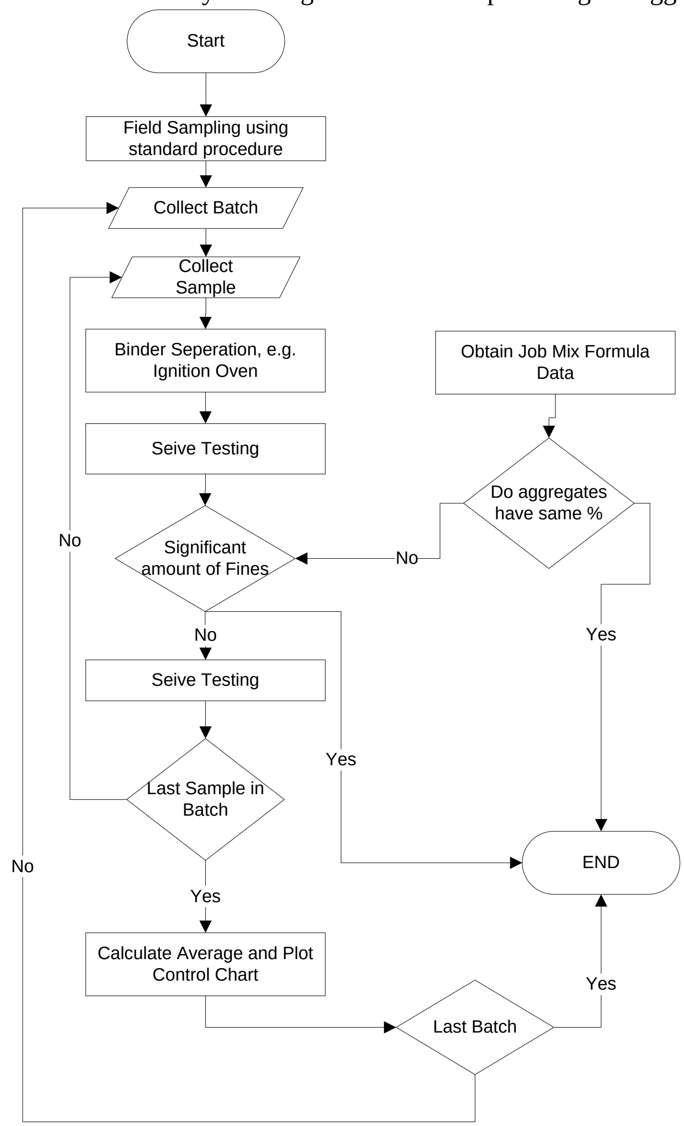

Figure 1: Flow chart of the proposed procedure

PROCEDURE TO TEST FOR RAP

There is a possibility that increased percentages of RAP could be included in the mix as a means to decrease the cost of the final product (Nouledin and Wood 1989). Increasing the percentage of RAP more than what is allowed in the mix can have unfavorable effects on the pavement performance for several reasons. Firstly, the binder in the RAP material will typically have hardened with age in the field. Secondly RAP stockpiles usually will have natural variability and possibly contamination. This will depend on the degree of accumulation of various RAP sources and stockpiling techniques. Thirdly, mixes with high RAP amounts require heating of virgin components to higher levels to expel moisture and to assist blending of the old binder attached to the RAP with the new virgin binder.

Therefore, a careful RAP mixture design will achieve the target binder properties in the blend by considering aged binder properties, virgin binder properties, and the proportions of these two binder components to be present in the final blend (Stroup-Gardiner and Wagner 1999). Considering that the asphalt binder contributed from RAP is aged, a softer (i.e. less viscous) virgin asphalt binder grade may be required when more than 15 percent RAP is used to compensate for this increased stiffness. (FHWA, 1993). Once the design is established, it is also necessary to ensure that the target RAP amount is not significantly deviated from during mixture production. Too much RAP can lead to a brittle mixture, and too little RAP may lead to an excessively soft mixture (when a softer virgin binder grade is utilized).

