Assessment of a Hot-in-Place Recycling Process

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Abstract

This paper documents the effectiveness of a recycle-in-place (Remixer) process on US175, using results from GPR, FWD, PSPA, condition surveys (crack mapping) and laboratory testing.

FWD and PSPA results indicate that the remixed sections are stiff, and the deflection values are in the range typically observed in the Interstate Highway system. This recycling process removes 38mm of AC and adds 25% new material, for a finished thickness of 48mm. The stiffness of the overall pavement structure was not significantly increased by the Remixer process, as the studied pavement sections were already very stiff.

Laboratory testing indicated that the Remixer process yields a low penetration number, meaning the material is relatively hard and brittle. Based on the results from FWD, PSPA, and laboratory testing, the pavement structure of the Remixer section possesses sufficient strength to resist rutting. PSPA and Hamburg Wheel-Tracking test results show that the Remixer yields a stiffer material than a conventional overlay. The pavement structure is stiff and should resist rutting.

Many reflected cracks have been observed in the Remixer sections. Crack-seal may need to be applied after 1-2 years (or as soon as those cracks open enough to apply crack-seal) to prevent water from entering the pavement layers. The cause for the next major rehabilitation to US175 will mainly be related to reflected cracking. It is concluded that the Remixer treatment with 75% RAP is not a viable treatment in cases where there is a problem with cracking. It is suggested that for US175, the RAP reclaim content should be lowered to approximately 30%, using lower-viscosity asphalt to reduce cracking.

Key Words: RAP, Rehabilitation, FWD, SPA, GPR, Hot-in-place Recycle

1. Introduction

The Remixer (hot-in-place recycled) process gave excellent rut resistance on US281 of the Fort Worth District. The Dallas District has identified a candidate section and experimented with the Remixer process on US175. The Remixer process has given US175 a smooth surface, and is a generally satisfactory application. The Dallas District wants to know how long the pavement will last. To achieve the objective of determining the life of the pavement, several tasks were laid out as follows:

(1) Determine the effectiveness of the Remixer process by comparison of Falling Weight Deflectometer (FWD) and Portable Seismic
Pavement Analyzer (PSPA) data taken both before and after the rehab.

(2) Apply non-destructive testing techniques [FWD, Ground-Penetrating Radar (GPR), and PSPA] to determine the in-situ qualities of pavement layers.

(3) Apply laboratory testing to assess the Remixer’s ability to resist rutting.

(4) Determine the best timing of FWD tests to find stiffness values. It has been reported that the stiffness values change in the first several months after construction.

(5) Determine moisture content variation of shoulder and travel lanes immediately after rainfall to see if the rehabilitation process causes water to be trapped in the pavement system.

2. Site Description

US175 is a moderately traveled highway with two lanes per direction. The Average Daily Traffic (ADT) for this roadway in 1998 was 16,700 vehicles, about 13% of which were trucks. The sections used in this study are located on US175 near Kemp, TX.

Originally, the entire project was to use the Remixer process. The reason the Dallas District chose to put a conventional overlay on some sections of US175 is because some stripping, which would severely limit the effectiveness of a Remixer rehab, was found in the eastbound lanes. Figures 1(A) and 1(B) show the general location of US175 and the studied sections. Figure 1(C) shows the five studied sections of US 175. Sections 1-3 are in the westbound lanes, recently rehabbed using the Remixer process. The underlying pavement of these sections was badly cracked, both transversely and longitudinally, but exhibited low FWD deflections of about 0.127mm (5 mils) at 40kN (9000 lbs). Through GPR testing, some stripped layers were found in sections of the eastbound lanes. The stripping was then verified by collecting core samples. Sections 4 and 5 in Fig. 1(C) had this stripping, and were rehabbed using a conventional 38mm (1.5 in) overlay. Both rehabs were completed by November of 1999.

The underlying structure of all sections is considered sound, as the westbound lanes now have 200+mm (8+ in) of AC and the eastbound lanes have old underlying PCC. Under the surface treatment are 300mm (12 in) of lime-stabilized base and 455mm (18 in) of lime-stabilized subgrade.

