EVALUATION OF OPERATIONAL VARIABLES THAT CAN IMPROVE OVERLAY TESTER RESULTS

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ABSTRACT

The premature cracking of the hot mix asphalt (HMA) layers in flexible pavements is one of the major concerns of the pavement community. The Overlay Tester (OT) is considered by several highway agencies as a routine test to evaluate the cracking potential of HMA mixes in the laboratory setting. The repeatability of the number of cycles to failure measured with the OT is considered as a concern to reliably characterize the potential of HMA mixes to cracking.

The main objectives of the work presented in this paper are to report on the process of evaluating the performance of the current OT test protocol and propose practical improvements when feasible. A laboratory evaluation of key steps in the OT test protocol was carried out on synthetic specimens to minimize the material-related variability and to improve the protocol of the OT test from the onset of gluing to the application of the repeated loads. HMA specimens prepared from a common mix were then tested using the modified protocol to verify the effectiveness of the proposed changes. Alternative parameters from the load-displacement curve that could serve as less uncertain surrogate crack assessment parameters were also evaluated. From this study, the consistency of parameters measured with the OT test seems to improve if the operational parameters proposed in the new guideline are followed.
INTRODUCTION

An HMA layer must have a balance of both rutting and cracking resistant properties to perform well in the field (1, 2). Over the past decade, HMA mixes have been modified to improve their rutting potential using wheel-tracking tests such as the Hamburg test. Stiffer binders and good stone-to-stone contact may improve rutting resistance but they may also reduce the mix flexibility and cracking resistance of the HMA (3-5). Much effort has been recently directed toward the development of testing and analysis methods to study the cracking mechanism of asphalt pavements (6-10). One such test, the overlay tester (OT), measures the number of cycles to 93% reduction in maximum load of the HMA specimens by simulating the opening and closing of joints and/or cracks induced by daily temperature variations and high tensile strain generated by vehicular loads.

Germann and Lytton (1) introduced the OT to predict the reflective cracking resistance of asphalt overlays on long beam specimens. Zhou et al. (2) recommended using the OT test in conjunction with the Hamburg rutting test to design asphalt mixes with adequate reliability in terms of rutting and cracking resistance. Zhou et al. (11) reported a number of case studies where the OT results correlated well with the field performance. Zhou and Scullion (3) performed a sensitivity study to analyze the influence of operational parameters such as test temperature, opening displacement, air voids, asphalt performance grade, and asphalt content on the variability of the results. They found that the OT results are sensitive to the key components of HMA mixtures such as the grade of asphalt binder, asphalt binder content, air voids, and aggregate properties. Walubita et al. (12, 13) comprehensively studied a number of parameters that influenced the repeatability of the OT results, especially for coarse and dense-graded mixes. Walubita et al. (12) noted that one of the key problems contributing to the reported high variability in the OT test results was non-adherence to the OT test specifications and laboratory procedures. Walubita et al. (12) also concluded that, aside from the HMA response behavior, the variability in the OT test might be a function of the sample fabrication and test setup. Recommendations were given for the gluing method, sample drying method, curing time prior to testing, and the sample conditioning time to reduce the variability on the results. Although those studies helped to improve the OT procedure, the variability of the number of cycles measured with the OT test on replicate specimens is still a concern to reliably assess the cracking resistance of HMA specimens in the laboratory setting.

OBJECTIVES AND SCOPE OF WORK

The focus of this paper is to identify any operational step related to specimen preparation and testing processes that may contribute to the variability of the results. A systematic laboratory test program was carried out to evaluate the effects of a number of parameters. A step-by-step study was conducted to gain an in-depth understanding of the key issues related to the OT testing procedure. The study includes sensitivity analyses of key operational parameters to improve the testing process, a preliminary evaluation of the improvements to the repeatability of the OT test results, and analyses as a result of proposed improvements.

This paper includes a brief description of the current OT equipment, followed by the explanation of an experimental study to understand the sources of variability, itemization of suggested changes to the process, and a preliminary evaluation of the improvements in the performances of the OT test using HMA specimens. Finally, a summary of the key findings and recommendations are presented to conclude the paper.
OVERLAY TESTER (OT)

Details of the OT test procedure have been outlined in the Texas Department of Transportation (TxDOT) test procedure designation Tex-248-F (http://ftp.dot.state.tx.us/pub/txdot-info/cst/TMS/200-F_series/pdfs/bit248.pdf), which is similar to the ASTM WK26816 protocol. The OT is an electro-hydraulic system that applies repeated direct tensile displacement to asphalt specimens. The device contains two platens: one is fixed and the other slides horizontally, simulating the opening and closing of joints and/or cracks induced by daily temperature variations and high tensile strain generated by vehicular loads. The test is conducted in a displacement-controlled mode at a repeated loading rate of one cycle per 10 sec. The sliding platen applies a cyclic triangular waveform to a constant maximum displacement of 0.025 in. (635 μm) at a testing temperature of 77°F (25°C). In each cycle, the platen is forced to come back to its starting position after it slides to its maximum displacement. The displacement cycles are repeated until the OT specimen reaches “failure.” Failure is currently defined as a 93% load reduction from the maximum peak load measured from the first cycle or as reaching a preset maximum number of cycles.

