I-55 / I-57 WARM MIX PROJECT IN MISSOURI
CONTRACTOR’S WMA EXPERIENCE

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September 2011

2,749 words, 10 figures, 10 photos and 4 tables
170,000 tons of Warm Mix in Missouri

Photo 1: Paving I-55 with Foamed Asphalt Warm Mix

Figure 1: Location Map

❖ ABSTRACT

170,000 tons of Foamed Asphalt Mixes were placed between June 2009 and October 2010 in the base and the shoulders of the I-55 / I-57 Project in southeastern Missouri; making it the largest Warm Mix road project ever completed to date. COLAS Solutions Technical Center, COLAS Inc. Central laboratory monitored the production and placement.

In addition to the technical obligations of the contract, a thorough Performance, Constructability and Environmental evaluation was completed. Foamed Asphalt Mix production met all volumetric and density specifications requirements. Furthermore, in addition to reducing asphalt binder aging, the lower production temperature was shown to have preserved the elastomeric properties of the polymer-modified binder; increasing the pavement durability, its resistance to rutting as well as to low temperature cracking. Emissions at the plant were drastically reduced; energy consumption was cut by 15%.

❖ BACKGROUND

I-55 is the main north-south transportation artery in the Midwestern United States. This Interstate connects Chicago to New-Orleans 980 miles (1,570 km) further south, moving through major cities such as St. Louis and Memphis along the Mississippi valley. I-57 another north-south artery between Chicago and the South cuts short through the State of Illinois and connects with I-55 at the north end of our project. Both highways are crucial to the freight traffic between the Chicago midcontinent hub and the Gulf of Mexico.
The project located in Southeastern Missouri, includes the I-55/I-57 junction and extends southward to Interstate 155 (see Figure 1: Location Map). The contract totaled 260,000 tons of bituminous mixes laid on 66 lane-miles (106 km) from June to December 2009 and from March to October 2010. The structure placed over the existing concrete slabs is composed of:

- 5-cm of base course, high traffic 19-mm Superpave Design using a polymer modified binder
- 4-cm of 12.5 mm of Stone-Matrix-Asphalt surface course
- 9.5-cm of 19-mm Marshall Mix for the shoulders.

I-55 project was one of the first four projects in the nation to be awarded as part of The American Recovery and Reinvestment Act, enacted in 2009 by the Federal Administration to stimulate the economy.

The Missouri Department of Transportation has taken a very proactive approach to new technologies that benefit the environment. Delta Companies, COLAS Inc.’s subsidiary in the Midwest, seized the opportunity to introduce one of the newest ideas in the area of asphalt mix production, namely Warm Mix. Conversations were begun with Missouri Department of Transportation officials in the initial stages of the project. Delta Companies proposed the substitution of 170,000 tons of base and shoulder “Hot Mix” with Warm Mix using foamed asphalt technology and committed for those to meet all the hot mix production contractual requirements. As a result of the intangible benefits that MODOT could realize, the change order was quickly approved.

COLAS Solutions Technical Center took advantage of the size of the project to perform a comparative performance evaluation of the Hot and Warm Mix productions through the two paving seasons. This evaluation covered mix performance, constructability and plant environmental controls. The main results are presented below.

Since 2005, COLAS Inc. has been evaluating technically, environmentally and economically the available warm mix technologies: organic waxes, chemical surfactants and foam technologies. COLAS Solutions Technical Center coordinated this methodical laboratory and field research jointly with operations, equipment, environmental and laboratory personnel.

This evaluation evidenced that Warm Mix technologies have benefits in terms of mix performance, energy savings and emissions reduction; however foamed asphalt technologies stood out in terms of practicality, cost-effectiveness and low carbon footprint: no additive is greener than water. This led COLAS companies to invest in foam technologies, resulting in an exponential growth of warm mix tonnage: last year 18.5% of COLAS Inc. bituminous mixes were foamed produced; in 2011 the share is projected to be over 30%.

Foamed asphalt mix refers to a bituminous mixture in which 1% to 3% of water injected into the hot bitumen, results in spontaneous foaming and temporary alteration of the physical properties of the binder; when foam dissipates the original properties of bitumen are regained. By foaming the bitumen temporarily:

1. Expands its volume, facilitating the coating of the cooler aggregates,
2. Increase mixture workability at lower temperature thanks to Foam’s Shear Thinning qualities.

