NCAT Report 07-03

UTILIZATION OF AUTOMATION AND REAL-TIME TESTING TO IMPROVE QC/QA PROCEDURES FOR HOT MIX ASPHALT

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ABSTRACT

Numerous advances have been made in the hot-mix asphalt industry over the past several decades. Innovations have been made in plants and construction equipment, and improved materials specifications and mix design methods are now in use. However, the basic methods for assuring the quality of hot mix asphalt have changed little during this period. It is believed that significant advancements can be made in HMA quality and performance if new concepts and new measurement technologies are adopted by the industry.

For decades, Quality Assurance programs for hot mix asphalt have been based on laboratory testing of the mix for specific properties. Historically, the owner agency performed testing for acceptance analysis, and separate quality control (QC) testing was performed by contractors. The Alabama Department of Transportation (ALDOT), like many other highway agencies, now uses contractor quality control test results for acceptance with limited verification testing by agency personnel.

This project was initiated to evaluate the potential of several new technologies for automated sampling and testing of component materials during HMA production. The automation devices evaluated in this project included: (1) microwave based moisture content probes on the aggregate and RAP feed belts, (2) belt sweepers for obtaining samples of aggregate and RAP, (3) sample drying units to remove moisture from the materials, (4) a sieve-based gradation device for the virgin aggregate, (5) an asphalt calibration tank for checking the accuracy of the asphalt meter, and (6) an in-line asphalt viscometer. Other existing plant control components, such as the asphalt metering system and the mix temperature sensor, were also included in the evaluation. Results of this preliminary project indicate that some of these automated technologies appear to have promise for use in gathering unbiased QC data at a higher frequency than the traditional technician/laboratory testing approach. Several refinements are recommended for improving these automated testing systems. However, it is also evident that the data available with the above automation technologies only provides part of the information necessary to fully evaluate the composition and quality of HMA mixtures during production. More work is needed to develop and evaluate ways to determine the composition of RAP and the quantity of baghouse fines or other mineral fillers added to the mix during production.

Utilization of Automation and Real-Time Testing to Improve QC/QA Procedures For Hot Mix Asphalt

Randy C. West and Pamela Turner

INTRODUCTION

Background

Numerous advances have been made in the hot-mix asphalt (HMA) industry over the past several decades. Innovations have been made in plants and construction equipment, and improved materials specifications and mix design methods are now in use. However, the basic practices for assuring the quality of hot mix asphalt during production have changed little during this period. It is believed that significant advancements can be made in HMA quality and performance if new concepts and new measurement technologies are adopted by the industry.

Current quality control (QC) practices for HMA are manpower and time intensive which leads to inefficient gathering of information needed to monitor and control the production of quality asphalt mixtures (*1*). The attention of QC testing is now often simply focused on sampling and testing HMA mixtures well after it is produced because that is where the pay factors are based. Considering that it typically takes about three hours to complete the suite of tests commonly used for QC of asphalt mixtures, and that the majority of plants commonly produce HMA at rates of 200 to 300 tons per hour, then it is common for 600 to 900 tons of HMA to be produced before the results are known and the acceptability of the sampled mixture is determined. This lag of information puts the HMA producer at significant financial risk and the customer (i.e. agency) at risk of accepting a significant amount of poor quality materials.

In addition to the risks associated with the QC information time lag, it is recognized by the collective HMA industry that most of the tests used in QC and acceptance testing suffer from poor precision. Part of the poor precision is attributable to sampling and testing variability which are related to the skill and ability of technicians. The effect of this poor precision is that it confounds decision making. If uncertain about a test result, QC technicians or managers will often resample and test to validate the first result. This further extends the information lag and increases the risks. However, if the technician or manager incorrectly reacts to bad data, then the mixture may be adjusted when it should not have been. More effective techniques are needed to assure that quality HMA is being produced.

Automated testing should improve current QC practices in two ways. First, automated testing removes the human element from the processes of obtaining some QC information. This includes the automation of sampling, testing, calculations, and data management. By removing human technicians from the processes, it is expected that overall testing variability will be reduced and potential bias will be eliminated. The second key difference of automated testing is the point in the production process where

samples are taken. Automated testing can return attention to assessing if the raw materials going into the mix are correct and consistent at the time of production.

Over the past decade, attention has been given to improving the laboratory tests used for quality control of HMA. Many of the improvements have centered on making the tests faster and less variable. For example, the NCAT ignition furnace test, developed in the mid 1990's, has provided a faster and more reliable method of determining the asphalt content of plant produced mixtures (*2*). Faster and better lab procedures, although a worthwhile pursuit, provide only incremental improvements to quality control. As it is envisioned, automated testing could provide a quantum leap forward in quality control.

Purpose

This project was a pilot study to select, install, and evaluate new technologies for real-time quality control testing of asphalt mixtures during plant production.

Scope

This study evaluated six automated testing devices installed on East Alabama Paving Company's hot mix asphalt plant in Opelika, AL in October 2004. The automation devices included the following equipment:

- Automated Belt Sampling for Aggregate and RAP
- Automated Moisture Contents of Aggregate and RAP Using Moisture Probes
- Automated Moisture Contents of Aggregate and RAP Using Sample Drying Units
- Automated Gradation of Virgin Aggregates
- Automated Viscosity of Asphalt Binders
- Automated Measurement of Mix Temperature

Further details of these automated systems are provided in the following sections. In addition to the automated testing hardware installed on the plant, a central computer control and data acquisition system was set up in the plant's control house. The HMA plant was a 2003 double-barrel drum mix plant built by Astec Industries with a rated production capacity of 300 tons/hour. The plant was equipped with a materials control system which includes the capability to automatically control the asphalt content based on aggregate and RAP belt scale measurements and the asphalt binder metering system. The ability of the plant's controls to accurately produce mixtures with correct asphalt contents was also assessed.

The sampling plan was to obtain data from the automated devices during the production of several mixtures. When the plant was producing the desired mix, the automated equipment was activated up to six times per day to obtain data. Samples of the aggregates, binder, RAP, and mix were also obtained to coincide with the automated test measurements for direct comparisons to tests performed on the materials in the laboratory.

Three HMA mixtures were sampled and tested over the period of several months:

1. Mix 1 was a 25.0 mm nominal maximum aggregate size (NMAS) permeable asphalt treated base with A PG 76-22 asphalt binder. The ALDOT designation for this mix is 327 E PATB.
2. Mix 2 was a 25.0 mm NMAS Superpave mix containing all virgin aggregate and a PG 67-22 asphalt binder.
3. Mix 3 was a 19.0 mm NMAS Superpave mix containing 20% RAP and a PG 67-22 asphalt binder.

DESCRIPTION OF EQUIPMENT

Automated Belt Sampling

Automated belt samplers (Figure 1) were used to obtain samples of aggregate and RAP from moving conveyor belts. When a belt sampler was activated, an open box rapidly swept transverse across the belt closely following the contour of the belt so that all of the material in the cross-section was removed. The sweep occurs very fast to obtain an even cross-section of material and minimize the potential influence on belt scales. These type of belt samplers have been used by other industries, particularly the mining industry, for several decades, so this technology is mature and the equipment is robust enough for the HMA industry. The sample obtained by the belt sampler can be deposited into a bucket or go straight into another automated device such as a drying unit or gradation unit. The mass of the sample obtained by the automated belt sampler depends on the amount of material on the belt and the size (width) of the box. A typical sample mass obtained by an automated belt sampler will be between 20 to 30 pounds for the HMA industry. For this project, belt samplers manufactured by Astec Industries were installed on the virgin aggregate conveyor and the RAP conveyor. Automated belt samplers are manufactured by several companies and their costs range from $10,000 to $15,000 installed. Some conveyors may require additional support or frame modification.

Figure 1. Aggregate Belt Sampler.

Automated Moisture Content of Aggregates and RAP

For continuous mix HMA plants, the moisture content of the aggregate and RAP are needed to correct the mass measurement (e.g. tons/hour) of the belt scales. Two technologies were evaluated on this project to determine moisture contents. The first technology utilized probe type sensors that were inserted into the stream of material traveling on the belt (Figure 2). These probes are based on a microwave technology which instantaneously senses the microwave energy absorbed by the material. The energy absorbed is proportional to the moisture content of that material. This technology has been used in several other manufacturing applications, including the ready-mix concrete industry. For this project, a moisture probe was installed on the virgin aggregate conveyor belt which takes the materials to the drier. From the perspective of plant operations, this was the most logical location since this is where the belt scale is located and it is after the scalping screen which acts to mix the component aggregates to provide a more uniform bed of material on the belt. The scalping screen also acts to aerate the aggregates which can cause moisture loss. The moisture content correction for adjusting the belt scale is a composite moisture content of all the materials on the belt. This moisture content is an input to the plant's controls for correct proportioning of the asphalt content. Another moisture probe was similarly installed on the RAP conveyor belt. The installed cost for the two moisture content probes on this project was approximately $7,500. The moisture probes were manufactured by Hydronix Ltd.

FIGURE 2. Microwave Moisture Content Probe.

The second method for determining moisture content in this study was with automated sample driers which received materials from the automated belt samplers. Two automatic sample driers were installed on the plant for this study: one was used for virgin

aggregates and the other was used for testing RAP. The driers used on this project were first production units manufactured by Astec Industries. The driers (Figure 3) used electric heating elements to heat the samples to approximately 204ºC (400ºF) until the sample reaches a constant mass. The drying units were suspended on load cells so that the sample mass could be monitored by a programmable logic controller (PLC) and the moisture content of the sample automatically calculated. Drying times for a 9 to 18 kg (20 to 30 pound) sample were in the range of 30 to 100 minutes depending on how wet the sample was at the start of the test. The installed cost for the two automatic sample driers for this project was $28,000. Very limited data was obtained on this project with the automatic drier for the RAP samples because only one mix included in the sampling plan contained RAP.

FIGURE 3. Automatic Drying Unit.

Automated Gradation of Virgin Aggregate

After the virgin aggregate samples were dried by the automated drying unit, they were directed into an automatic gradation device (Figure 4). The automatic gradation unit (AGU) is similar to laboratory sieving equipment. The AGU used on this plant was equipped with seven screen trays, but only six standard sieves were installed on the unit. These screens were the 12.5 mm, 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm and 0.030 mm sieves. The shaking of the screens was accomplished with two variable frequency vibrators. After shaking for a programmed interval, the entire unit automatically rotated 90 degrees and each screen was emptied one at a time into a catch pan and weighed.