The major cracks were mapped along the three, 274m (900-foot) sections prior to the Remixer operation. Every 9.1m (30 feet) along these sections, FWD and PSPA tests were run. In addition, five smaller areas within Section No. 3, of varying distress, were mapped in greater detail. These sections will be monitored to determine the effectiveness of the rehab.
3. The Remixer Process

The Remixer process involves several propane heaters, which travel ahead of the Remixer machine, as shown in Figure 2. The amount of heat transferred to the pavement depends on several variables, including weather conditions and the speed of the operation. After the pavement has been heated enough to soften the top 38mm (1.5 in) of AC, the Remixer machine mills off that AC, and mixes in about 25% new material before replacement. Local undulations in the roadway are milled flat, leading to some variation in rehab depth and improved ride quality of the finished pavement. The recycled pavement is then compacted with steel-wheel vibrating and pneumatic rollers, as with a conventional overlay.

The added material is a standard Type C mix utilizing a performance-grade (PG 64-22) binder. Approximately 0.5% of polymer-modified emulsified rejuvenator was added to the new mix. The 75% recycled component tends to lower both the penetration number and resistance to cracking. In this case, a nominal 38mm of old AC was heated and milled off, and 48mm (1.9 in) was replaced.

An FHWA report [2] suggests that for recycled asphalt pavement (RAP) contents greater than 15%, the selection of the new asphalt cement or recycling agent added to recycled HMA should be based on a viscosity blending chart or equivalent procedure. However, the selection of new asphalt cement for mixes containing high RAP contents is sometimes done with little regard for the stiffening effect of aged/recycled material. Some state materials engineers have shown this to be a problem leading to greater frequency of transverse cracking or premature fatigue cracking. The FHWA report [2] also documented that the majority of the RAP is actually less than 35% recycled material. In this case of 75% recycling, no effort was made to design the mix using a viscosity blending chart.

Despite the material savings, the Remixer process is slightly more expensive than a conventional overlay of comparable depth, due to equipment costs and the fuel required to heat the old pavement. The average costs (local to this job) for Remixer and regular overlay are $35,682 and $27,425 per lane mile, respectively. The speed (and ultimate cost) of the Remixer operation depends on the depth of rehab, heat from the propane pre-heaters, air temperature,
wind conditions, and pavement temperature. Typically, one mile can be remixed per day. The remixed pavement can be reopened to traffic on the same day.

3.1 Pavement Conditions Before the Remixer Process

There were many tranverse and longitudinal cracks before the Remixer process, as shown in Figure 3. This is related to environmental effects and the underlying expansive soil in the region. In addition, the underlying 300mm (12 in) of base and 455mm (18 in) of subgrade were both stabilized with lime. Over time, the varying moisture and shrink/swell cycles of the stabilized base and subgrade layers caused those layers to crack. Eventually the cracks propagated through to the surface. The pavement sections investigated have not received major rehabilitation for more than 10 years. Due in part to underlying strengthening with lime stabilization, the pavement sections yielded no sign of rutting. The Remixer process has also yielded excellent resistance to rutting on US281 where the underlying layers are sound. The surface cracks on sections 2 and 3 were surveyed and mapped before the Remixer process was conducted. An example of the surface crack map is presented in Fig. 3(E).

3.2 Pavement Condition After the Rehabilitation Process

Within two weeks of the Remixer process, some of the underlying cracks have reflected to the surface of the Remixer sections (1, 2 and 3). Three months after the Remixer process, more than 50% of cracks that can be observed in the shoulder continue into the main lanes. Due to the lack of severe underlying cracks in the overlay sections (4 and 5), no reflected cracks have yet been observed.

Five small sections of varying condition were also marked out and mapped, as in Figure 4 and 5. Two of the small sections were in good condition (no cracking) while the other three had cracks of various depths. The crack position and depth for each section were carefully recorded. Figure 5B shows the condition of the five small sections after the Remixer process.
Figure 3. Pavement condition before the remodel process and the existing surface cracks of sections 2 and 3

Figure 4. Selection of sections with different levels of distress
A) Examination of the roadway prior to the remodel operation
B) No Cracking
C) Moderate Cracking
D) Severe Distress
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4. FWD Results

Since FWD and seismic measurements are affected heavily by the AC temperature, 5 points were chosen for repeated tests so that temperature effects could be quantified. PSPA and FWD tests were used to collect data every 30 minutes on these points as the pavement temperature changed during the day. This was then used to temperature-correct measured stiffness from other points on the studied sections. This on-site calibration of FWD and PSPA data greatly increases the accuracy of data analysis by removing the effect of temperature. Figure 6(A) shows the relationship between temperature and W1 (first sensor) deflection. FWD results presented henceforth are corrected to a temperature of 25°C (77°F).

