Evaluation of Warm Mix
Asphalt in Kentucky

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ABSTRACT
Warm mix asphalt (WMA) has the potential to revolutionize the paving industry. The ability to reduce costs and emissions while improving pavement performance could potentially change the direction the asphalt industry moves in the future. In 2009 and 2010, Kentucky constructed nine wax/chemical additive WMA projects across the state. Each project consisted of one hot mix asphalt (HMA) control section, and at least one WMA test section. Where possible, the contractor built multiple WMA test sections, each using a different WMA technology. In these sections, every effort was made to keep all other variables constant, including mix design, layer thickness, paving equipment, rolling pattern, and evaluation procedures. The temperature was monitored throughout the paving process, starting at the plant and continuing through the construction process. In addition to asphalt temperatures, field testing monitored density and in-situ permeability at various cross-section locations throughout the test and control sections. In-situ testing was done at the centerline joint, and at 6”, 18” and 60” distances from the joint. This test matrix allowed for comparisons to be made regarding temperature and density at significant points (i.e. center of driving lane, wheel path, adjacent to the joint) across the surface.

This research closely monitored WMA temperatures at production, placement, and compaction in order to correlate those temperatures with in-situ densities. Past research shows that an increase in in-situ density can lead to lower permeability, and therefore an increase in pavement life (1). Attention was also given to the contractors’ opinions regarding workability and ease of placement. Without a standardized test measuring workability in the field, the best data available were the opinions and observations of the workers on the paving crew. Given their extensive hands-on experience, they were able to give valuable feedback that would have otherwise gone undocumented. In addition, asphalt cores, bulk field samples, and virgin binder samples were collected for each project, from both the control and test sections. Lab analysis is currently being done to determine compacted density, aggregate gradation, and binder characteristics.

The primary focus of this research was to compare temperatures and corresponding in-situ densities between test and control sections on each project. As previously mentioned, every effort was made to minimize variability between test and control sections. In addition, contractors were encouraged to construct each section as they normally would. The reason for this request was to ensure the data reflected real-world construction practices and situations. An increase in density combined with a decrease in production/placement/compaction temperatures could indicate that WMA may eventually be a suitable substitution for HMA.
INTRODUCTION
Warm mix asphalt (WMA) could have the ability to revolutionize the paving industry. The potential to reduce cost and emissions while improving performance could profoundly shape the future of the asphalt industry. However, caution should be used when any new material or process is being considered for acceptance. In 2009 and 2010, Kentucky constructed nine wax/chemical additive WMA projects across the state. Each project consisted of one hot mix asphalt (HMA) control section, and at least one WMA test section. Where possible, the contractor built multiple WMA test sections, each using a different WMA technology. On each of these projects, every effort was made to keep all other variables throughout the construction process constant, including mix design, layer thickness, paving equipment, rolling pattern, and evaluation procedures. The temperature was monitored throughout the paving process, starting at the plant and continuing throughout the construction process. In addition, field tests were conducted to monitor density and in-situ permeability at varying cross-sectional locations throughout the test and control sections. In-situ testing was done at the centerline joint, and at 6”, 18” and 60” distances from the joint. This test matrix allowed for comparisons to be made regarding temperature and density at significant points: i.e. center of driving lane, wheel path, adjacent to the joint.

BACKGROUND
Asphalt is the predominant material used for paved roadways in the United States. Provided that it is such a widely-used material, even a slight decrease in cost or increase in benefit could have a substantial impact across the industry. WMA could potentially serve to lower fuel consumption, increase density, and improve long-term performance. WMA producers claim that WMA can deliver these benefits. However, when compared to HMA, WMA is a relatively new material and not yet widely accepted. Its use may require changes in the design process, changes in the materials used, and additional additives and/or equipment. Before Kentucky can move toward using WMA in the future, WMA should be evaluated. It is necessary to evaluate several different technologies used to produce WMA and determine how they compare to traditional HMA as well as how they compare to each other. Also, an assessment of current acceptance specifications should be made with respect to how WMA is evaluated.