The catch pan was suspended on three small load cells connected to a PLC which calculated the gradation as percent passing each sieve. The gradation unit used on this project is one of the first built for use at an asphalt plant. The cost of the automatic gradation unit (AGU) for this project was approximately $35,000. The AGU was manufactured by Astec Industries. Similar gradation units have been installed on a few aggregate crushing plants.

FIGURE 4. Automatic Gradation Device.

Automated Viscosity of Asphalt Binders

An in-line viscometer was installed in the asphalt supply line from the plant's tanks to the point of mixing in the drum (Figure 5). The purpose of the in-line viscometer was to indicate if the correct binder grade (e.g. PG 67-22 or a PG 76-22 binder) was being used in the mix. This viscometer utilizes a magnetically oscillated rod in the flow of the fluid (asphalt). The dampening effect of the fluid on the amplitude of the oscillation is proportional to the viscosity of the fluid. To compensate for the effect of temperature on the viscosity of asphalt, the instrument also records the temperature of the material and a processor corrects the viscosity to a standard reference temperature. For this project, the reference temperature was set at 135ºC (275ºF). The cost of the in-line viscometer and installation for this plant was approximately $17,000. The in-line viscometer was a MIVI 8002 model process viscometer manufactured by Sofraser Instruments. In-line viscometers are used in several industries to monitor and control fluid mixing and viscosities including the chemical industry, and large combustion engines and burners.

FIGURE 5. In-Line Viscometer Installed in the Asphalt Supply Line.

Plant Mix Discharge Temperature

The HMA plant was equipped as a standard item with an infrared temperature sensor located at the discharge of the drum where the mix drops into the slat conveyor as shown in Figure 6. Mix temperature is continuously measured using this sensor as a plant process control function to provide information to the plant operator for mix start up and burner adjustments. Most HMA plants are equipped with this type or a similar mix discharge temperature device.

FIGURE 6. Infrared Temperature Sensor at Drum Discharge.

Automated Asphalt Content Control

Modern asphalt plants are equipped with computer controlled asphalt delivery to the point of mixing. For continuous mix plants, the asphalt flow rate is controlled through a pump and meter system. The plant's controls proportion the flow rate of the asphalt binder to the feed rates of aggregate and RAP so that the mix will continuously be produced with the correct asphalt content. This is a closed loop system that requires the plant operator to input the target asphalt content, the moisture content of the aggregate and RAP, and the target production rate. The plant controls then continuously monitors the aggregate and RAP feed rates, calculates the needed binder to be pumped, and controls the pump to deliver that amount of binder. A separate non-driven pump or meter then continuously monitors the binder flow rate and provides the feedback to the plant controls on whether or not the correct amount binder is being supplied to the mix.

Some agencies allow this type of asphalt metering system to be used for quality control and acceptance of the mix asphalt content. For this type of system to work properly, calibration is critical for the aggregate weigh bridge, the recycle material weigh bridge, and the asphalt meter. The controls also have to be adjusted for timing of the different measurements, and corrected for temperature of the binder to convert volume to mass.

On this project, the accuracy of the plant controls for asphalt content were checked using two laboratory test methods, AASHTO T 287 and T 308, namely the nuclear method and the ignition method, respectively. This also required recording of the plant's asphalt content meter reading, the mix production tonnage, and creating a tonnage log from the plant's mixing zone to the time the mix was loaded from the silos so that the mix tested in the laboratory would be related to meter readings at a specific time.

RESULTS AND DISCUSSION

Moisture Contents of the Virgin Aggregate

During HMA production, discrete moisture content measurements were obtained with the microwave probes and automatic sample drying unit several times per day. Once per day, the plant was stopped to physically obtain a sample of the aggregate from the conveyor belt. These samples were taken immediately to an on-site field laboratory weighed and dried in an oven using AASHTO T 255 (*3*) to determine the moisture content of the belt cut samples. The entire belt cut sample was tested. Results are shown in Tables 1 through 3.

For accurate readings, the microwave moisture probes have to be calibrated for the material that the probe is sensing. However, calibration of the probes was more challenging with this approach since each mix design requires a different calibration, and each calibration requires testing of moisture contents over the working range expected to be encountered (*4*). The locations of the probes on the plant were not near a convenient water source to add water to the materials for the calibrations. Therefore, the results shown for the microwave moisture probes are not calibrated for the materials.

Table 1. Aggregate Moisture Contents Obtained During the Production of Mix 1.

Date	Sample time	daily sample #	cumul. sample #	Moisture Content, %		
				Micro. Probe Uncalib.	Auto Sample Dryer	Belt Cut, T 255
10/26/04	10:55	1	1	2.0	0.3	1.2
	13:54	2	2	2.0	0.6	--
10/27/04	NR	1	3	1.9	0.0	0.9
	12:27	2	4	2.0	1.4	--
10/29/04	8:01	1	5	2.0	1.9	0.7
	9:01	2	6	2.0	0.8	--
	9:59	3	7	2.1	2.7	--
	11:18	4	8	2.0	0.6	--
	13:49	5	9	2.0	1.1	--
11/10/04	8:37	1	10	2.1	2.8	0.8
	NR	2	11	2.1	0.6	--
	NR	3	12	2.1	1.1	--
	NR	4	13	2.1	1.3	--
	NR	5	14	2.1	--	--
	NR	6	15	2.0	0.8	--
11/15/04	NR	1	16	2.0	1.1	1.2
	NR	2	17	2.0	1.3	--
	NR	3	18	2.0	1.0	--

NR – time not recorded

From Table 1, it can be seen that the laboratory tested moisture contents of the aggregates in Mix 1 were in a fairly narrow range of 0.7 to 1.2 percent. The uncalibrated

microwave moisture probe readings ranged from 1.9 to 2.1 percent, which possibly indicates a calibration offset of about -1% for this mix. However, the proper calibration procedure would need to be performed to verify this factor. The small variations observed for the results of the microwave probes are likely due to the lack of calibration.
The results of the automatic sample drier ranged from 0.0 to 2.8 percent. Direct comparisons of samples from the belt cuts show that the moisture contents from automatic sample drier do not track with lab results. During the first few days of operation of the automatic sample drier, the unit had some malfunctions with the heating elements and air system which are probably reflected in these results.

Table 2 shows the results of the moisture content measurements for Mix 2 over four days of production. From the belt cut samples, the moisture contents appeared to be consistently around 2.6 percent for the first three days and then increased by about a percentage on the last day. The uncalibrated microwave moisture probes also indicated that the moisture content of the virgin aggregates was very consistent, but the only result from the last day did not indicate the increase in moisture as shown with the lab test. The automatic sample drier results indicated more variation in the moisture content within each day. It is unknown if this variation is due to real variations in the moisture content of the material or if it is due to testing variability with this device. It is probably some of both. The fact that the device operates in a fairly exposed outdoor environment makes it susceptible to ambient moisture and wind effects which could cause variations in results.

Table 2. Aggregate Moisture Contents Obtained During the Production of Mix 2.

Date	Sample time	daily sample #	cumul. sample #	Moisture Content, %		
				Micro. Probe, Uncalib.	Auto. Sample Dryer	Belt Cut, T 255
10/29/04	7:10	1	1	2.5	2.6	2.6
	8:19	2	2	2.5	4.2	--
	11:08	3	3	2.4	3.1	--
	11:55	4	4	2.4	4.3	--
	14:15	5	5	2.4	2.8	--
	15:00	6	6	2.4	2.3	--
11/02/04	7:34	1	7	2.4	3.2	2.7
	9:30	2	8	2.4	2.5	--
	10:41	3	9	2.5	3.0	--
	11:17	4	10	2.4	3.3	--
	12:48	5	11	2.4	2.6	--
11/03/04	7:25	1	12	2.4	3.3	2.5
	8:10	2	13	2.5	4.3	--
	8:51	3	14	2.5	3.6	--
	9:31	4	15	2.4	4.3	--
	10:08	5	16	2.5	3.4	--
	10:30	6	17	2.4	4.0	--
11/04/04	7:42	1	18	2.6	5.3	3.6

Overall, the results of the automatic sample drier were higher than the results of the lab tests. This may have been due to differences in drying temperatures for automatic sample

drier and the lab test. The automatic sample drier operates at a nominal 400ºF, whereas the lab samples were dried at 230±9ºF.

Moisture content measurements from Mix 3 are shown in Table 3. This mixture contained RAP and so moisture measurements were also made on this material. The results of the lab tests on the virgin aggregate show that moisture contents ranged from 2.4 to 6.8 percent. The uncalibrated microwave moisture probe readings indicate that the aggregate moisture content was very consistent (4.4 to 5.0%) except for the readings made on May 19 (1.8 & 1.9%). As with the other mixtures, the automatic sample drier results for the virgin aggregate were more variable with moisture content results ranging from 1.7 to 5.5 percent. Some problems were noted during this period with the dump gate from the automatic drying unit. Direct comparison of results from both automated devices to the lab results of samples taken at the same time show that the devices were not tracking well with actual moisture contents.

A similar observation can be made form the moisture content results from the RAP. The lab moisture contents for the RAP were in the range of 4.2 to 5.3 percent except for the sample taken on May 19. Most of the uncalibrated readings from the microwave moisture probe were in the range of 6.7 to 8.6 percent. One of the readings outside of this range was the first sample on March 29 (1.9%) which had a corresponding lab result of 5.3 percent. The other microwave probe results that day were closer to the other readings for this device. During the first several days of production of this mix, the RAP moisture contents from the automatic sample drier were generally consistent and lower than the lab results. However, the results of the last two days contradict that trend.

Table 3. Aggregate & RAP Moisture Contents from the Production of Mix 3.