Shear thinning means that viscosity decreases as shear rate increases; it occurs in substances such as shaving cream and is crucial to its use: the cream stays put in your hand but glides smoothly on your skin under the blade of the razor. Similarly foamed asphalt Shear Thinning properties help maintaining a thick film of binder without risks of draindown when stored in the silo or when hauled in a truck, but increase its workability under the shear of the screed and the compactive effort of the rollers.
WARM AND HOT MIX COMPARATIVE PERFORMANCE

Contractual mix requirements were thus closely monitored and Warm Mix production volumetrics properties consistently matched Hot Mix Production ones and Missouri DOT specifications. Similarly, in the field, compaction requirements were achieved at a 30°C average lower temperature (Table 1:)

<table>
<thead>
<tr>
<th>Table 1: Hot and Warm Mixes Average Temperatures and Final Compaction</th>
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</thead>
<tbody>
<tr>
<td>I-55- I-57</td>
</tr>
<tr>
<td>Average Production T°</td>
</tr>
<tr>
<td>Compaction T° range</td>
</tr>
<tr>
<td>Average final compaction, % Gmm</td>
</tr>
</tbody>
</table>

During the course of the project a comprehensive performance testing on WMA and HMA productions was carried out:

- **Moisture sensitivity.** The potential for moisture damage is estimated by comparing the tensile strengths of a dry subset and a conditioned subset of specimens compacted at the expected field void level (7%). ASTM conditioning method D4867 was used with the freeze-thaw and wet cycles. The data obtained showed that the WMA had 81% retained strength compared to 94% for the HMA (Figure 2). However, the WMA noticeably higher dry initial strength appears to account for some of the larger percentage loss value obtained.

![Figure 2: Tensile Strength Test](image)
- **Resistance to permanent deformation** is measured by two simulative rutting tests conducted on gyratory asphalt mix specimens compacted to the expected field void level (7%). Tests can also be performed on roadway cores.

  - The *Asphalt Pavement Analyzer Test* – APA (AASHTO T 340) - Six specimens preheated at the regional high performance grade temperature, 64°C, are submitted to 8,000 cycles applied by three loaded steel wheels through 100 psi / 689.5 kPa inflated hoses (Photo 2).
  - The *Hamburg Loaded Wheel Test* – HLWT (AASHTO T 324) measures the combined effects of rutting, attrition and moisture damage by rolling two 72 kg steel wheels directly across the surface of four specimens immersed in 50°C water (Photo 3)

Both APA and HLWT tests (Figure 3 & Figure 4) evidences a significant improvement in rutting resistance when foam warm mix technology is used; this improvement is particularly significant with the Hamburg Loaded Wheel test, which denotes higher resistance to rutting as well as to moisture damage.
• **The Dynamic Modulus Test** (AASHTO TP 79 –Photo 4) measures the linear viscoelastic response of the asphalt material to low levels of compressive sinusoidal stress. The test is performed over a range of temperatures/frequencies that simulates road service conditions. It characterizes asphalt material’s structural contribution to the road structure and is the main entry in the new AASHTO Mechanistic-Empirical Pavement Design Method (MEDPG). Master curve representations show (Error! Reference source not found.) an average 10% overall decrease in E* values from the HMA to WMA production mixes. The effect that this change will have on the pavement life calculations has not been evaluated in MEDPG but is anticipated to be fairly small.

![Photo 4: Dynamic Modulus Test](image1)

![Figure 3: Hamburg Loaded Wheel Test rutting Chart](image2)

![Figure 4: Asphalt Pavement Analyser Rutting Chart](image3)

![Figure 5: HMA & WMA E* Mastercurves at 20C ref. Temp.](image4)