WMA technology is becoming more prevalent in routine roadway construction across the country. It could possibly provide many benefits over conventional HMA. Some of these benefits are a decrease in mixing and placement temperatures, a decrease in fuel consumption, reduced emissions, a safer work environment, and higher densities with lower compactive effort. There are three groups of technologies currently being used to achieve these lower temperatures: chemical additive, organic additive (wax), and water additive (foamed). These technologies are different, yet they all function on the same basic concept. Each decreases the viscosity of the liquid binder, thus allowing the binder to more easily coat the aggregate at a cooler temperature. This decrease in temperature results in lower energy costs for the producer, as well as decreased emissions that could be harmful to workers and the environment. The decrease in binder viscosity can also lead to achieving greater in-place densities with less compactive effort. The potential for these and many other benefits are motivation to further evaluate the use of WMA.
OBJECTIVES
The overall objective of this study was to evaluate WMA paving technologies currently available to the industry, and to observe and quantify several aspects of WMA construction and performance. Once these aspects were measured, they were compared to similar hot mix metrics. The following is an itemized list of the objectives originally proposed for this study.

1. Review the available technologies for WMA paving.
2. Conduct controlled field trials on selected construction projects to evaluate characteristics of the selected technologies, including constructability, mix design issues and potential cost savings.
3. Evaluate the early age performance of WMA technologies versus conventional HMA, and transition these projects into the Long-Term Monitoring Project with the Kentucky Transportation Center.
4. Review potential specification changes reflecting changes in permitted paving techniques.

PROJECTS
There were nine projects chosen to be included in this study. It was important to choose asphalt resurfacing projects that were fairly simple and straightforward in their construction. By minimizing external variables, the effect of the additive on the overall pavement was isolated as much as possible. If projects chosen were difficult to construct, the variability of construction could have had an effect on the final product. Each of the test and control sections were chosen strategically, with every effort made to ensure uniformity throughout all sections. For example, if AADT varied greatly within different portions of the length of the project, every effort was made to choose test and control sections that had similar AADTs. Each project used PG 64-22 binder, had a similar aggregate gradation, and maintained a constant mix design throughout each individual construction project.

Each construction project was broken into multiple sections. All but one of the projects were broken into a control section (HMA) and a test section (WMA). There was one project that contained a HMA section, a wax WMA section, and a chemical WMA section. Four projects were constructed with a wax WMA test section, and six projects were constructed with a chemical WMA test section. Sasobit was chosen as the wax to be used, and Evotherm 3G was chosen as the chemical to be used.

FIELD MEASUREMENTS
WMA, by definition, is heated less than conventional HMA. As a result, less oxidation should occur in the WMA asphalt, all things being equal. With a decrease in oxidation should occur an increase in the flexibility of the asphalt, both in the long-term and short-term. Given that these projects are just over one year old, it is a little too early to draw conclusions regarding their long-term resistance to cracking. However, there are several factors measured at construction that give some indication as to how the pavement should perform long-term. The factors of primary interest in this study were density, temperature, and permeability.

In-situ density was measured by the Pavement Quality Indicator (PQI), manufactured by TransTech Systems, Inc. In addition, cores were extracted in every location the PQI was used, and these density values were compared to one another for validation purposes. For every construction project, there were five to seven cross-sectional locations within each section (WMA and HMA). At each cross-sectional location, tests were run at the construction joint, and
at 6”, 18”, and 60” distances from the joint. This was done to measure a representative sample across the entire mat.

Production and placement temperatures can play a significant role in a pavement’s long-term performance. As observed by a similar study conducted by the Virginia Transportation Research Council, some WMA technologies may contribute to reduced in-service binder aging (2). An increase in temperature can lead to an increase in oxidation, therefore reducing the long-term flexibility of the asphalt. The surface temperature was measured using a thermal infrared temperature gun. While the temperature gun only measures the temperature at the surface (which is not the most representative temperature of the asphalt), it does allow for a much greater range of testing. An infrared temperature gun was chosen because it allowed measurements to be taken inside the hopper and in the middle of the paving lane. If a thermometer was used to measure internal temperature instead, the number and location of temperature readings would have been severely limited. The temperatures were measured as the dump truck dumped into the hopper/material transfer vehicle (MTV), immediately behind the paver, and just before the first roller. By measuring the temperature throughout the construction process, the variability in the data created by fluctuating times between the roller and paver was greatly reduced.