Date	Sample time	daily sample #	cumul. sample #	Moisture Content, %					
				Virgin Aggregate			RAP		
				Micro. Probe, uncalib.	Auto. Sample Dryer	Belt Cut, T255	Micro. Probe, uncalib.	Auto. Sample Dryer	Belt Cut, T 255
03/24/05	10:06	1	1	4.7	5.5	3.1	7.0	3.6	4.6
	13:04	2	2	4.7	3.9	--	7.1	3.6	--
	NR	3	3	4.7	3.9	--	8.6	3.5	--
03/25/05	6:12	1	4	4.7	4.1	2.8	8.6	3.1	4.7
	7:17	2	5	4.5	--	--	8.4	2.4	--
03/29/05	8:46	1	6	4.9	2.5	3.9	1.9	2.6	5.3
	11:33	2	7	5.0	3.5	--	6.7	4.2	--
	15:11	3	8	4.7	1.7	--	6.7	4.5	--
05/19/05	11:06	1	9	1.9	--	2.4	1.8	--	1.0
	15:30	2	10	1.8	--	--	2.7	--	--
05/20/05	9:34	1	11	4.8	--	--	7.2	--	--
6/16/05	9:10	1	12	4.5	3.0	2.2	8.4	8.1	4.4
	11:30	2	13	4.5	2.9	--	8.6	5.7	
6/17/05	8:00	1	14	4.4	4.6	6.8	8.6	5.9	4.2
	12:40	2	15	4.5			8.6	4.9	

A few other observations about both of the automated moisture content systems are worth noting. First, the system built to insert the microwave moisture probes into the materials streams on the belts worked well. A funneling attachment was added to the probe inserting mechanism for the RAP belt in order to crowd sufficient material across the sensor on the probe. These probe insertion systems minimized wear on the probes by retracting them when readings were not being taken and would allow for easy maintenance on the probes as needed in the future. For the automated sample driers, there were several hardware and software issues that arose during the study but most were corrected. Hardware issues included a malfunction of the air system and trouble with the drop gate. It was also evident while watching the system display in the control house during some tests that wind seemed to be affecting the load cells. Another issue that required some programming adjustments was the initial drying time before checking for a constant weight. When the initial time was set low, the test would stop before the materials had even started drying. The final issue was the drying temperature. The ADU was set up to heat the samples to approximately 400ºF to aid in drying samples quickly. However, this could drive off more moisture than lab tests which are standardized at 230±9ºF. Drying times typically ranged from 40 minutes to an hour.

The last comment to make on the issue of moisture content measurements is that the accuracy of the measurements is not highly critical. For a typical set of plant conditions such as a production rate of about 250 tons per hour and a target asphalt content of 5.0%, moisture contents would have to be off by more than 2.0% to affect the asphalt content by 0.1%.

Gradation of the Virgin Aggregates

For evaluation of the results from the automatic gradation unit (AGU), the aggregate samples from the unit were collected twice per day, reduced to lab sample size by splitting, and sieved in the field lab first using the dry gradation procedure, AASHTO T 27, and then using the washed gradation procedure, AASHTO T 11 (*3*). Since the AGU determines the gradation based on dry aggregate only, comparisons are made between the AGU results to the laboratory dry gradation test results. These comparisons are illustrated in Figures 7, 8, and 9 for Mix 1, 2, and 3, respectively. These plots are based on the gradations from the upper five sieves in the automatic gradation unit, the 12.5 mm, 9.5 mm, 4.75 mm, 2.36 mm, and 1.18 mm sieves. Analysis of the results of the finest sieve (0.3 mm) indicated that the comparisons were not favorable. Tabulated results are provided in Appendix A.

To aid in the comparison of results, the graphs include the limits of precision for aggregate gradation testing from AASHTO T 27. The acceptable range of two results (d2s limits) for single operator and multilaboratory comparisons are shown as red dashed lines and green solid lines, respectively, on each side of the line of equality. A linear regression between the lab results and AGU results is also shown in the figures.

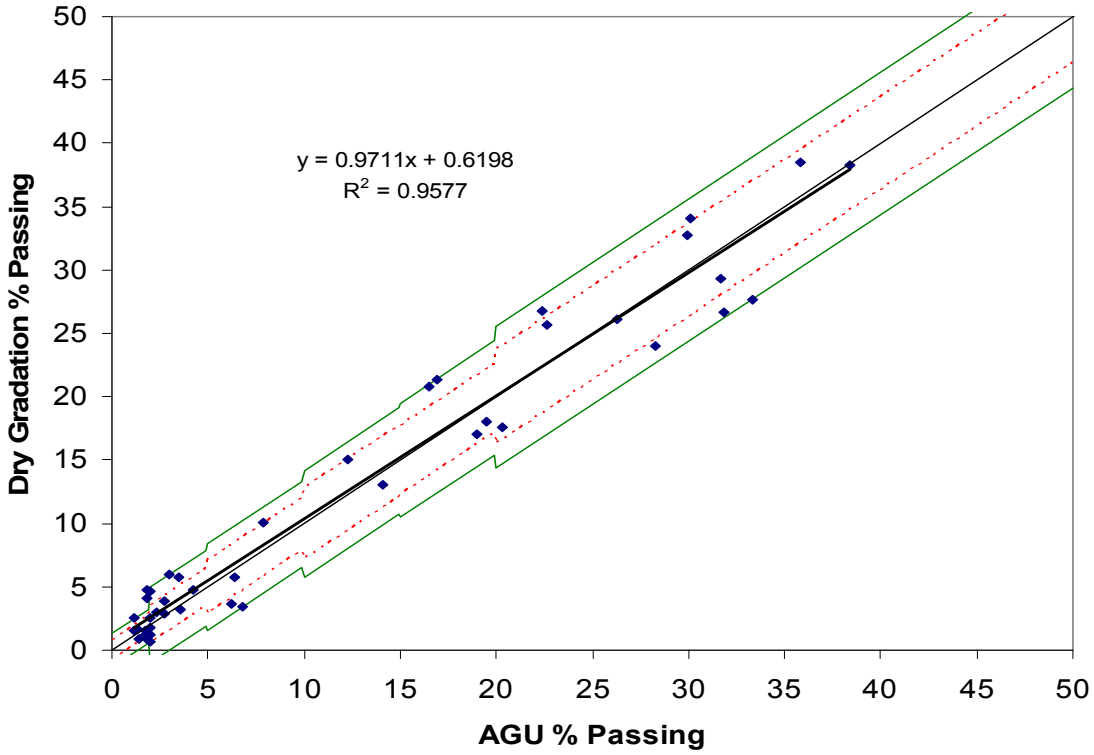

Figure 7. Graphical Comparison of Lab and AGU Results for Mix 1

The results from Mix 1, shown in Figure 7, indicate a good agreement between the AGU and the lab tested dry gradations. The regression through the data for this mix shows that the AGU results were highly correlated with the dry gradations from the lab and the relationship was very near unity. Thirty-two of the forty (80%) data points were within the between laboratory range. Of the eight data points outside of the multilaboratory range, half were from the same sample. The other four data points outside the multilaboratory range are very close to the range.

Since this mix was a gap-graded coarse gradation, a high percentage of the aggregate was designed to be retained on the 12.5 mm sieve and so the percentages passing the sieves in the AGU were low. To provide more utility for process control testing for a range of mix sizes, including several larger sieves in the AGU would be an improvement.

Figure 8 shows the comparison of lab results and the AGU for Mix 2. This comparison also indicates a very good correlation between the automatic gradation device and the laboratory test. Fifty-four of sixty (90%) data points were within the multilaboratory range. Of the six results outside of the multilaboratory range, four results were very low percentages where the acceptable range between two results is quite narrow. The regression of this data set also shows that the laboratory test tends to yield gradations slightly finer than the automatic gradation unit. On average, the laboratory results were

1.4% finer than results from the automatic gradation device. This trend may be due to incomplete sieving of the material which could be caused by overloading or blinding of screen cloths in the automatic gradation unit.

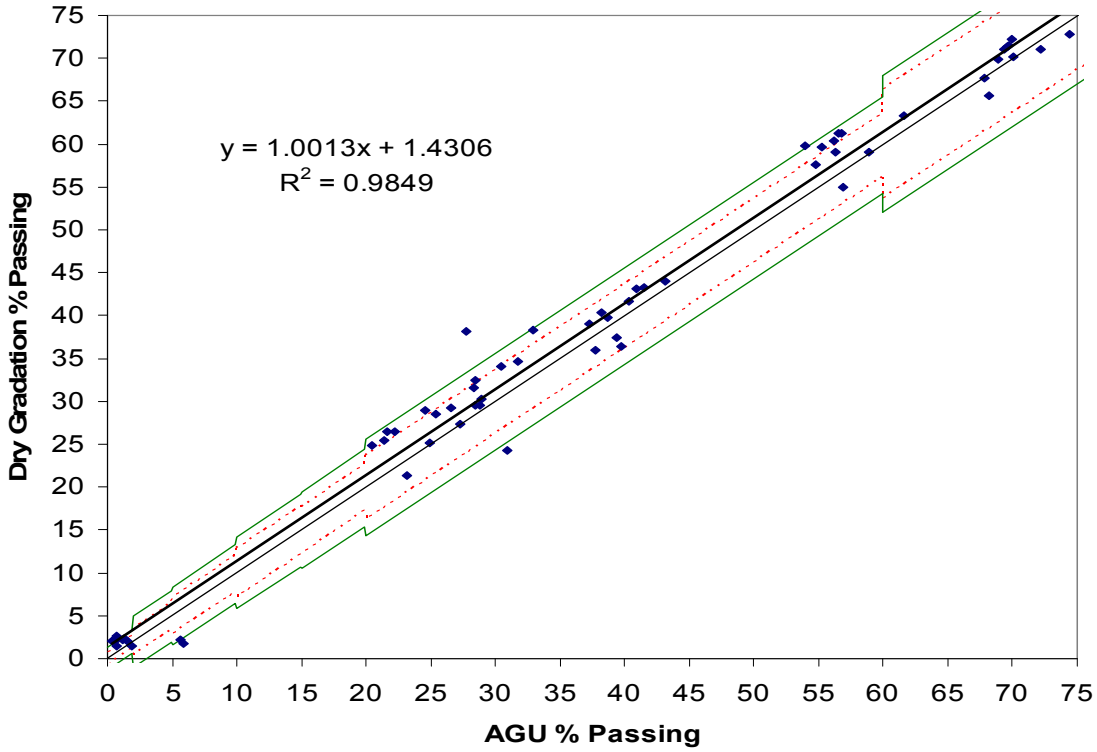

Figure 8. Graphical Comparison of Lab and AGU Results for Mix 2

The comparison of automated gradation results versus the laboratory dry gradation for Mix 3 is shown in Figure 9. The comparison of results for this mix was less favorable than the other two mixtures due to problems with several samples which are noted on the graph. It is believed that the problems on May 19 and March 29 may have resulted from an error in the tare weight of the catch pan. A visual inspection of the AGU screens and catch pan did not reveal any problems such as holes, blinded sieves, or build up of material. The problem self corrected as was evident from good results the following month.

