Seven Year Itch - Evaluation of Caltrans Full Scale Experiment on Asphalt Rubber Modified Pavements

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ABSTRACT: The California Department of Transportation (Caltrans) has been using scrap tire rubber in asphalt pavements since the 1970s in chip seals and the 1980s in Rubberized Asphalt Concrete (RAC). In 2004, Caltrans and the California Integrated Waste management Board (CIWMB), now known as CAL Recycling, initiated a joint effort to develop technically sound, cost effective, and environmentally friendly solutions to scrap tire management through the increased use of scrap tire rubber in roadway projects. A full scale field experiment project was constructed for the above purpose. The project is a two-lane overlay project located on Highway 33 near the town of Firebaugh in the central valley of California. Caltrans developed the experimental design and specifications.

The experiment consisted of nine pavement test sections with various rubber-modified asphalt concrete mixtures and a control section of a dense-graded asphalt concrete (DGAC). The rubber-modified asphalt concrete sections included a Gap Graded Rubberized Hot Mix Asphalt (RHMA, field wet process), a Gap Graded Rubber Modified Asphalt Concrete mix (dry process), a Gap-Graded Modified Binder mix (terminal blended), and a Dense-Graded Modified Binder mix (terminal blended). The project specifications required the asphalt rubber binders to have at least 15% Crumb Rubber Modifier (CRM) by weight of asphalt. The nine test sections provided an opportunity to evaluate the constructability and performance of two different layer thicknesses: 45 mm (Half Thickness) versus 90 mm (Full Thickness). The pavement structural sections were designed for 10 years traffic level of approximately 2.5 millions of equivalent single axle loading (ESALs). The paving was completed in June 2004.

Seven years have gone by, how have these test sections been performing? In the summer of 2011, Caltrans engineers revisited the project, conducted another round of field condition survey, and noted significant differences in the surface condition among the various test sections.

KEY WORDS: Rubberized asphalt concrete, rubberized hot mix asphalt, asphalt rubber modified pavements, modified binder, asphalt concrete, rubber-modified mixes.
1. Introduction

The California Department of Transportation (Caltrans) began experimenting with Rubberized Asphalt Concrete (RAC) in 1978 and has used RAC successfully as a maintenance strategy since 1983 (Ravendale Project, Van Kirk, *Caltrans Experience with Asphalt-Rubber Concrete-An Overview and Future Direction*). The majority of RAC projects have been constructed using field blended asphalt rubber binder (wet process). Early field and heavy vehicle simulation (HVS) evaluations of RAC projects resulted in Caltrans decision to reduce thickness of RAC equivalent to one-half the required thickness of conventional DGAC for remediation of reflection cracking (Caltrans 2001, Flexible Pavement Rehabilitation Manual). In 1995, after an extensive evaluation of existing RAC projects (Van Kirk & Hildebrand), Caltrans established a single specification for the binder which includes extender oil and aggregate structure (gap graded). In the early 1990s, Caltrans evaluated the field performance of 17 existing RAC projects, evaluated the performance of the binders involved, and developed Modified Binder (MB) specifications (Reese 1994) that require performance criteria for rubber modified binders. Caltrans approved the use of MB specifications in 1996 for mixes with both dense graded (Type D-MB) and gap graded aggregate structures (Type G-MB). However, there were concerns regarding the suitability of using MB binder mixes for half thickness design because MB mixes had about 5%-10% Crumb Rubber Modifier versus the 18% ± 1% in RAC (wet process) and Rubber Modified Asphalt Concrete mix (dry process).
2. Project Information

2.1 Project Location & Test Section Layout

The Project is located on Highway 33 north of the town of Firebaugh in Fresno County, in the California Central Valley (Rubberized Asphalt concrete Firebaugh Project Volume 1 – Construction Report). Figure 1 shows the location and layout of test sections on Highway 33.