In addition, in-situ permeability was measured with the Air-Induced Permeameter (AIP) (1). This device was developed by the Kentucky Transportation Center (KTC). The AIP uses an air chamber that is sealed against the surface of the pavement. A vacuum is created inside this chamber, and within a few seconds an equilibrium vacuum pressure is reached. This pressure is then measured and converted to a feet-per-day permeability. The pressure inside the chamber is inversely related to the asphalt permeability; as the permeability decreases, the vacuum pressure increases. The permeability readings were taken before, and in the same locations as, the cores were cut. Asphalt characteristics can vary greatly over a small distance. Measuring permeability and cutting cores in the same location served to greatly reduce that variability, thus allowing a direct comparison between the density and permeability of an exact location.

Several additional factors were observed in order to possibly explain anomalies in the data. These factors were air temperature, weather conditions, paver specifications, roller type and age, and time of day paved.

**LAB TESTS**

Once the cores were extracted, they were then brought back to the KTC asphalt lab for testing. The bulk specific gravities were measured in the lab and compared to the measured in-situ densities. In the lab, the bulk specific gravities were measured using AASHTO T-166 “Bulk Specific Gravity of Compacted Asphalt

![FIGURE 1 Gilson SG-4 Asphalt Bulk Specific Gravity device.](image-url)
Mixtures Using Saturated Surface-Dry Specimens”. While this test is the standard test used in asphalt labs, it is believed that more accurate tests may be available.

Most asphalt pavements are designed today using the Superpave mix design method. It is generally accepted that Superpave mixes are more open-graded than their Marshall mix design predecessors. Therefore, the density of each core was also measured with the Gilson SG-4 Asphalt Bulk Specific Gravity device (Figure 1). It is believed that this means of measuring density gives a better estimate of in-situ density than simply relying on the non-nuclear density device used in the field. In addition, some of the projects evaluated in the field did not have contract pay factors associated with in-situ density requirements (known as Option-B). Roads with lower traffic volumes do not warrant as strict of density guidelines. Without in-situ density requirements, inspectors with core-calibrated density gauges were not present. For these projects, there was no way to measure in-situ density with the PQI density gauge; therefore lab core densities were used as the only means to measure density.

RESULTS
In order for any warm mix technology to be accepted as a suitable replacement for hot mix, the WMA must perform, at a minimum, as well as its HMA counterpart. A large portion of performance, however, is related to how well the pavement resists distresses over time. Since these projects are relatively young, there simply isn’t enough long-term data to make definitive conclusions regarding overall pavement performance. However, long-term performance is closely related to construction density, and for that reason it was decided to assume an increase in initial construction density would correlate to an increase in long-term pavement performance. Likewise, it is assumed that a less-permeable pavement will perform better over time, with all things being equal.

As previously stated, each individual construction project was broken into multiple sections. Because each project had its own unique average density, it would be inaccurate and possibly misleading to group all HMA results together and compare them to all WMA wax results and to all WMA chemical results. For that reason, the HMA test results have been divided into two groups, based on the type of WMA additive that was used on that specific construction project. Figure 2 shows the average densities for all measurements in this study. As can be seen,
the chemical WMA and HMA achieved very similar densities. In addition, it can be seen that the wax WMA sections slightly outperformed their HMA counterparts. The error bars of Figure 2 represent the standard deviation. While the wax additive may have served to increase density slightly more than the chemical additive, it should be noted that the chemical additive served to lower the variability of density tests more so than the wax additive. When considering the scale of variation in density and variance, it would be impetuous to come to any conclusion other than both of these additives allowed the asphalt to be placed at densities that were as good as or better than their HMA counterparts.