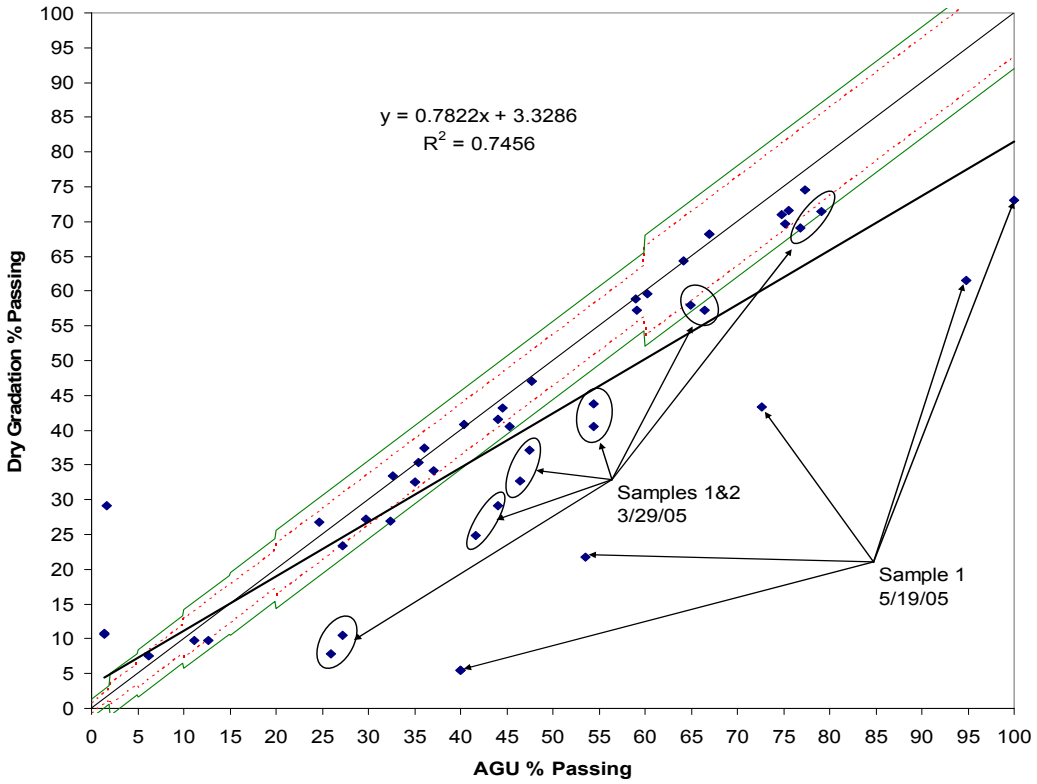

Figure 9. Graphical Comparison of Lab and AGU Results for Mix 3

Viscosities of the Binders

The in-line asphalt binder viscometer provided continuous viscosity and temperature data during the production of HMA. For evaluation of the in-line viscometer, average readings were obtained from the automated system computer over a 90 second interval. Typically, two times per day, samples of the binder were obtained from a sampling valve adjacent to the instrument at the same time as the readings were obtained from the in-line viscometer. The binder sample was tested for viscosity at 135ºC in the field lab using a common rotational viscometer per AASHTO T 316 (3). The data from the in-line viscometer and the lab measured viscosity of the binders taken during mix production are shown in Figure 10. Overall, there is a reasonably good agreement between the results of the automated viscosity and lab viscosity measurements. Both viscosity measurements clearly show when the plant was using modified and un-modified binder. Clearly, the lab measurements are more consistent and therefore probably more reliable. The in-line viscosity data is more erratic, especially in the results after about sample 20.

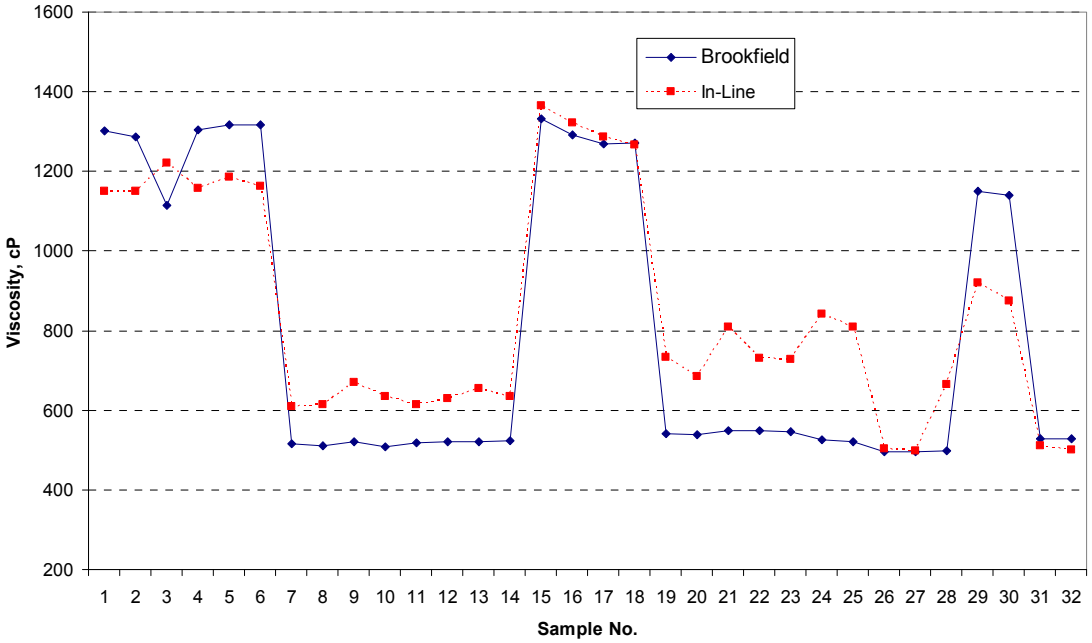

Figure 10. Chart of In-line and Laboratory Measured Binder Viscosities

Some states have used viscosity checks during production to verify that the correct binder is used in the mix being produced. The average lab viscosity of the PG 67-22 binder samples was 522 centipoises, and the average viscosity of the PG 76-22 binder samples was 1281 centipoises. Even considering the variability of the in-line viscosity measurements for the two binders, there is sufficient separation between the viscosities of the two grades for this to be used as an indicator of the binder grade. This can be seen in the box plot, Figure 11, comparing viscosities for the two grades of binder used during this study. Theoretically, some modified binders can have relatively low viscosities and the modification system will change the phase angle, δ, such that the rutting factor $G^*/\sin\delta$ meets the minimum values required at the grade temperature. In other words, viscosity of a binder by itself may not always be a good predictor of the binder grade. However, for quality control purposes, this data indicates that it is a reasonably good indicator. Future work should explore setting ranges around the in-line viscosity measurements for each grade that could serve as control chart action limits so that if or when in-line viscometer measurements were outside of the expected ranges, then further testing would be immediately initiated to verify that the proper binder was being used in the mix being produced.

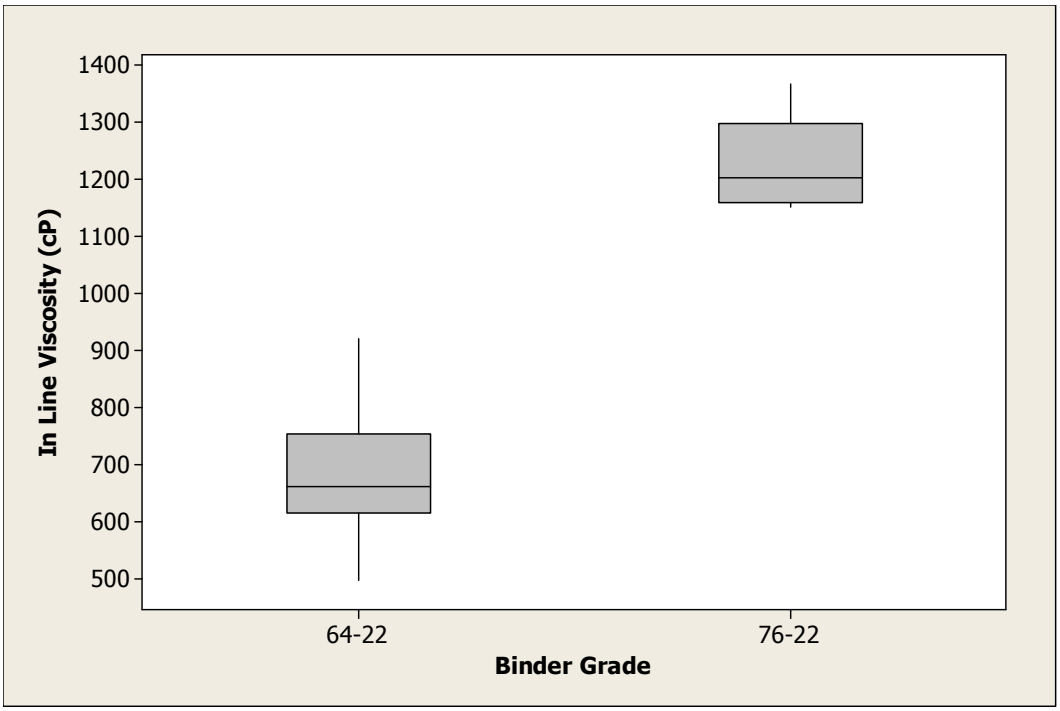

Figure 11. Boxplot of Viscosity Measurements for the Two Binder Grades

Discharge Temperatures of the HMA Mixtures

Typically five times per day, comparison measurements of mix discharge temperature at the bottom of the slat conveyor were taken with the plant's infrared temperature device and a common hand-held infrared temperature gun. Each time, six measurements with the temperature gun were taken 10 seconds apart for one minute. The average of these six measurements was compared to the average plant IR temperature sensor recorded in the plant's control house during that minute. This data is plotted in Figure 12.

Overall, the handheld temperature measurements verified the plant's mix temperature sensor. A paired-t test was conducted on the two measurements to determine if there was a statistical difference between the two devices. The results of the statistical analysis, shown in Table 4, indicate that the measurements are not significantly different.

Table 4. Paired t Test for Mix Temperature Measured by the Plant Sensor and the Handheld IR Thermometer.

	N	Mean	StDev	SE Mean
T-plant	63	307.298	17.726	2.233
T-handheld	63	308.665	21.079	2.656
Difference	63	-1.36667	7.869	0.991

95% CI for mean difference: (-3.34852, 0.61518)
T-Test of mean difference = 0 (vs not = 0): T-Value = -1.38 P-Value = 0.173

However, from the graph it appears that there are small biases due to the mix type. Mix 2 tended to yield slightly higher temperature with the handheld temperature sensor, whereas Mix 3 yielded higher temperatures with the plant's temperature sensor. These mixtures differed in several regards including gradation, maximum aggregate size, and mix components. However, the bias observed in the graph is more likely due to differences in technique by the technician operating the handheld sensor or time of the year when the measurements were made.