The test sections represented three different processes of Crumb Rubber Modifier (CRM) addition to asphalt concrete/Hot Mix Asphalt (HMA). The wet process is by far the most widely used method of CRM modification. In this process, CRM is added to the asphalt binder along with a known proportion of extender oil, allowed to react for at least 45 minutes until a specified viscosity range of 1500 to 4000 Pa.s ($10^3$) is achieved. In the dry process CRM is added along with the aggregate before the addition of asphalt binder. Both these processes are also known as field blending processes. In the terminal blended wet process, CRM is added to asphalt binder at the asphalt refinery and the blended product is then transported to the hot mix plant. For this full-scale experiment, all three processes had a minimum of 15% CRM by weight of asphalt binder.
The test sections consisted of a 90mm Dense Graded Asphalt Concrete (DGAC) control section, 90mm (full thickness) and 45mm (half thickness) RAC-G (gap graded wet process), 90mm (full thickness) and 45mm (half thickness) RUMAC-GG (gap graded dry process), 90mm (full thickness) and 45mm (half thickness) MB-G (gap graded-terminal blended) and 90mm (full thickness) and 45mm (half thickness) MB-D (dense graded-terminal blended) sections.

2.2 Project Pavement Design

The pavement structural sections were designed for a design life of 10 years with approximately 2.5 million equivalent single axle loads (ESALs). Within each test section, a 152m (500 ft) long performance evaluation section (PES) was established for performance monitoring over a period of at least five years. Deflection test data was used to develop the proposed overlay thickness of 90mm DGAC. Caltrans Highway Design Manual (HDM) allows the substitution of half thickness for RAC-G mixes for reflection crack mitigation. The full and half pavement overlay thicknesses for each of rubber modified sections were selected to facilitate a side by side comparison of performance under similar traffic and environmental conditions.

2.3 Pre-construction Deflection Testing & Pavement Condition Survey

Deflection testing was performed over the entire project limits, average normalized (40KN-9kips) deflection in the proposed test section area ranged from 0.3mm to 0.5 mm. Pavement condition surveys of existing pavement were carried out in March 2004. Pavement condition surveys for the test sections were performed in accordance with the Distress Identification Manual (June 2003) for Long Term Pavement Performance (LTPP) project and the distresses were recorded (mapped) in the proposed 152m PES. These distress maps were used to track post overlay distress development, and overlay performance. Load related fatigue cracking in wheel paths, block cracking, medium to high severity transverse cracking and occasional pumping were some of the distresses observed and noted during condition surveys.

3. Mix Design and Construction

3.1 Mix Design and Materials

Hveem mix design method was used for each of the RAC mixes (wet, terminal and dry processes). The mix designs were developed by the contractor and verified by Translab, Caltrans. Key mix design parameters at 4% air voids for the mixes used are presented in Table 1. All mixes, except MB, used an AR-4000 asphalt binder supplied by Greka – Santa Maria Asphalt Refinery and the MB with a minimum of 15% CRM was supplied by Valero Refining Company.
Table 1: Mix Properties at 4% design air void content.

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>RAC-G</th>
<th>RUMAC-GG</th>
<th>MB-G</th>
<th>MB-D</th>
<th>DGAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>---</td>
</tr>
<tr>
<td>19</td>
<td>97</td>
<td>97</td>
<td>97</td>
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<tr>
<td>12.5</td>
<td>85</td>
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<td>---</td>
</tr>
<tr>
<td>9.5</td>
<td>68</td>
<td>68</td>
<td>68</td>
<td>68</td>
<td>70</td>
</tr>
<tr>
<td>4.75</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>48</td>
<td>50</td>
</tr>
<tr>
<td>2.36</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>33</td>
<td>36</td>
</tr>
<tr>
<td>0.6</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>0.075</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
<td>4.2</td>
<td>5.4</td>
</tr>
</tbody>
</table>

Mix Properties

- Optimum Binder Content (OBC), % *: 7.9, 7.9, 6.3, 5.3, 4.8
- Maximum Density @ OBC: 2.35, 2.36, 2.40, 2.44, 2.46
- Asphalt Absorption @ OBC, %: 0.70, 0.79, 0.67, 0.93, 0.98
- Stability @ OBC: 36, 35, 29, 38, 47
- Void in Mineral Aggregate (VMA), %: 18.3, 18.4, 15.4, 12.8, 12.1
- Voids Filled with Asphalt (VFA), %: 83.0, 79.9, 82.4, 79.9, 76.2

* By dry weight of aggregate.

3.2 Construction

Construction of test sections began on June 14, 2004 and was completed on June 30, 2004 without any major problems or equipment failures. The bottom lifts of full thickness (90 mm) test sections were placed along with the half thickness (45 mm) test sections. Top lifts (45 mm) were placed the next day.