Each WMA technology is able to be produced at typical hot mix temperatures without damaging the additives. However, in order to ensure that the contractors were actually producing WMA (and not HMA with an additive), the contractors were required to keep the production and placement temperatures below 260°F. Figure 3 shows the average surface temperatures immediately behind the paver. On average the temperature of the chemical WMA was 10°F less than the wax WMA surface temperature.

It should be noted that the difference is simply due to the contractors’ choice. On average, contractors using the chemical additive chose to produce their WMA 10°F cooler than the wax WMA contractors. Given that the chemical WMA had a larger drop in temperature than did the wax WMA, one would anticipate seeing a lesser gain in density with the chemical WMA than with the wax WMA. In other words, by choosing a greater reduction in temperature, it would appear that the “chemical contractors” were choosing to save more money in fuel usage, at the cost of a small amount of density gain. The opposite is also true; the “wax contractors” chose to spend slightly more money on fuel, and in doing so gained slightly more density, on average. The decision of whether to increase the temperature and therefore increase the fuel usage is based on a cost-benefit analysis, and is outside the scope of this study.

FIGURE 3 Average temperatures measured behind paver for all data points.
Figure 4 shows the average density at each cross-sectional location for the wax WMA projects. The wax WMA increased in density as the distance from the test location to the centerline joint increased. However, the density of the HMA section actually decreased moving away from the joint.

Figure 5 shows the average density for the chemical WMA projects. The chemical WMA and HMA averages were very similar to one another. As previously noted, the lack of significant density improvements could be attributed to the contractor’s choice to reduce the temperature even more, therefore using even less fuel. Nonetheless, it is safe to say that the densities of both the wax and the chemical WMA test sections were as good as or better than the HMA sections.

In addition to temperature and density, permeability was also measured at each test and control point using the AIP. The AIP creates a vacuum adjacent to the asphalt surface. As the feet-per-day permeability increases, the equilibrium pressure inside the vacuum decreases. This is because air can more easily travel into the vacuum chamber of a more-permeable asphalt pavement. The majority of distress on a typical asphalt surface occurs on or very close to the joint. It is believed that this phenomenon is due to a decrease in density (and a corresponding increase in feet-per-day permeability) close to the joint. Figure 6 shows the average permeability of each asphalt type at each significant cross-sectional location. (Note: an increase in feet-per-day permeability is synonymous to a decrease in vacuum pressure permeability, thus it is expected that high-density asphalt would have a high permeability pressure as measured by the AIP.) From the permeability data represented in Figure 6, there is no significant difference in permeability between any of the asphalt types.
FIGURE 5 Average densities for chemical additive projects, by cross-sectional location.

FIGURE 6 Average in-situ permeabilities, by cross-sectional location.
CONCLUSIONS
WMA is a relatively new product. As such, testing and evaluations must be priority before widespread acceptance should occur. This study is an attempt to address that need. The data collected in this research show that the initial construction metrics of both the wax WMA and the chemical WMA achieved as good as or better densities and permeabilities than the HMA sections to which they were compared. It appears that the wax additive seemed to produce slightly higher densities than did the chemical additive, however the chemical additive allowed for a greater temperature reduction than did the wax additive. Each additive has strengths. However, this study was not a competition between the two WMA additives, but rather a comparison between the WMA additives and their HMA counterparts. To that end, it is clear that the WMA test sections were able to achieve as good as or better densities and permeabilities, and at significantly lower temperatures, than the HMA control sections.

As with any new product, an ongoing evaluation process should ensue. Further testing should include additional additives as well as new and innovative production methods to truly identify the long-term performance of WMA additives.
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This study is part of an ongoing investigation sponsored by the Kentucky Transportation Cabinet to evaluate Warm mix asphalt. Once the study is complete, the full report will be available via the Kentucky Transportation Center’s website at www.ktc.uky.edu.
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