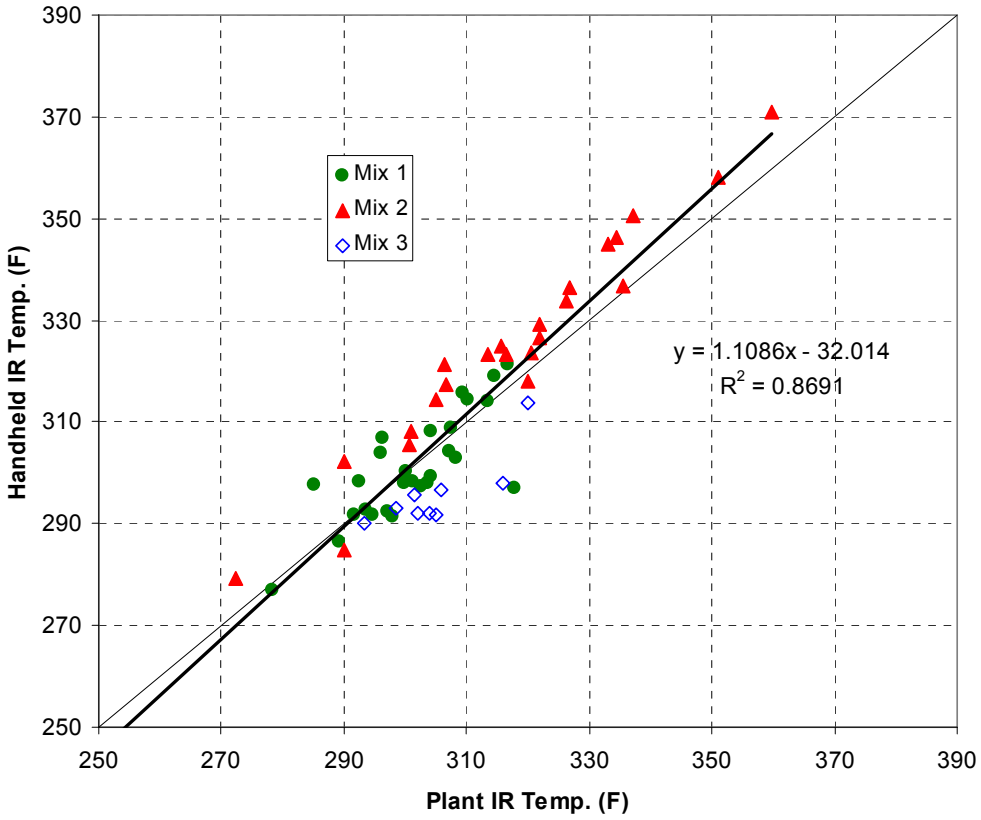

Figure 12. Verification of Plant's Mix Temperature Sensor at Drum Discharge.

Asphalt Contents of the HMA Mixtures

Twice per day, samples of the HMA were manually obtained in accordance with AASHTO T 168 from haul trucks after being loaded from the plant's silo. These samples were taken specifically to coincide with readings from the plant's automated controls for metering of asphalt content. To accomplish this, the plant control readings had to be recorded for a one minute period. Since the plant's typical production rate was about 240 tons/hour, a one minute reading typically represented about four tons of mix. The day's cumulative tonnage at the time of the reading was recorded. When that tonnage was later loaded from the silo into a truck, a sample was taken from that truck. These samples were taken to the lab for determining asphalt content using the ignition method and the

nuclear asphalt content gauge, AASHTO T 308 and T 287 (*3*), respectively. The laboratory samples were dried to a constant mass before the asphalt content tests. The purpose of conducting both laboratory asphalt content tests on each sample was to provide a check on these methods. Results of the laboratory asphalt content determinations and the plant readings for all of the HMA samples taken during this study are shown in Table 5.

From this data it can be seen that the plant's control settings for asphalt content were held constant during the production of the first two mixtures. For Mix 1, the mix design target binder content was 2.35%. The plant setting was held at 2.1% and the average of the laboratory tests (both methods combined) was 2.28% with a standard deviation of 0.20%. This indicates that the lab results were reasonably close to the plant setting for asphalt content for Mix 1.

Table 5. Plant Asphalt Content Settings and Results of Asphalt Content Tests

			Asphalt Content (%)		
Mix	Date	Sample	Plant	Ignition	Nuclear
Mix 1	26-Oct-04	1	2.1	1.99	2.14
	26-Oct-04	2	2.1	1.99	2.08
	27-Oct-04	3	2.1	2.42	2.22
	27-Oct-04	4	2.1	2.52	2.25
	28-Oct-04	5	2.1	2.53	2.26
	28-Oct-04	6	2.1	2.63	n.t.
	10-Nov-04	7	2.1	2.57	2.34
	10-Nov-04	8	2.1	2.31	2.13
	15-Nov-04	9	2.1	2.15	2.30
	15-Nov-04	10	2.1	2.52	2.03
Mix 2	29-Oct-04	1	3.9	4.59	4.54
	29-Oct-04	2	3.9	4.33	4.62
	2-Nov-04	3	3.9	4.50	4.47
	2-Nov-04	4	3.9	4.44	4.03
	3-Nov-04	5	3.9	4.63	4.44
	3-Nov-04	6	3.9	4.66	4.18
	4-Nov-04	7	3.9	4.74	4.72
	4-Nov-04	8	3.9	4.78	4.18
Mix 3	24-Mar-05	1	5.4	4.50	4.73
	25-Mar-04	2	5.9	4.49	4.64
	25-Mar-05	3	5.2	4.70	4.74
	29-Mar-05	4	5.3	4.88	4.90
	29-Mar-05	5	5.4	4.30	4.74
	19-May-05	6	5.9	4.64	4.30
	20-May-05	7	5.1	4.67	n.t.
	16-Jun-05	8	5.7	4.87	4.60
	16-Jun-05	9	5.8	4.85	4.70
	17-Jun-05	10	5.9	4.70	4.63
	17-Jun-05	11	5.5	4.60	4.39

n.t. – not tested

For Mix 2, the mix design target binder content was 4.15%. During the period this mix was sampled for this study, the plant setting for asphalt content was held at 3.9%. The average asphalt content from the lab tests (both methods combined) was 4.49% with a standard deviation of 0.22%. This indicates that the plant reading for asphalt content was significantly lower than what was actually measured with the laboratory tests.

For Mix 3, the mix design target binder content was 4.5%. During the period this mix was sampled for this study, the plant setting for asphalt content was apparently adjusted to try to dial in on the target asphalt content; plant control settings ranged from 5.2 to 5.9%. The average asphalt content from the lab tests (both methods combined) was 4.65% with a standard deviation of 0.17%. Figure 13 shows a control chart of asphalt content for Mix 3. From this chart it is evident that the plant readings for asphalt content were consistently higher than the laboratory tests.

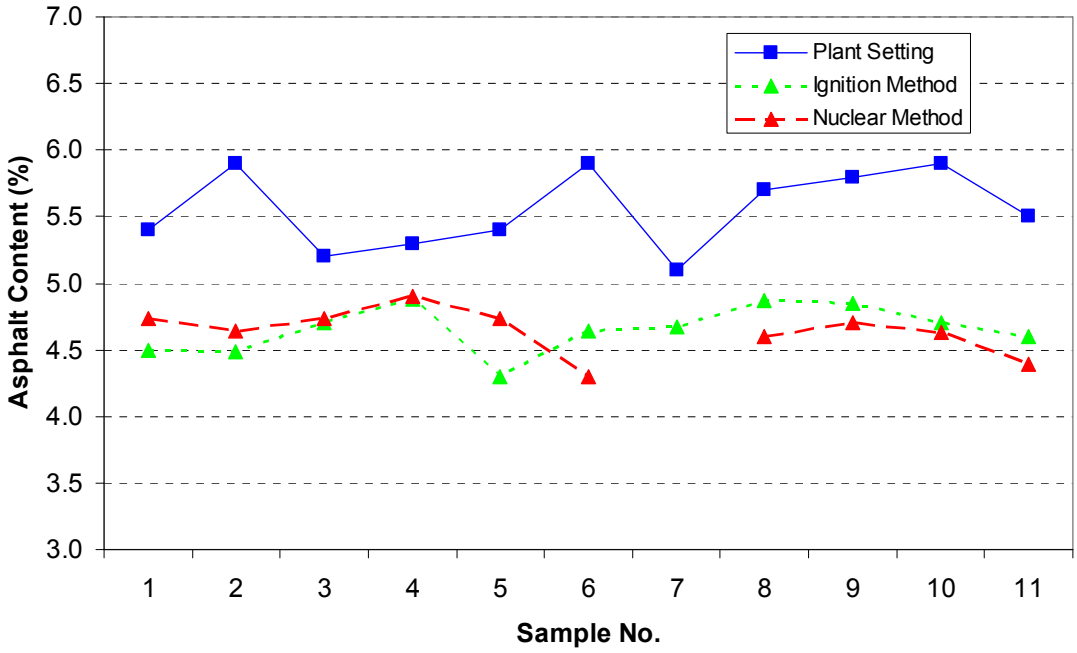

Figure 13. Control Chart of Asphalt Contents for Mix 3.

Although there may be a couple of possible explanations for the lack of agreement between the laboratory test results and the plant settings for two of the mixtures sampled in this study, the most probable reason is due to poor calibration of the plant systems required for precise asphalt content control. Four elements or systems on the plant have to be accurately calibrated to achieve good asphalt content control with continuous mix plants:

1. the aggregate belt scale (weigh bridge) and belt tachometer
2. the RAP belt scale and belt tachometer
3. the asphalt metering system
4. the dust return system

In addition, the plant operator must input correct moisture contents for the virgin aggregate and the RAP to adjust the belt scale readings. Plant records indicate that the virgin aggregate weigh bridge was calibrated on August 14, 2004, about a month before the installation of the belt sweepers. The recycle weigh bridge was calibrated over a year earlier on July 2, 2003, and the asphalt metering system was calibrated on November 2, 2004, which was the same day that samples 3 and 4 were taken for Mix 2. This plant had been recently equipped with an asphalt meter calibration tank system.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions and recommendations are based on this pilot evaluation project of several new technologies for automated testing of materials during HMA production. The observations and analyses are based on limited testing during the production of three mixture types. It should be reiterated that several of the automated testing devices were essentially prototype units. Other devices may have been used in other industries, but have not been used in the asphalt industry. In general, most of the technologies appear to have promise for use in aiding the process control of asphalt mixture production, but improvements are needed in nearly each application. Some of the deficiencies can be attributed to the lack of experience with the instruments. Specific conclusions regarding the automated testing systems are as follows:

1. The belt sweepers on the aggregate and RAP belts appeared to function properly during the study. A video of the aggregate belt sweeper taken during this project showed that the belt surface appeared clean of fines where the sweeper sampled the aggregate. However, no tests were conducted to determined whether or not the sweepers were able to remove all of the material from the belts during the belt sampling operation.
2. The test results with the microwave moisture probes were inconclusive due to the inability to properly calibrate the devices. For each of the three mixtures evaluated, the microwave moisture probe data showed little change in moisture contents of the materials. The probe retraction system worked well for the installation of the probes with conveyor belts.
3. The automatic sample drier had a number of operational problems with its air system, the dump gate, and susceptibity to winds affecting the load cells. For each mixture, the moisture content results with the automatic sample drier were more variable than the lab measured moisture contents based on belt cut samples. Accuracy of the moisture contents from the automatic drying unit may have been affected by a higher drying temperature than is used in the laboratory method. The higher drying temperature for the automatic sample drier was set by the manufacturer to speed up the drying time and obtain results faster.
4. The automatic gradation unit generally functioned well during this study. The unit was limited to six screens and performed dry gradations. Comparison of

gradation results from the automatic gradation unit and laboratory tests on the same samples showed good agreement between the automatic and manual methods in most cases. A few results from the AGU appeared to be off due to an incorrect tare weight.