The main goal of the procedure defined below is to check that percentage of RAP from a field sample of the pavement is the same as was originally designed for in the job mix. The job mix formula that was designed for the particular job is usually available from the DOT. This includes the number of different aggregates used in the mix as well as their gradations. The proposed procedure can be used as a rapid detection method to be used on site and can be divided into five steps; sampling, separation of binder, sieves testing, problem set up and solution. A flowchart of the proposed procedure is shown in figure 1. Batches of samples were collected from each project will be collected for analysis. Simultaneously, the job mix formula can be obtained from plant readouts. The samples are then analyzed using the procedure described below and checks on the aggregate percentages and the amount of fines is conducted. Finally, quality control charts can be constructed. The five main steps of the procedure are:

Step 1: Sampling

To accomplish this, firstly a sample from the field has to be taken. Field or plant samples can be taken under the DOT's supervision and using its sampling procedures. The production mix has to be sampled in the same day. This is done to reduce variability of the stockpiled aggregate material by sampling before and after mixing. The standard sampling procedures for the specific DOT can be followed.

Step 2: Separation of Binder

Next, the asphalt binder needs to be separated from the aggregates in the sample. There may be several ways to accomplish that. For example, an ignition oven test can be carried out on the collected samples. The aggregates generated from the ignition oven test represent the mix containing all the aggregate types, including RAP, used in the job mix formula. Two replicates of each sample need to be tested to determine the variability for different RAP types and the repeatability of the test. The standard ASTM D4125 procedure for determination of asphalt content using an NCAT ignition oven can be used for testing purposes. More details on this can be found in ASTM 2001, ASTM 1988, ASTM 2003, Brown 1994, Brown 1984.

Step 3: Sieve Tests. A sieve test should then be performed on these aggregates to determine their gradation. From the gradation of the aggregates left over after the ignition oven, we can determine the percent passing through each of the n sieves, p_i, ($i = 1, 2, 3, \ldots, n$). These sieves may be chosen as the SuperPave™ (FHWA 1997) designed sieves for the mix at hand.

Step 4: Problem Set Up. Once the aggregate gradation is determined, the percentages of the different aggregate types can be determined. This section explains how these percentages can be calculated. In addition to the gradations found by the sieve tests explained above, we know the number of different aggregate types used, m, in the job mix formula. For each aggregate type j, we also know the percent passing through each of the n sieves $A_{i,j}$ ($i = 1, 2, 3, \ldots, n$) and $j = 1, 2, \ldots m$. What we need to determine now is the quantity of each aggregate type x_j, ($j = 1, 2, m$) expressed as a percentage and compare that with the one used in the job mix formula.

In this problem, since the number of sieves (usually eleven) is more than the number of aggregate types (usually between 2 and 4) including RAP, (i.e. $n > l$) we will have more equations than unknowns. In this case, it is usually impossible to find a solution that satisfies all the equations. In our case, since we know that the contractor actually used certain percentages in the job mix formula, we would expect that a solution actually exists that will satisfy all the equations for the different sieves.

Step 5: Problem Solution. In order to find that solution, an error minimization problem is set up, which would iteratively search through various solutions and find the aggregate percentages that minimize the error *E*. However in order to have a more useful formula, we need to find a closed form solution for the RAP percentage. A simple closed form answer that can be calculated easily on site using programmable calculators or on a spreadsheet was defined. The closed form solution gives the percentages of the aggregates and RAP that were originally used in the mix, therefore providing quality assurance method for on-site QC professionals to verify the amount of RAP used.

Limitations of the Proposed Method. It is important to note that the procedure may not yield accurate results in two specific cases. Firstly, an accurate result may not be found if the blend consists of two aggregate types with similar gradations. This is because one will not be able to determine which percentage pertains to which aggregate type. Secondly, often when using the ignition oven to determine the aggregates gradation of the mix, some fines may be lost with the burned asphalt binder. In these cases, another test is needs to be performed. As part of this research a procedure using gyratory testing is recommended but is not discussed here. More information on the using gyratory testing procedure can be found in Buttlar et al 2004.