Some variation of FWD results is expected due to the underlying cracks. On average, the W1 (at the load center) deflections are in the range of 0.102-0.127 mm (4-5 mils) at a 40 kN load, indicating that the pavement structure is relatively strong and sound. W1 deflections of 0.152-0.254mm (6 to 10 mils) are commonly seen in Interstate Highways. Recent FWD tests conducted on IH35 just south of Austin yielded 0.076 to 0.254 mm (3 to 10-mil) W1 deflections.
Figure 7 shows the W1 deflections before and after the rehab for sections 2 and 3. Note that only the higher deflections seen at the beginning of the section were significantly reduced by the rehab. The same trend was observed in the wave velocities from the PSPA data. No FWD data were collected before the overlay (on sections 4 and 5), so no before/after comparison was made.

It has been reported that the stiffness values change in the first several months after construction. With this in mind, an effort was made to determine the best timing of FWD tests to find suitable stiffness values. On one of the studied sections, FWD tests were run one week after the Remixer operation. Then the same section was FWD-tested (at the same 30 points) 2-week, and three months after the rehab. These deflections were corrected for load and temperature so the true change in strength could be observed. Observation of FWD data collected after rehabilitation indicated that there was only minimum variation among test intervals, as
shown in Figure 7. The overall structure was already very stiff before the rehab, and the 48mm Remixer operation did not have a significant impact on the pavement response. Though FWD deflections were never particularly high, the largest change occurred between the first and second week after the rehab, as shown in Figure 7. Based on this data, it is estimated that FWD data collection to assess the quality of Remixer rehabs can be done anytime following a 2-week stabilization period.

5. PSPA Results

The PSPA was employed to determine the stiffness of the upper layer and to serve as an independent method to verify the FWD results. Details on PSPA equipment and testing can be found in reference [4]. Figure 8 shows the variation in effective modulus of the pavement, which is consistent with the FWD results shown in Figure 7. The average modulus of the AC increased, and the variation in modulus from point to point decreased in both of these two sections. Both PSPA and FWD results indicate that the Remixer treatment only slightly increased the overall stiffness, and that section 3 generally possesses higher stiffness than section 2.

The average AC moduli in five sections, before and after the two rehabs, are shown in Fig. 9. From this figure, it can be seen that the AC in the conventional overlay sections (sections 4 and 5) was weaker than in the Remixer sections, which is consistent with the Hamburg wheel tracking test results. As expected, the AC in section 5 (slow lane) was considerably weaker than that in section 4 (fast lane).

![Figure 8. Variation in AC modulus before and after remixer treatment (one point every 30 feet)](image)

![Figure 9. Average moduli of AC in five test sections of US175](image)

The AC moduli reported here have been adjusted to 25°C. The relationship (see Figure 6B) used for the adjustment was obtained from the PSPA measurements at five fixed points located in section 1.

6. Material Testing

Several core samples were taken from US175, including both the conventional overlay (eastbound direction) and Remixer (westbound direction) rehab. The cores were tested using the Hamburg Wheel-Tracking test, which measures the resistance of the samples to rutting. The cores used for this test were collected near sections 1 (Remixer) and 4 (overlay). This test was conducted in accordance with standard TxDOT method Tex-242-F, which measures rut resistance of bituminous mixtures immersed in water at 50°C (122°F). Only the top 68mm (2.7 in) layer was tested. The test is terminated at 20mm (0.8 in) deformation or 20,000 passes, whichever occurs first. Test results are summarized in Table 1.
Table 1. Hamburg wheel-tracking test results for remixer process and conventional overlay

<table>
<thead>
<tr>
<th></th>
<th>Number of Cycles to Maximum Deformation</th>
<th>Total Deformation</th>
<th>Stripping Inflection Point (cycles)</th>
</tr>
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<tbody>
<tr>
<td>Remixer</td>
<td>20,000</td>
<td>9.93mm (0.39&quot;)</td>
<td>None</td>
</tr>
<tr>
<td>Overlay</td>
<td>8,000</td>
<td>20mm (0.81&quot;)</td>
<td>6,028</td>
</tr>
</tbody>
</table>

The proposed TxDOT standard for heavy-duty pavements is 12.5mm or less total deformation at 20,000 cycles. The Remixer sample passes this criterion. However, mix from the overlay failed with 20mm deformation, after only 8,000 passes. The Hamburg test results indicate that the recycled AC is much more rut-resistant than the conventional overlay.