5. Overall, the in-line viscosity measurements tracked reasonably well to the results from the laboratory viscosity tests. The results with the in-line binder viscometer appeared to become more variable later in the study. The in-line viscosity measurements appeared to provide a good indicator of whether the PG 67-22 binder or the PG 76-22 binder was being used at any time during the study.
6. Handheld infrared temperature measurements were well correlated to the plant's continuous infrared temperature sensor at the point of discharge from the double-barrel mixer. The measurements covered a wide range of mix temperatures from about 275 to 370ºF.
7. Comparisons of the plant's asphalt content control system to laboratory test results were inconsistent for the three mixtures. For the first mix, the results from the plant readings and the lab tests were reasonably close. For the second mix, the lab results indicated about 0.5% higher asphalt content than the plant readings. For the third mix, the lab test results were on average about 0.9% lower than the plant readings.

Recommendations

Further development and evaluation work should be conducted to improve the automated testing technologies. From the experience with the devices included with this study, possible refinements for future work are suggested.

1. Microwave moisture probes should be installed in the individual aggregate cold feed bins and the RAP bin. This would allow for easier calibration since each probe would have to be calibrated for only one material. Since the combined moisture content from the bins would have been calculated from the percentages of material being used from each bin in the mix, the probes would have to be integrated with the plant controls.
2. The automatic drying unit and automatic gradation unit should be modified to reduce environmental effects such as wind and precipitation.
3. The automatic gradation unit should be modified to make it easier to inspect the screens for wear and blinding.
4. Calibration requirements should be established for the weigh bridges and asphalt meters. This should include frequency of calibration checks, ranges over which the feed rates and flow rates should be checked, calibration tolerances, and documentation of changes to calibration settings.
5. A mix temperature sensor should be located at the discharge from the silos to the trucks to record the average and standard deviation of mix temperature for each truck load of HMA. This information could be added to the delivery tickets for easy reference by paving crews and paving inspectors.
6. Add a system to quantify the rate of baghouse fines being returned to the mix.

Development of new technologies would also be beneficial, including:

1. Establishing an automated data management program to track results with control charts and create automated alerts when action limits are exceeded.
2. Add a mix sampling device to mixer discharge or the slat conveyor to allow for capturing of samples for laboratory tests as the mix is being placed in a silo. Testing of such samples could then proceed without having to wait for the material to move through the silo.
3. Developing a means of automatically determining the asphalt content of RAP materials before introduction into the plant and mix exiting the plant.

REFERENCES

1. West, Randy C., Development of Rapid QC Procedures for Evaluation of HMA Properties During Production, NCAT Report 05-01, January 2005.

2. Brown, Elton, R., Nicholas E. Murphy, Li Yu, and Stuart Mager, Historical Development of Asphalt Content Determination by the Ignition Method, NCAT Report 95-02, March 1995.

3. Standard Specifications for Transportation Materials and Methods of Sampling and Testing, American Association of State and Highway Transportation Officials, 25th Edition, 2005.

4. Hydro-Probe II User Guide, Revision 3.0.0, Hydronix Limited, U.K, July 2006.

APPENDIX A

Test Summary Reports

Date 10/26/2004
Sample No. 21
Mix I.D. 327 E

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100.0	100.0	100.0
1		95.1	95.4	96.2
3/4		72.8	73.9	62.2
1/2	30.1	34.1	34.7	29.8
3/8	16.5	20.8	21.0	19.8
#4	3.5	5.7	5.8	7.7
#8	2.7	3.9	3.9	5.4
#16		3.4	3.5	5.0
#30		3.2	3.2	4.9
#50		2.9	3.0	4.8
#100		2.3	2.7	4.7
#200		1.7	2.2	4.3

Date 10/26/2004
Sample No. 22
Mix I.D. 327 E

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100.0	100.0	100
1		94.4	95.3	96.2
3/4		68.9	70.0	59.6
1/2	29.9	32.7	32.9	28.2
3/8	16.9	21.4	20.6	19.1
#4	3.0	6.0	4.8	7.5
#8	1.8	4.8	3.4	5.3
#16		4.5	3.1	4.9
#30		4.3	2.9	4.7
#50		4.1	2.8	4.6
#100		3.6	2.5	4.6
#200		3.0	2.0	4.1

Date 10/27/2004
Sample No. 24
Mix I.D. 327 E

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100.0	100.0	100.0
1		92.6	91.0	96.5
3/4		65.9	60.4	76.0
1/2	25.4	31.6	27.6	36.8
3/8	13.4	22.6	17.3	23.7
#4	2.7	11.3	5.7	6.6
#8	2.4	10.0	4.2	4.5
#16		9.7	4.0	4.1
#30		9.5	3.8	4.0
#50		9.3	3.7	4.0
#100		8.8	3.3	3.9
#200		8.2	2.9	3.3

Date 10/27/2004
Sample No. 27
Mix I.D. 327 E

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100.0	100.0	100.0
1		93.1	93.8	99.0
3/4		72.5	73.9	74.5
1/2	38.4	38.3	39.6	42.7
3/8	22.6	25.7	26.5	30.5
#4	4.2	4.8	5.8	9.4
#8	1.2	2.5	3.5	6.8
#16		2.1	3.2	6.4
#30		1.9	3.0	6.3
#50		1.6	2.8	6.3
#100		1.1	2.5	6.2
#200		0.5	2.1	5.6

Date 10/28/2004
Sample No. 29
Mix I.D. 327 E

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100.0	100.0	100.0
1		94.6	95.8	95.4
3/4		64.6	65.0	73.7
1/2	31.7	29.3	30.5	45.1
3/8	19.5	18.0	18.9	31.5
#4	6.8	3.4	4.4	12.6
#8	1.8	1.0	2.0	7.0
#16		1.0	1.9	6.3
#30		0.9	1.8	6.0
#50		0.9	1.8	5.8
#100		0.7	1.7	5.4
#200		0.2	1.3	4.3

Date 10/28/2004
Sample No. 34
Mix I.D. 327 E

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100.0	100.0	100.0
1		94.9	96.1	95.7
3/4		70.1	71.1	75.9
1/2	35.8	38.5	38.0	48.8
3/8	22.4	26.8	26.0	35.8
#4	7.8	10.1	9.0	14.1
#8	2.0	5.9	4.6	6.2
#16		5.3	4.0	5.2
#30		5.0	3.8	4.9
#50		4.7	3.6	4.7
#100		4.2	3.3	4.4
#200		3.6	2.7	4.2

Date 11/10/2004
Sample No. 73
Mix I.D. 327 E

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100.0	100.0	100.0
1		89.3	91.8	94.3
3/4		58.6	60.6	75.6
1/2	31.8	26.7	28.4	42.2
3/8	19.0	17.2	18.9	31.5
#4	6.4	5.7	7.2	12.6
#8	2.0	2.5	4.0	6.6
#16		2.1	3.8	5.8
#30		1.9	3.6	5.5
#50		1.8	3.6	5.3
#100		1.5	3.4	5.1
#200		1.0	3.0	4.4

Date 11/10/2004
Sample No. 77
Mix I.D. 327 E

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100.0	100.0	100.0
1		88.8	89.5	95.8
3/4		61.7	62.9	63.0
1/2	33.3	27.6	29.2	30.5
3/8	20.3	17.6	19.5	20.9
#4	6.2	3.7	5.3	10.5
#8	2.0	1.2	2.8	7.6
#16		1.0	2.6	6.9
#30		0.8	2.5	6.5
#50		0.7	2.5	6.2
#100		0.5	2.3	6.0
#200		0.1	2.0	5.1

Date 11/15/2004
Sample No. 79
Mix I.D. 327 E

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100.0	100.0	100.0
1		89.4	90.3	90.4
3/4		61.8	63.4	64.1
1/2	26.3	26.1	27.4	26.6
3/8	12.3	15.0	16.3	17.6
#4	2.3	3.0	4.4	7.6
#8	1.7	1.6	2.9	5.5
#16		1.4	2.7	5.3
#30		1.3	2.7	5.0
#50		1.2	2.6	5.0
#100		1.0	2.5	4.9
#200		0.7	2.2	4.2

Date 11/15/2004
Sample No. 81
Mix I.D. 327 E

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100.0	100.0	100.0
1		93.1	88.6	99.0
3/4		62.8	62.0	68.8
1/2	28.3	24.0	25.2	39.6
3/8	14.1	13.0	14.5	27.7
#4	3.5	3.2	7.4	10.6
#8	1.4	1.7	2.7	6.9
#16		1.5	2.6	6.4
#30		1.5	2.5	6.2
#50		1.4	2.5	6.2
#100		1.2	2.4	6.1
#200		0.9	2.1	5.3

Date 10/29/2004
Sample No. 36
Mix I.D. 424 Base

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		94.9	95.9	100
3/4		83.1	83.3	91.8
1/2	67.8	67.7	68.2	78.4
3/8	54.8	57.6	58.1	68.3
#4	37.7	35.9	36.7	49.2
#8	27.3	27.4	28.3	39.1
#16	23.1	21.3	22.6	32.6
#30		14.4	16.1	23.9
#50	1.9	6.7	8.7	14.8
#100		3	4.8	8.4
#200		1.5	3.6	5.4

Date 10/29/2004
Sample No. 37
Mix I.D. 424 Base

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		95.4	96.6	98.7
3/4		81.7	82.1	86
1/2	69.7	71.5	71.9	73.1
3/8	56.8	61.2	61.7	63.6
#4	40.3	41.7	42.3	45.2
#8	28.5	32.4	33.3	36.6
#16	21.6	26.4	27.5	31
#30		18	19.6	23.3
#50	1.2	8.8	10.8	15
#100		4.1	6.1	9
#200		2.2	4.2	6.1