• **Low temperature cracking resistance** was measured with the Disc-Shaped Compact Tension test DC (T) (ASTM D7313) at the Advanced Transportation Research and Engineering Laboratory in Rantoul, Illinois. The Disc-Shaped Compact Tension test, or DC (T), is a practical method for the determination of the low-temperature fracture properties of 6-inch cylindrical asphalt concrete specimens or road cores. The test consists in measuring the Crack Mouth Opening Displacement (CMOD) of a saw-cut notch under tensile loading (Error! Reference source not found. & Photo 6). The fracture energy required to generate a unit racked surface area is related to mixture’s resistance to thermal cracking and is deducted from the area under the load-CMOD curve. Test temperature is 10°C greater than the regional low temperature performance grade of the asphalt binder, i.e. -12°C here. The DC (T) specimens are easily produced from both gyratory or road cores; this allows testing freshly produced mix or roadway material.
The average fracture energy for the mixture Hot Mix Asphalt produced at 360°F/180 °C was found to be 365 J/m$^2$, where the Foamed Warm Mix produced at 305°F/150°C resulted in 25% higher fracture energy with an average of 454 J/m$^2$ (Figure 6). The threshold for a sufficiently resistant asphalt mixture to thermal and reflective cracking lies between 350 and 400J/m$^2$. However, in order to alleviate cracking with increased reliability, 400J/m$^2$ is recommended. This prediction is based upon field cracking data correlated to CMOD fracture energy by Buttlar et al (2010) displayed in Figure 7. These results suggest that the warm asphalt mixture will be more resistant to thermal and reflective cracking over its service life, than the hot mix control.

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**BINDER TEST RESULTS**

Original PG 76-22 polymer modified binder along with “Hot” and “Warm” recovered binders were tested to understand what impact the use of the warm mix technology has on the binder properties and how it relates to the mixes’ performances presented above. Testing followed Superpave Performance Grading (AASHTO MP 320) and Multi-Stress-Creep-Recovery test procedure (ASTM D 7405). The recovery technique used ASTM D5404 Rotavapor method for the extraction of the binder.

Superpave Performance Grade (PG) test results

The PG grade evaluations of the original and recovered binders based on Dynamic Shear Rheometer (DSR) and Bending Beam Rheometer (BBR) tests evidence that difference in the fail temperatures ranges is relatively small (See Table 2)

<table>
<thead>
<tr>
<th>Site Information</th>
<th>I-55</th>
<th>I-57</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original PG binder</td>
<td>PG 76-22</td>
<td>PG76-22</td>
</tr>
<tr>
<td></td>
<td>(80.14-23.88)</td>
<td>(76.38-23.23)</td>
</tr>
<tr>
<td>Recovered from HMA</td>
<td>PG82-16</td>
<td>PG76-22</td>
</tr>
<tr>
<td></td>
<td>(82.75-21.68)</td>
<td>(77.84-24.03)</td>
</tr>
<tr>
<td>Recovered from WMA</td>
<td>PG76-16</td>
<td>PG76-22</td>
</tr>
<tr>
<td></td>
<td>(80.55-21.33)</td>
<td>(78.83-23.68)</td>
</tr>
</tbody>
</table>

Table 2: Performance grading information (AASHTO M320 Table 1) and continuous

Multi-stress creep and recovery test (MSCR)

Binder Dynamic Shear testing is conducted at low levels of stress and the G*/ Sin(δ) criterion does not correlate well with mixture rutting when polymer modified binders are used. Recent research (D’Angelo, 2007)\(^2\) has demonstrated the need to evaluate binders at higher strain levels to fully capture their response outside the linear viscoelastic domain, and better predict bituminous mixtures rutting. The new criteria are the non-recoverable compliance (Jnr) and percent recovery, based on binder creep and recovery testing at several higher stress levels.

The Jnr and elastic recovery were measured at 64°C, the high regional performance grade temperature. Results presented in Figure 8, evidence that the recovered foamed polymer-modified binder has a higher elastic response than its “hot” counterpart. This suggests that the **“warm” binder has a better elastomeric polymer network.**

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Gel permeation chromatography

In order to relate the better elastomeric properties of the “warm” recovered binder to the condition of the SBS-Polymer network a comparative Gel Permeation Chromatography (GPC) was performed at the COLAS’ Technical and Scientific Campus in Paris, France on (1) the original PG 76-22 binder; (2) the binder recovered from the Warm Mix produced at 152°C; (3) the binder recovered from the Hot Mix produced at 182°C and (4) the binder recovered from an over-heated Hot Mix sample at 193°C.