Cores from the recycled section were tested for density, asphalt content and penetration number. Those results are presented in Table 2. The results in Table 2 are more variable than would be expected for a new hot mix job. This is understandable considering that the recycled pavement consists of 75% old and 25% new material. The penetration numbers for new HMAC are typically in the mid 30s. The Remixer samples yielded penetration numbers between 20 and 25, indicating that the mix is stiffer and more brittle than new HMAC.

A significant difference between the Remixer and conventional overlay became apparent in the penetration test results. For the Remixer material, the measured penetration numbers ranged from 20 to 25, significantly lower than with the conventional overlay, which ranged from 31 to 48. These results are not surprising, given that the recycled mix is a blend of old and new HMA. This means that the binder in the recycled material is a lot stiffer than the new material, which implies that it will be more prone to both fatigue and reflection cracking. Fatigue cracking is not a primary concern on US175, as the base layer is very stiff. However, reflective cracking is a concern.

7. Ground-Penetrating Radar

Ground-Penetrating Radar (GPR) data was collected twice on the Remixer section. This was done during a dry period (Nov. 1999) and shortly after a heavy rainfall (Feb. 2000). GPR data was collected longitudinally along the roadway along six lines, one for each shoulder and one for each wheelpath of the two lanes. The GPR positions are shown in Figure 10.

![Figure 10. GPR positions and possible collection of water beneath the remixer layer](image)

The initial concern, as shown in Figure 10, was that water would be trapped at the bottom of the Remixer layer due to changes in permeability between the travel lane and shoulder. Segregation is visible and obvious on the surface of the Remixer layer, and could have led to excessive trapped moisture. Segregation, coupled with inadequate drainage or low permeability of the underlying layers could also lead to stripping and premature failure of the rehab. Some moisture and stripping of this type was found in a similar Remixer pavement, US281 near Jacksboro, TX [1]. GPR data was collected to determine if excessive moisture was present after rainfall.

Since this roadway is crowned for drainage, the majority of water was expected to collect near and under the downhill wheelpath. If this was the case, the GPR would record a higher dielectric constant in the top layer of the left wheelpath after a rainfall.

Table 2. Laboratory test results for remixer and conventional overlay

<table>
<thead>
<tr>
<th></th>
<th>Density (pcf)</th>
<th>AC content (%)</th>
<th>Penetration #</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remixer 1</td>
<td>140.4</td>
<td>4.75</td>
<td>20</td>
</tr>
<tr>
<td>Remixer 2</td>
<td>132.2</td>
<td>4.80</td>
<td>25</td>
</tr>
<tr>
<td>Remixer 3</td>
<td>138.3</td>
<td>5.33</td>
<td>21</td>
</tr>
<tr>
<td>Overlay 1</td>
<td>143.1</td>
<td>4.62</td>
<td>32</td>
</tr>
<tr>
<td>Overlay 2</td>
<td>136.4</td>
<td>4.60</td>
<td>48</td>
</tr>
<tr>
<td>Overlay 3</td>
<td>137.1</td>
<td>4.15</td>
<td>31</td>
</tr>
</tbody>
</table>
Three important observations can be made from Figure 11A and 11B, which are plots of the dielectric constants of the Remixer layer along section 2. The first is that all measured dielectric constants are low, about 5.0 to 5.5 for both wheelpaths and 4.0 to 4.4 for the shoulder. The normal range for dry AC pavement is 5.0 to 6.5. Saturated layers tend to have a dielectric constant of 10 or greater. The second observation is that the dielectric constants did not significantly increase after the rainfall, indicating that little moisture gets trapped in the top layer. Finally, the right (uphill) wheelpath exhibited a slightly larger increase than the left wheelpath, the opposite of what was expected. Both shoulders yielded dielectric constants of about 4, lower than any of the main lanes.