Date 11/2/2004
Sample No. 46
Mix I.D. 424 Base

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		96.6	95.7	94.5
3/4		81.9	82.3	86.4
1/2	68.1	65.6	65.9	74
3/8	56.9	55	55.9	65.8
#4	39.7	36.4	37.2	44.8
#8	26.6	29.3	30.3	36
#16	30.9	24.4	25.6	30.7
#30		17.3	18.9	22.8
#50	3.1	8.8	10.9	14.5
#100		4	6	8.5
#200		2	4.1	5.6

Date 11/2/2004
Sample No. 48
Mix I.D. 424 Base

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		97.3	97.3	96.2
3/4		86.8	87.2	90.2
1/2	70.1	70.2	70.9	70.7
3/8	56.3	59	60.1	60.5
#4	38.6	39.8	40.8	43.8
#8	28.3	31.6	32.7	36.4
#16	22.2	26.4	28	31.7
#30		18.3	20.6	24
#50	0.8	8.5	11.4	14.9
#100		3.6	6.4	9.3
#200		1.5	4	6.3

Date 11/3/2004
Sample No. 51
Mix I.D. 424 Base

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		98.2	98.2	99
3/4		89	89.5	91.6
1/2	70.0	72.2	72.6	77.9
3/8	55.2	59.7	60.4	66.6
#4	37.3	39	39.4	46.6
#8	28.9	30.2	30.8	37.5
#16	21.4	25.4	26.3	32.5
#30		18.1	19.3	24.2
#50	1.3	9.2	10.9	14.6
#100		4.5	6.3	8.7
#200		2.3	4.2	5.6

Date 11/3/2004
Sample No. 53
Mix I.D. 424 Base

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		95.2	95.5	98.5
3/4		85.6	86.3	93
1/2	68.9	69.9	70.6	78.1
3/8	56.6	61.2	61.8	66.2
#4	41.5	43.3	43.8	45.9
#8	31.7	34.6	35.3	36.6
#16	28.5	29.5	30.4	31.9
#30		20.9	22.3	23.8
#50	1.3	10.6	12.5	14.4
#100		5	6.9	8.4
#200		2.6	4.5	5.2

Date 11/4/2004
Sample No. 58
Mix I.D. 424 Base

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	
1		98.1	99.2	
3/4		88.6	89.1	
1/2	69.6	71.4	71.8	
3/8	54.0	59.8	60.3	
#4	38.2	40.4	40.9	
#8	30.4	34	34.6	
#16	24.6	28.9	29.9	
#30		20.5	21.6	
#50	2.2	10.2	12.0	
#100		4.5	6.3	
#200		2.2	3.9	

Date 11/4/2004
Sample No. 63
Mix I.D. 424 Base

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	
1		98.4	98.8	
3/4		87.9	88.7	
1/2	72.2	71	72.1	
3/8	58.9	59	59.7	
#4	39.4	37.4	38.1	
#8	28.8	29.6	30.4	
#16	24.9	25.1	26.1	
#30		18.3	19.6	
#50	5.9	9.5	11.3	
#100		3.9	5.9	
#200		1.8	3.6	

Date 12/16/2004
Sample No. 85
Mix I.D. 424 Base

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		98.1	97.6	98.7
3/4		86.7	86.8	84.7
1/2	69.4	71	71.8	67.1
3/8	56.2	60.4	60.9	54.0
#4	43.1	44	44.6	37.4
#8	32.9	38.3	39.9	33.2
#16	25.4	28.5	29.6	26.0
#30		20	21.6	19.9
#50	5.7	10.6	12.8	12.8
#100		4.7	7.2	7.9
#200		2.2	4.6	5.4

Date 12/16/2004
Sample No. 86
Mix I.D. 424 Base

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		98.8	98.8	96.5
3/4		88.6	89.1	91.1
1/2	74.4	72.8	73.7	80.3
3/8	61.6	63.3	64.1	70.0
#4	40.9	43.2	44.2	51.7
#8	27.7	38.2	39.9	49.5
#16	20.5	24.8	26.3	34.6
#30		17.3	19.3	25.4
#50	1.3	9.3	11.8	16.1
#100		4.2	7	10.1
#200		2.1	5	7.1

Date 3/25/2005
Sample No. 1
Mix I.D. 424 Upper Binder

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		100	99.2	98.4
3/4		86.2	86.2	93.2
1/2	75.2	69.7	70.4	80.6
3/8	59.1	57.2	57.6	70.5
#4	45.3	40.6	41.4	54.5
#8	37.1	34.2	35.1	46.8
#16	32.4	26.9	28.2	38.9
#30		18.6	20.1	29.8
#50	12.6	9.8	11.6	20.5
#100		4.5	6.1	14.4
#200		2	3.3	10.9

Date 3/25/2005
Sample No. 2
Mix I.D. 424 Upper Binder

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		100	100	99.3
3/4		89.6	90	91.5
1/2	75.5	71.6	72.4	79.0
3/8	59.0	58.9	59.5	68.5
#4	44.5	43.2	43.9	51.5
#8	35.4	35.4	36.4	44.0
#16	29.8	27.2	28.4	36.2
#30		18.6	20.3	26.7
#50	11.2	9.8	11.8	16.6
#100		4.3	6.1	9.7
#200		1.9	3.3	6.1

Date 3/29/2005
Sample No. 1
Mix I.D. 424 Upper Binder

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		100	97.5	98
3/4		90.6	90.5	93.2
1/2	79.2	71.5	72.2	78.7
3/8	66.4	57.3	58	69.7
#4	54.5	40.6	41.2	55.9
#8	46.4	32.7	33.4	47.7
#16	41.7	24.8	25.8	38.7
#30		16.2	17.4	28.2
#50	25.9	7.8	9.1	17.5
#100		3.2	4.4	10.6
#200		1.6	2.7	6.7

Date 3/29/2005
Sample No. 2
Mix I.D. 424 Upper Binder

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		98.6	99.1	99.4
3/4		85.3	85.5	92.9
1/2	76.8	69.1	69.5	79.6
3/8	64.9	58	58.5	69.1
#4	54.5	43.8	44.4	54.3
#8	47.5	37.2	38	46
#16	44.1	29.1	30.1	37.5
#30		19.8	21	27.4
#50	27.2	10.5	12	17.2
#100		4.9	6.3	10.4
#200		2.2	3.6	6.6

Date 5/19/2005
Sample No. 1
Mix I.D. 424 Upper Binder

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		99.3	97.6	98.6
3/4		89.2	91.3	94.5
1/2	100.0	73.1	74	84.9
3/8	94.8	61.6	62	74.7
#4	72.6	43.3	45.5	57.2
#8	64.4	32.6	36.7	47.5
#16	53.6	21.7	28.4	39.3
#30		11.4	20.4	29.4
#50	40.0	5.5	11.9	19
#100		2.4	6.7	11.5
#200		1.2	4.1	7.4

Date 5/19/2005
Sample No. 2
Mix I.D. 424 Upper Binder

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		97.8	97.8	100
3/4		88.2	88.1	96.7
1/2		71.7	72.5	87.5
3/8		63.4	63.7	78.8
#4		47.6	48.2	60.7
#8		39.1	39.9	50.5
#16		32.6	33.4	41.6
#30		25.5	26.6	31.1
#50		15.4	16.8	20.1
#100		7	8.6	12.3
#200		3.3	4.9	8.1

Date 6/16/2005
Sample No. 1
Mix I.D. 424 Upper Binder

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		100	100	99.6
3/4		88.9	89.1	94.6
1/2	100.0	68.5	69.4	85.3
3/8	100.0	54.4	55.5	75.4
#4	98.9	36.7	37.8	58.3
#8	98.9	30.2	31.4	49.4
#16	98.9	24.2	25.6	41.3
#30		16.4	18.2	30.5
#50	98.9	8.1	10.2	18.7
#100		4.1	6.2	11.9
#200		2.4	4.3	8.1

Date 6/16/2005
Sample No. 2
Mix I.D. 424 Upper Binder

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		98.7	98.7	99.3
3/4		85.5	86.1	95.5
1/2	78.3	60.8	62.2	84.8
3/8	66.2	46.1	47.4	76.2
#4	53.2	32	33.5	58.9
#8	45.5	27.5	29.1	50.2
#16	38.5	21.8	23.6	41.8
#30		14.8	17	28.2
#50	19.1	7.3	9.9	16.5
#100		3.9	6.3	11.2
#200		2.3	4.5	7.8

Date 6/17/2005
Sample No. 1
Mix I.D. 424 Upper Binder

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		98.6	99	98.9
3/4		88.6	89	93.6
1/2	74.8	71	72.2	84.9
3/8	60.2	59.6	60.6	74.8
#4	44.0	41.5	42.7	56.4
#8	35.0	32.5	33.8	48.3
#16	27.2	23.4	25.1	40.2
#30		15.4	17.2	30
#50	6.1	7.6	9.8	18.9
#100		4.3	6.4	12.3
#200		2.5	4.5	8.7

Date 6/17/2005
Sample No. 2
Mix I.D. 424 Upper Binder

	Gradations - Percent Passing			
Sieve Size	AGU	Lab Dry	Lab Washed	Ignition Washed
1.5		100	100	100
1		98.5	98.5	100
3/4		88.2	88.3	94.1
1/2	67.0	68.2	68.7	82.9
3/8	53.4	55.3	55.8	73.1
#4	40.4	40.8	41.7	57.2
#8	32.7	33.5	31.6	49.4
#16	24.7	26.8	24.6	41.1
#30		18.9	16.8	30.4
#50	1.4	10.8	10.3	18.9
#100		6.2	6.7	12.1
#200		3.6	5.1	8.2

In-Line and Lab Viscosity Data

Date	Binder Grade	In-line Viscosity (cP)	In-line Temp. (F)	Lab Meas. Viscosity (cP)
25-Mar-04	67-22	731	302	550
26-Oct-04	76-22	1151	308	1302
26-Oct-04	76-22	1151	308	1287
27-Oct-04	76-22	1222	303	1115
27-Oct-04	76-22	1159	302	1305
28-Oct-04	76-22	1184	299	1317
28-Oct-04	76-22	1162	297	1316
29-Oct-04	67-22	610	311	515
29-Oct-04	67-22	615	309	510
2-Nov-04	67-22	671	286	520
2-Nov-04	67-22	636	305	508
3-Nov-04	67-22	615	312	518
3-Nov-04	67-22	628	312	520
4-Nov-04	67-22	655	312	520
4-Nov-04	67-22	635	306	523
10-Nov-04	76-22	1365	246	1332
10-Nov-04	76-22	1321	254	1292
15-Nov-04	76-22	1287	291	1268
15-Nov-04	76-22	1268	292	1271
16-Dec-04	67-22	734	318	540
16-Dec-04	67-22	684	312	538
24-Mar-05	67-22	810	301	550
25-Mar-05	67-22	729	304	545
29-Mar-05	67-22	842	302	525
29-Mar-05	67-22	808	298	520
19-May-05	67-22	502	305	495
19-May-05	67-22	497	313	495
20-May-05	67-22	666		498
16-Jun-05	67-22	920	325	1150
16-Jun-05	67-22	875	325	1140
17-Jun-05	67-22	510	312	528
17-Jun-05	67-22	502	304	528