GPC allows separating molecules according to their molecular weight; chromatograms analysis provides information on the average molecular weight of binders’ components as well as on their size distribution.

The GPC chromatograms (Figure 9) exhibit two distinct peaks, one for the polymer and one for the bitumen. A closer look at the polymer peak shows that from 152°C to 182° and 193°C, the polymer peaks are less pronounced and wider revealing that with increasing temperature (1) the polymer average molecular weight decreases and that (2) the polymer molecular weight range increases, due to degradation.

- These observations are consistent with the progressive degradation of the polymer network with temperature.
CONSTRUCTION CONTROL

Provided that improved workability and compaction are one of the expected benefits of warm asphalt processes, density evolution vs. compaction energy and mat temperature were monitored (Photos 7 & 8, Figure 9). This was particularly critical because 19 mm high traffic designs (PG76-22, 125 gyrations) placed in 2-in are usually not the easiest to compact.

Average Warm Mix density behind the screed matched HMA’s at 85% MTD but at about 20°C lower temperature (137-140°C vs. 156°C). The two breakdown rollers were moved up in tandem closer to the paver and after the fourth pass, WMA mat density matched HMA.

Target 94% MTD density was achieved at an average 20°C lower temperature with the same compaction energy thanks to the enhanced Foam Mix workability.
**PLANT CONTROLS**

All mixes were produced from DELTA’s mobile Cedar Rapids 400 t/h parallel flow plant equipped with a 70 tons surge bin (Photo 9). The plant is equipped MAXAM AQUABLACK™ foam device (Photo 10).

Plant controls included temperatures checks; Oxygen O₂; emissions of Carbon Monoxide CO, and Nitrogen Oxides NOₓ, as well as energy consumption. Main results are summarized below (Table 3 & Table 4):
Table 3: Energy Consumption on 2009 I-55 Production

<table>
<thead>
<tr>
<th></th>
<th>Mix Tons</th>
<th>Av Mix T°</th>
<th>Av. Agg. Moist (%)</th>
<th>Av. KBTUs/ton</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HMA</strong></td>
<td>85,467</td>
<td>175°C</td>
<td>1.8</td>
<td>241</td>
</tr>
<tr>
<td><strong>WMA</strong></td>
<td>70,644</td>
<td>149°C</td>
<td>1.7</td>
<td>205</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>156,111</td>
<td>-26°C</td>
<td></td>
<td>-15%</td>
</tr>
</tbody>
</table>

Table 4: HMA, WMA productions comparative CO emissions

<table>
<thead>
<tr>
<th></th>
<th>Av. HMA</th>
<th>Av. WMA</th>
<th>Δ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix chute T°</td>
<td>177°C</td>
<td>153°C</td>
<td>-24°C</td>
</tr>
<tr>
<td>CO ppm</td>
<td>1308.0</td>
<td>465.2</td>
<td>-64%</td>
</tr>
</tbody>
</table>
CONCLUSIONS:

I-55/I-57 project, the largest Warm Mix road project ever completed to date, successfully met all contract technical specifications and confirmed several of Warm Mixes’ benefits: lower emissions, reduced energy consumption and enhanced constructability. In addition the performance evaluation conducted pointed out that not only Warm Mix Technologies allow reducing asphalt binders aging, but they also permit to preserve the elastomeric properties of the polymer-modified binders.

- **Performance**: Mix Rutting tests and binder MSCR testing have evidenced the better resistance of the polymer modified Warm Mix production to large nonlinear plastic deformations. As opposed to testing in the linear viscoelastic domain where mix and binder showed slightly lower dynamic and shear moduli, respectively. This differentiated response is attributed to the lower production temperatures which (1) preserved the elastomeric properties of the polymer (better resistance to plastic deformations); (2) reduced the aging of the viscoelastic asphalt binder (lower moduli). This reduced aging also translates into higher resistance to low temperature cracking.

- **Constructability**: Thanks to foamed asphalt increased workability density goals were met at 20ºC lower temperature with the same compaction energy as hot mixes.

- **Emissions & Energy**: Measures on I-55 production showed that an average 30ºC temperature drop resulted in a 64% Carbon-Monoxide (CO) reduction and 15% Energy Savings.