Table 1, JMF Information for Mix A, Collinsville Surface Mix

Mix Type	Plant	Gradation												
(A)	Collinsvill ,IL		1-(032CMM16)		2-(038FAM20)		3-(037FAM01)		4-(004MFM01)		Rap			
	Surface Mix		Perct 1=	55.4	Perct 2=	17.8	Perct 3=	9.1	Perct 3=	3.3	Perct 4=	14.4	100	Formula
		Seive	%pass	%Blend	%pass	%Blend	%pass	%Blend	%pass	%Blend	%pass	%Blend		
		1	100.0	55.40	100.0	17.80	100.0	9.10	100.0	3.3	100.0	14.40	100.00	100.0
		3/4	100.0	55.40	100.0	17.80	100.0	9.10	100.0	3.3	100.0	14.40	100.00	100.0
		1/2	100.0	55.40	100.0	17.80	100.0	9.10	100.0	3.3	99.8	14.37	99.97	100.0
		3/8	98.0	54.29	100.0	17.80	100.0	9.10	100.0	3.3	95.4	13.74	98.23	98.0
		#4	38.0	21.05	100.0	17.80	99.1	9.02	100.0	3.3	66.6	9.59	60.76	61.0
		#8	4.8	2.66	83.0	14.77	92.0	8.37	100.0	3.3	44.6	6.42	35.53	36.0
		#16	3.0	1.66	50.4	8.97	71.3	6.49	100.0	3.3	37.6	5.41	25.84	26.0
		#30	2.6	1.44	27.0	4.81	42.0	3.82	100.0	3.3	31.6	4.55	17.92	18.0
		#50	2.3	1.27	15.0	2.67	16.7	1.52	100.0	3.3	22.8	3.28	12.05	12.0
		#100	2.1	1.16	6.9	1.23	4.9	0.45	98.0	3.2	10.0	1.44	7.51	8.0
		#200	2.0	1.11	4.8	0.85	3.0	0.27	76.0	2.5	6.1	0.88	5.62	5.6

Table 2: Aggregates % Output for Mix (1)

Test #	Aggregate1	Aggregate2	Aggregate3	Aggregate4
Test 1	44.8%	15.2%	12.6%	27.4%
Test 2	45.2%	14.1%	14.8%	25.9%
Test 3	39.3%	23.1%	12.6%	25.1%
Test 4	37.3%	25.7%	14.8%	22.2%
Test 5	44.5%	11.7%	14.8%	29.0%
Test 6	35.7%	24.3%	10.4%	29.7%
Test 7	35.1%	15.1%	6.8%	43.0%
Actual % of the mix	42.7%	24.0%	13.3%	20.0%

TESTING AND VERIFICATION

In order to verify the proposed procedure, QC/QA, data was collected from IDOT for four mixes already in-service in district four. Individual aggregate gradation where obtained from the contractor. Final blended aggregate gradation was obtained from ignition oven tests run by IDOT. Illinois Department of Transportation (IDOT) sampling procedures were followed in all sampling activities for this project. Sample sizes were chosen based on proportioning the Job Mix Formula (JMF) to the required number of laboratory specimens to be prepared. Sample JMF sheets are shown in Table 1. For each of the four mixes, at least six samples were collected and tested in the ignition oven as part of the routine inspection activities for the IDOT QC/QA. Sieve tests were then performed to determine the gradation. The averages for the aggregate percentages were obtained for each ignition oven test. The percentages were then calculated for each test sample for the four mixes. These tables show the results of the test carried out. The tables show the aggregate percentages for the output of the mix design. The last row in these table 2 shows the percentages used in the design. Table 2 for example shows that the actual percentage of aggregate1 is 42.7%, which represents the design value. The results from the seven tests varied from 35.1% to 45.2 %, indicating that in this case the contractor was very close to the design value, with around 7% deviation from the design. By comparing these results with the mix design one can make conclusions on how close the mix design was adhered to.

Since the calculations involved in the procedure described above are cumbersome to perform by hand a computer tool was implemented to help in the calculations. This is described in the next section.