Mix Temperature, Mix 1

			Temperature (F)	
Date	Test #	Mix	Plant	Infrared Gun
10/26/2004	1	327E	302.5	297.3
	2	327E	289.2	286.3
	3	327E	308.4	303.0
	4	327E	317.9	296.8
	5	327E	278.4	276.8
10/27/2004	6	327E	294.8	291.7
	7	327E	291.7	291.7
	8	327E	303.7	297.8
	9	327E	307.2	304.2
	10	327E	301.3	298.2
	11	327E	299.8	297.8
10/28/2004	12	327E	297.9	291.3
	13	327E	293.6	292.7
	14	327E	297.1	292.3
	15	327E	300.1	300.2
	16	327E	304.1	299.2
11/10/2004	40	327E	292.4	298.4
	41	327E	316.8	321.3
	42	327E	313.4	314.1
	43	327E	304.2	308.1
	44	327E	310.2	314.4
	45	327E	314.5	319.1
11/15/2004	46	327E	307.6	308.8
	47	327E	309.3	315.6
	48	327E	285.0	297.7
	49	327E	295.9	303.9
	50	327E	296.4	306.8

Mix Temperature, Mix 2 and 3

			Temperature (F)	
Date	Test #	Mix	Plant	Infrared Gun
10/29/2004	17	424B	320.5	323.5
	18	424B	321.8	329.2
	19	424B	333.1	344.9
	20	424B	326.8	336.5
	21	424B	315.7	325.1
	22	424B	337.2	350.5
11/2/2004	23	424B	320.0	318.0
	24	424B	290.1	285.0
	25	424B	306.3	321.3
	26	424B	306.6	317.3
	27	424B	359.6	371.0
11/3/2004	28	424B	326.2	333.8
	29	424B	290.0	302.2
	30	424B	300.9	308.2
	31	424B	351.1	358.2
	32	424B	322.0	326.5
	33	424B	300.6	305.4
11/4/2004	34	424B	335.4	336.9
	35	424B	316.5	323.3
	36	424B	304.9	314.5
	37	424B	272.4	279.4
	38	424B	313.5	323.2
	39	424B	334.3	346.4
12/16/2004	51	424B	297.7	300.3
	52	424B	300.4	300.4
	53	424B	329.1	331.7
3/24/2005	54	424B w/RAP	305.9	296.8
	55	424B w/RAP	301.6	295.7
	56	424B w/RAP	305.1	291.8
	57	424B w/RAP	298.4	293.2
3/25/2005	58	424B w/RAP	319.9	313.7
	59	424B w/RAP	315.9	298.0
3/29/2005	60	424B w/RAP	293.2	290.0
	61	424B w/RAP	247.9	244.5
5/19/2005	62	424B w/RAP	301.9	292.0
	63	424B w/RAP	303.9	292.0

APPENDIX B

Contractor's Mix Designs

ALABAMA DEPARTMENT OF TRANSPORTATION

1409 Coliseum Boulevard, Montgomery, Alabama 36130-3050

Don Siegelman
Governor

G. M. Roberts
Transportation Director

NOVEMBER 17, 2000

EAST ALABAMA PAVING CO
P.O. BOX 2630
OPELIKA AL 36608

Project No. _____

County _____

Dear Sir:

The job mix below may be used only at the plant noted and for materials listed. The plant mix will be manufactured in compliance with the applicable specifications, plan notes, and special provisions.

PLANT: EAST ALABAMA PAVING CO., AUBURN & OPELIKA AL

Section: 327 E PATB
Max. Size Aggregate:

ESAL Category:
Binder Grade: PG 67-22 HUNT

MATERIALS:

% (APPROX)	*DESCRIPTION*	*I. D. #*	*SOURCE*	*BPN-9*
88	# 57 LIMESTONE	1604	HANSON MAT'LS OPELIKA AL	25
12	# 78 LIMESTONE	1604	HANSON MAT'LS OPELIKA AL	25

JOB MIX:

SIEVES	*% PASSING*
37.5 mm	100
25.0 mm	100 (-)
19.0 mm	
12.5 mm	26
9.5 mm	
4.75 mm	5
2.36 mm	2
1.18 mm	
600 µm	
300 µm	
150 µm	
75 µm	0.9

OTHER INFORMATION: (Blow)

% AC Required	2.35
ACReq'd/Metric Ton,kg	23.5
Max. Sp. Gr. Mix	
Mass, kg/m³	
Stability, (kN)	
TSR	
Anti-Strip	0.50%
Effective AC	
Dust/Asphalt Ratio	
Coarse Agg. Angularity	
Fine Agg. Angularity	
Sand Equivalent	
Agg. Bulk SG	
% VMA	

NOTE:

_____ must be added to the mix. The remaining comes from the RAP.

DESIGN CALIBRATION FACTOR:

GYRATIONS:

ADDITIONAL NOTES:

Burson T. Hff
Hot-Mix Asphalt Engineer

cc: Hot-Mix Asphalt Engineer
4TH Division

st 200 /cg

ALABAMA DEPARTMENT OF TRANSPORTATION

1409 Coliseum Boulevard, Montgomery, Alabama 36110

Bob Riley
Governor

Joe McInnes
Transportation Director

FEBRUARY 17, 2004

EAST AL PAVING CO., INC.
P.O. BOX 2630
OPELIKA AL 36803

Project No. _____

County _____

Dear Sir:

The job mix below may be used only at the plant noted and for materials listed. The plant mix will be manufactured in compliance with the applicable specifications, plan notes, and special provisions.

PLANT: EAST ALABAMA PAVING COMPANY, INC.

Section 424 BASE
Max. Size Aggregate: 11/2" THRU RESTRICTED ZONE

ESAL Category: RANGE E
Binder Grade: PG 67-22 HUNT

MATERIALS:

% (APPROX)	DESCRIPTION	I. D. #	SOURCE	BPN-9
39	#57 LIMESTONE	1604	HANSON MATL'S; OPELIKA, AL	25
22	#78 LIMESTONE	1604	HANSON MATL'S; OPELIKA, AL	25
20	M-10 GRANITE	0157	VMC; COLUMBUS, GA	
18	COARSE SAND	0261	MM; SHORTER, AL	
1	BAGHOUSE FINES		PLANT	

JOB MIX

SIEVES	% PASSING
1-1/2"	100
1"	100(-)
3/4"	90
1/2"	73
3/8"	61
# 4	43
# 8	36
# 16	28
# 30	19
# 50	10
# 100	6
# 200	4.2

OTHER INFORMATION: (Blow)

% AC Required	4.15*
AC Req'd/ Ton (lbs.)	83.0
Max. Sp. Gr. Mix	2.601
Wt./Cu.Ft. (lbs.)	155.4
Stability	N/A
TSR	0.89
Anti-Strip	N/A
Effective AC	4.06
Dust/Asphalt Ratio	1.03
Coarse Agg. Angularity	100/100
Fine Agg. Angularity	47
Sand Equivalent	
Agg. Bulk SG	2.775
% VMA	13.9

NOTE: *VIRGIN MIX

_____ must be added to the mix. The remaining comes from the RAP.

DESIGN CALIBRATION FACTOR:

GYRATIONS:

7	80	125
89.0	96.0	96.7

ADDITIONAL NOTES:
MIXING TEMP 325*F ST-48-G

William C. Dudley
Hot-Mix Asphalt Engineer

cc: Hot-Mix Asphalt Engineer
4 Division

ALABAMA DEPARTMENT OF TRANSPORTATION

1409 Coliseum Boulevard, Montgomery, Alabama 36110

Bob Riley
Governor

Joe McInnes
Transportation Director

FEBRUARY 18, 2004

EAST AL PAVING CO., INC.
P.O. BOX 2630
OPELIKA AL 36803

Project No. _____

County _____

Dear Sir:

The job mix below may be used only at the plant noted and for materials listed. The plant mix will be manufactured in compliance with the applicable specifications, plan notes, and special provisions.

PLANT: EAST ALABAMA PAVING COMPANY, INC.

Section 424 UPPER BINDER
Max. Size Aggregate: 1" THRU RESTRICTE ZONE

ESAL Category: RANGE C/D
Binder Grade: PG 67-22 HUNT

MATERIALS:

% (APPROX)	*DESCRIPTION*	*I. D. #*	*SOURCE*	*BPN-9*
23	#57 LIMESTONE	1604	HANSON MATL'S; OPELIKA, AL	25
20	#78 LIMESTONE	1604	HANSON MATL'S; OPELIKA, AL	25
17	COARSE SAND	0261	MM; SHORTER, AL	
19	M10 GRANITE	0157	VMC; COLUMBUS, GA	
1	BAGHOUSE FINES		PLANT	
20	RAP		STOCKPILE #04-1-13 (US 280)	

JOB MIX

SIEVES	*% PASSING*
1-1/2"	
1"	100
3/4"	94
1/2"	82
3/8"	72
# 4	54
# 8	45
# 16	35
# 30	24
# 50	13
# 100	9
# 200	5.0

OTHER INFORMATION: (Blow)

% AC Required	4.50*
AC Req'd/ Ton (lbs.)	90.0
Max. Sp. Gr. Mix	2.577
Wt./Cu.Ft. (lbs.)	160.3
Stability	N/A
TSR	0.87
Anti-Strip	N/A
Effective AC	4.23
Dust/Asphalt Ratio	1.18
Coarse Agg. Angularity	100/100
Fine Agg. Angularity	46
Sand Equivalent	
Agg. Bulk SG	2.749
% VMA	14.3

NOTE:

*3.42% PG 67-22 must be added to the mix. The remaining 1.08% comes from the RAP.

DESIGN CALIBRATION FACTOR:

GYRATIONS:

7	80	125
88.8	95.9	96.6

ADDITIONAL NOTES:
MIXING TEMP 325*F ST-55-G

William C. Smith
Hot-Mix Asphalt Engineer

cc: Hot-Mix Asphalt Engineer
4 Division

at 55C-04 /cc