Although the dielectric values did increase by about 10% after the rainfall, the authors believe this will cause no harm to the pavement. The other sections exhibited similar trends, with no alarming increases in GPR-perceived moisture. Apparently the condition shown in Fig. 10 does not occur in this roadway, or at least is not detectable by GPR.

8. Discussion

The main problem associated with US175 is cracking. Lime stabilization of base and subgrade layers provides a pavement foundation which is sound but prone to cracking. The Remixer
process contained 75% of RAP, which is much higher than the typical 35% used by most other states. The high percentage of RAP would lower the penetration number, increase the resistance to rutting and decrease the cracking performance.

The Remixer process demonstrated its ability to resist rutting on the US281 rehab, where there were no underlying stripping or cracking problems [1]. Three months after the rehab on US175, more than half of the cracks that can be observed in the shoulder had continued into the rehabilitated lanes. It is estimated that crack seal will need to be applied after 1-2 years to prevent excessive water from entering the pavement.

There are several LTPP SPS5 sections (48A502 through 48A509) 3.2km (2 miles) from the Remixer site. After 8 years of service, only a few cracks were observed in the SPS5 sections. Recycled pavements were used in some SPS5 sections with 30% recycling. The 70% of new AC had an AC-5 grade binder. The penetration numbers for the SPS5 sections are all above 35. Base and subgrade structures are similar to the Remixer sections.

It is concluded that the Remixer treatment with 75% RAP is not a viable treatment when there is an existing cracking problem. It is suggested that when applying the RAP to US175, the reclaim content should be lowered to approximately 30%, and lower-viscosity asphalt should be used to reduce cracking.

9. Conclusions

This report documents the results from US175 using GPR, FWD, PSPA, condition surveys (crack map) and laboratory testing to determine the effectiveness of the Remixer process. Due to an underlying stripping problem, approximately 3.2km (2 miles) of this roadway were rehabilitated with a conventional 38mm overlay. Having the two rehab types close together gave an opportunity to compare them under nearly identical traffic and weather conditions. Prior to the recycling operation, the cracks were mapped so that the effectiveness of the rehab on cracks could be studied. Five small areas were mapped in greater detail so that the effect of existing crack severity (width and depth) could be studied. Based on available information gathered, the following conclusions are made:

- FWD and PSPA results indicate that the Remixer sections are relatively stiff, and the deflection values are in a range typically observed in the Interstate Highway system.
- FWD results show that the Remixer process did not significantly increase the stiffness of the overall pavement structure. The Remixer process did increase the structural capacity of the weaker locations, as demonstrated by the reduced FWD deflections.
- Observation of FWD data collected after rehabilitation indicates that there was only minimal variation in stiffness with time. Due to the underlying cracked pavement, the variation across FWD locations was typically greater than any variation with time. The pavement does seem to reach its maximum strength within two weeks, and that is the recommended waiting period.
- GPR results indicate that although there is an increase in moisture after heavy rainfall, the variations are insignificant. Due to variations in pavement materials between the shoulder and travel lanes, the moisture content of the travel lanes is higher than the shoulder, but not to a degree that should raise concern. All collected dielectric values were in a range typical of dry AC.
- Laboratory testing indicated that the Remixer yielded a low penetration number, meaning that as an AC, the material is hard and brittle. PSPA and Hamburg Wheel-Tracking test results showed that the Remixer AC is a stronger material than the conventional overlay used on the eastbound lanes.
- Based on the results from FWD, PSPA, and laboratory testing, the pavement structure of the Remixer sections possess adequate strength to resist rutting.
- Many reflected cracks have been observed in the Remixer sections. Crack-seal may need to be applied after 1-2 years (or as soon as those cracks open enough to apply crack-seal) to prevent water from entering the pavement layers. The cause for the next major rehabilitation to US175 will mainly be related to reflected cracking. Although no model is capable of accurately predicting how long the Remixer sections are able to resist underlying cracks, it is estimated that there will be no need for major repair for at least 5 years.
- It is concluded that the Remixer treatment with 75% RAP does not adequately fix problems with cracking. It is suggested that for US175 the reclaim content should be lowered to approximately 30%, and a lower-viscosity binder should be used.
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References


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