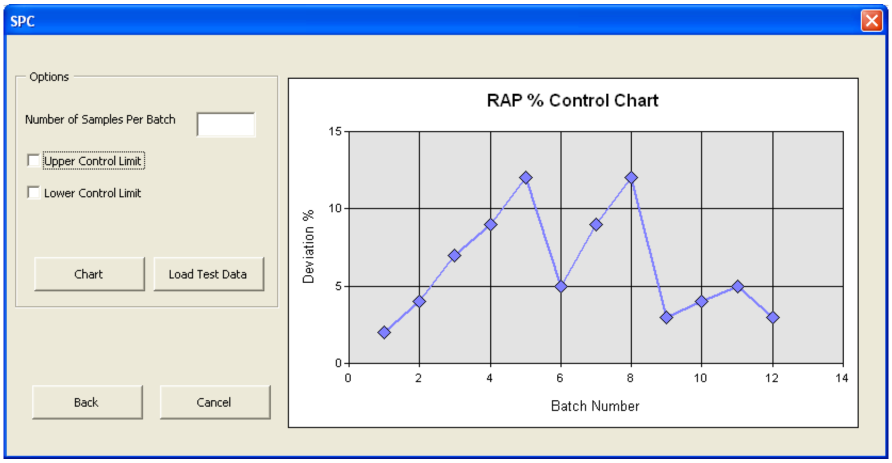

Figure 1: SPC Control Charts

COMPUTER IMPLEMENTATION

The developed spreadsheet tool can be used in two ways to ensure a secure mix. First, it can be incorporated into the plant readout system and the calculated RAP percentage, based on aggregate and mix gradations, reported in the form of control charts. The results may be implemented in the form of a control chart, where the back calculated aggregate percentages are plotted versus the number of tests. Any deviation from the design value can then be quickly noticed and proper correction measures taken to correct the problem. For example, table 6 shows the aggregates percentages versus the number of tests for mix 4. It shows clearly that aggregate 2 in sample 4 is far out of the actual limit- 15%. The limits on the control charts could be assigned on this chart and the errors can be spotted quickly after the ignition oven test is performed. The developed tool has the ability to plot control charts as well as calculate upper and lower control bounds for the control charts. Secondly, the calculated RAP percentage may be calculated for every QC/QA test and included as a pay item in the end-result specifications. Quality assurance and quality assurance data collected by both the contractor and the department can be directly entered in the Excel software and the RAP percentage calculated. If enough data is collected the upper and lower quality indices can be calculated and used to determine a pay factor for RAP percentage. This pay factor along with the asphalt content pay factor can be a strong indication of mix security.

CONCLUSIONS

The RAP is an aged product that considerably alters the properties of the existing mixture, generally resulting in a stiffer, more brittle mixture unless compensated for in mixture design and control (McDaniel and Anderson 1997). On the other hand a deficiency in RAP (from the mix design) may lead to an excessively soft mixture. With the increased use of RAP, DOTs' construction engineers and quality assurance personnel are interested in verifying that the percentages of those aggregate types in the field (including the RAP), is the same as that were used in the mix. Although there is a real need for a post-production quality assurance test for RAP, currently there are virtually no rapid test procedures or calculation methods (Buttler et. al. 2004). The proposed procedure and the numerical analysis suggested, allows for on-site quality control/quality assurance (QA/QC) professionals to verify the amount of RAP. One of the advantages and contributions of the procedure is that it does not require comprehensive or expensive laboratory tests (which may not be available to all Departments of Transportation).

This paper presented a novel procedure for testing and verifying the quantity of RAP in highway construction projects. The procedure presented here is simple yet robust enough to be implemented as a quality assurance test for the use of RAP. The procedure can also be used in end-result specifications as a pay factor or can be implemented in plant readouts. In order to verify the procedure, laboratory test methods were developed and assessed using field samples from a number of HMA projects containing RAP across Illinois. The procedure is shown to provide accurate estimates of the amount of RAP in any mix. Future extensions of the work presented here include addressing the problem of lost fines when performing the procedure. Also, the integration of Tri-Linear Charts as a back calculation method to check the percentages of aggregates in the analysis could be studied.

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