4. Post Construction Monitoring

4.1 Deflection Testing

Post construction deflection testing was performed in October 2004. Table 2 shows the effect of the overlay type and thickness on the surface deflection. For a 45-mm thick overlay, the RUMAC-GG mix appears to be most effective in reducing the surface deflection as is evident by the 27% reduction in deflection, followed by the MB-D mix and the RAC-G and MB-G mixes. For a 90-mm thick overlay, the RAC-G mix appears to be most effective with 42% reduction in deflection, followed in the order of RUMAC-GG, MB-D, DGAC, and MB-G mixes in deflection reduction. This is important since they indicate that the asphalt rubber mixes are as effective in reducing deflection (adding structural capacity) initially as the DGAC mix.
Table 2: Deflection values at test sections.

<table>
<thead>
<tr>
<th>Mix</th>
<th>Section</th>
<th>Thickness (mm)</th>
<th>Before Overlay (mm)</th>
<th>After Overlay (mm)</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td>STD</td>
<td>CV (%)</td>
</tr>
<tr>
<td>RAC-G</td>
<td>1</td>
<td>90</td>
<td>0.62</td>
<td>0.05</td>
<td>8.7</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>45</td>
<td>0.35</td>
<td>0.02</td>
<td>5.1</td>
</tr>
<tr>
<td>RUMAC</td>
<td>3</td>
<td>45</td>
<td>0.44</td>
<td>0.03</td>
<td>7.3</td>
</tr>
<tr>
<td>-GG</td>
<td>4</td>
<td>90</td>
<td>0.40</td>
<td>0.06</td>
<td>14.0</td>
</tr>
<tr>
<td>MB-G</td>
<td>5</td>
<td>45</td>
<td>0.29</td>
<td>0.04</td>
<td>14.3</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>90</td>
<td>0.36</td>
<td>0.04</td>
<td>11.4</td>
</tr>
<tr>
<td>MB-D</td>
<td>7</td>
<td>90</td>
<td>0.30</td>
<td>0.05</td>
<td>15.6</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>45</td>
<td>0.46</td>
<td>0.06</td>
<td>12.1</td>
</tr>
<tr>
<td>DGAC</td>
<td>9</td>
<td>90</td>
<td>0.44</td>
<td>0.02</td>
<td>5.0</td>
</tr>
</tbody>
</table>

¹ STD = Standard Deviation. ² CV = Coefficient of Variation. CV is the ratio of standard deviation divided by the mean (average) for a given sample used to measure spread.

Deflection testing was performed at the same test locations established during the first post construction monitoring cycle in subsequent monitoring cycles. Average deflection data gathered during May 2008 monitoring cycle is presented in Table 3. Average deflections show an increasing trend for all except the MB-D 45mm thick section. It is worth noting that almost four years after construction the average deflections are practically unchanged indicating no significant loss in structural capacity for six out of nine test sections.

Table 3: Deflection Measured in May 2008

<table>
<thead>
<tr>
<th>Mix</th>
<th>Section</th>
<th>Thickness (mm)</th>
<th>After Overlay (mm) October, 2004</th>
<th>After Overlay (mm) May, 2008</th>
<th>Deflection Change %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Average</td>
<td>STD</td>
<td>CV (%)</td>
</tr>
<tr>
<td>RAC-G</td>
<td>1</td>
<td>90</td>
<td>0.36</td>
<td>0.03</td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>45</td>
<td>0.30</td>
<td>0.03</td>
<td>11.2</td>
</tr>
<tr>
<td>RUMAC</td>
<td>3</td>
<td>45</td>
<td>0.32</td>
<td>0.03</td>
<td>7.8</td>
</tr>
<tr>
<td>-GG</td>
<td>4</td>
<td>90</td>
<td>0.27</td>
<td>0.03</td>
<td>12.3</td>
</tr>
<tr>
<td>MB-G</td>
<td>5</td>
<td>45</td>
<td>0.26</td>
<td>0.02</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>90</td>
<td>0.25</td>
<td>0.02</td>
<td>7.6</td>
</tr>
<tr>
<td>MB-D</td>
<td>7</td>
<td>90</td>
<td>0.21</td>
<td>0.00</td>
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<tr>
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<td>0.38</td>
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<tr>
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<td>9</td>
<td>90</td>
<td>0.30</td>
<td>0.01</td>
<td>4.2</td>
</tr>
</tbody>
</table>

However, three test sections, RUMAC-GG 90mm, MB-D 90mm and DGAC 90mm control section show >10% increased deflection, indicating decreased structural capacity. Average test section deflection for MB-D 45mm section decreased for the same period of time.
4.2 Pavement Condition Surveys

4.2.1 October 2004

Post construction pavement condition surveys were carried out periodically beginning October 2004. Except for the MB-G sections all other sections were distress free. Both MB-G (90mm and 45mm) sections had started bleeding within weeks of construction. The bleeding was more pronounced on the north bound direction compared to south bound direction.

4.2.2 February 2006

Second round of pavement condition survey was carried out in February 2006. Low severity reflected transverse cracks were observed and recorded in RAC-G, (both 45mm and 90mm) and RUMAC-GG (both 45mm and 90mm) test sections, shown in Figure 2.

Both MB-G (45 mm and 90 mm) sections had developed low severity rutting in the wheel paths along with the bleeding that had begun soon after construction. MB-G sections are shown in Figure 3.
In contrast, both MB-D (90mm and 45mm) sections and the DGAC section did not have any surface distress. The sections are shown in Figure 4.

**Figure 3.** Bleeding in Wheel Paths

**Figure 4.** The Zero Distress Sections

4.2.3 June 2007

Third round of pavement condition surveys were carried out in June 2007. Figures 5 through Figure 7 show the pavement condition. Low severity reflected block cracking was observed and recorded in RAC-G, (both 45mm and 90mm) and RUMAC-GG (both 45mm and 90mm) test sections, as shown in Figure 5. Low to medium severity bleeding in wheel paths was observed
and recorded for MB-G 45mm and MB-G 90mm thick sections respectively, as shown in Figure 6.

![90mm RAC-G Section](image1) ![45mm RAC-G Section](image2) ![90mm RUMAC-GG Section](image3) ![45mm RUMAC-GG Section](image4)

**Figure 5.** Reflected Block Cracking

![90mm MB-G Section](image5) ![45mm MB-G Section](image6)

**Figure 6.** Bleeding in Wheel Paths

Low severity raveling was observed in both MB-D sections, MB-D 45mm section had transverse cracks in the shoulder areas, as shown in Figure 7. The DGAC section showed longitudinal cracking in the outer wheel path and low severity raveling in the pavement surface (Figure 8).
Most recent pavement condition survey was performed on July 6, 2011, about seven years after the test section construction. Entire lengths of PES sections were walked over to observe and record the pavement surface condition. Severe wheel path fatigue cracking and block cracking were observed in RAC-G and RUMAC-GG sections, the cracked areas were >20% of PES area. The MB-G sections have bleeding in the wheel paths. In fact the MB-G 90mm section is rutted in the wheel paths. MB-D sections have a dull, oxidized appearance. A few transverse cracks were observed in the MB-D 90mm section, longitudinal and transverse cracking was observed in MB-D 45 mm, section The DGAC control section has low severity fatigue cracking in the wheel paths with transverse cracks and early stages of block cracking. Typical surface conditions are shown in Figures 9 through 12.
Figure 9. Reflected Block Cracking

Figure 10. Bleeding and Transverse Cracking
Figure 11. Transverse and Longitudinal Cracking

Figure 12. Block Cracking in DGAC Control Section.
5 Summary and Conclusions

Based on the field performance over seven plus years following conclusions can be drawn:

- MB-D mixes are similar to conventional DGAC mixes in their structural performance over time. The 90-mm MB-D section outperformed the 45-mm MB-D section.
- MB-G mixes bled during the construction; it was likely due to the aggregate structure and binder viscosity. MB-G mixes rutted more than other mixes.
- The sections with the RUMAC-GG and RAC-G mixes (both 90 mm and 45 mm thick) exhibited most cracking, indicating the mixes were least effective in mitigating reflective cracking.
- MB mixes with 15% CRM, both gap- and dense-graded, outperformed all other mixes in crack reflection mitigation.
- MB-D mixes outperformed MB-G mixes in rutting and crack mitigation.
BIBLIOGRAPHY