The main challenge associated with the OT test is the specimen preparation process. Specimen preparation requires cutting and gluing. Figure 1 illustrates the key components of an OT specimen mounted to the OT plates. The OT specimens are nominally 6 in. (150 mm) long, 3 in. (75 mm) wide and 1.5 in. (38 mm) thick. The specimens are trimmed from standard 6 in. (150 mm) diameter by 4.5 in. (114 mm) thick bricketts compacted with a Superpave Gyratory Compactor (SGC) in accordance with AASHTO T312 (ASTM D-6925). Laboratory molded specimens are compacted to an air-void target of 7±1.0%. OT specimens can also be obtained from field cores or slabs. OT specimens are glued to the horizontal platens with half of the length of the specimen resting on each platen. The accumulation of glue in the gap between the base plates (marked as “a” in Figure 1) and the uniformity of the glued area (marked as “b”) could be potential sources of variability. As described by Garcia and Miramontes (14), a linear variable differential transformer (LVDT) was added to the test setup (marked as “c”) to ensure that the specimens do not experience compression at the top.

FIGURE 1 OT schematic layout and sample setup.
During the overlay test, the device automatically measures and records parameters such as load, actuator displacement, top LVDT displacement (if installed), time, number of load cycles, and test temperature. The primary output of the OT test is the number of cycles for the specimen to fail which is measured as the cracking potential of an asphalt specimen.

Figure 2 represents a summary of the typical OT output data. Figure 2a illustrates the applied actuator displacement time history and the resulting load time history for the first ten cycles. The variation of the peak load with the number of cycles is represented in Figure 2b. The 93% load reduction criterion used to estimate the number of cycles to failure is shown in the figure as a dashed line. Although uncommon, the displacement and load acquired for each cycle can also be plotted against each other to inspect the hysteretic behavior of the mix as shown in Figure 2c for the first cycle of the data presented in Figure 2a. The first cycle provides the maximum load where the initial damage (crack initiation phase) occurs. The remaining cycles represent the crack propagation phase until the failure limit of 93% of the maximum load is reached. The shape and pattern of the hysteresis loop can provide a wealth of information. In summary, the relevant information reported and documented in this study is the following:

a) Cycle number when the load reaches 93% of the maximum load. – Cycle at which a 93% load drop is observed.

b) Maximum load of the first cycle – The maximum load of the first cycle (marked as “a” in Figure 2c) that causes the initial damage occurs at a displacement less than the maximum displacement of 0.025 in.

c) Displacement at maximum load – The displacement at which the maximum load is reached (marked as “b”), and

d) Area under the hysteresis loop – The total area under the first cycle hysteresis loop (marked as “c”).

EXPERIMENTAL STUDY

Two main sources of variability, apart from material-related heterogeneity, are the specimen preparation and testing process. To better understand the contribution of these two parameters to the uncertainty of the results, synthetic specimens with different hardness were used. Two synthetic specimens with durometers 90A (soft) and 55D (medium) were selected and tested as per Tex-248-F test protocol to assess the impact of the a) glue type, b) gluing method, and c) glued area. Due to the material composition of the synthetic specimens, the number of cycles was not considered in this analysis. The variables investigated were the load-displacement curve (hysteresis loop) and the maximum load.

In addition to the evaluation performed on the specimen preparation and testing process, HMA specimens were used to evaluate operational parameters of the current protocol. This work was conducted mainly to analyze the repeatability of the OT number of cycles using the modified gluing method. The preparation, molding, and trimming of the specimens took two days. The HMA specimens were molded utilizing a gyratory compactor and trimmed using a double-blade masonry saw. All the specimens were dried using a CoreDry™. The HMA specimens were then air-dried to room temperature to prevent moisture aging. The specimens were glued to the OT base plates on the third day. The adhesives were permitted to cure for 24 hrs. The OT test was then performed within a five-day window as permitted by the test procedure.
FIGURE 2 OT typical output data and interpretation of the results: a) Typical OT data, b) Maximum load vs. cycles and c) Hysteresis loop.
TESTING RESULTS AND ANALYSIS

Evaluation of Variables Described in Most Current Test Procedure
Considering Walubita et al. (12) study discussed above, further investigations were carried out on variables such as glue type, weight on top of the specimens and gluing method using synthetic specimens. Two synthetic specimens with different durometers were used: 90A and 55D (very soft and medium). The outcome of these studies are reported next.

Glue Type
To reduce the probability of failure of the OT specimens at the specimen-plate interface, a strong bond between the specimen and the OT plates is required. The current test procedure calls for using a 2-part, 2-ton epoxy for gluing the specimens to the OT test plates. The required glue type can potentially acquire a strength of 2500 psi when completely cured. While maintaining all the other operational parameters constant, the glue was replaced with a similar glue with a strength of 4400 psi for comparison purposes. Synthetic specimen 90A (Very soft) was used for this comparison. Figure 3 presents the typical performance of the 2500-psi and 4400-psi glues under OT monotonic loading. Monotonic loads were applied to exert greater displacements than normally used in the OT tests. The maximum load for the 4400-psi glue is greater than that of the 2500-psi glue. The hysteresis loop obtained from the 4400-psi glue demonstrated a more linear behavior and a higher maximum load that can thus be interpreted as less internal damage to the bond between the specimen and the plates. Implementing a glue with greater strength to achieve a strong bond between the specimens and the OT plates is recommended to minimize the probability of failure of the OT specimens at the specimen-plate interface.

Weight on Top of Specimen
A private communication with the company that manufactures the glue recommended to have a glue thickness greater than what is currently used for attaching the specimens to the OT plates. To increase the thickness of the glue, the synthetic specimen 90A (Very soft) was prepared using 5-lb instead of 10-lb weight. Figure 6 presents the load-displacement response curves using 5-lb and 10-lb weights on top of the OT specimens. The slopes of the two load-displacement curves
changed after a displacement of around 0.03 in. was reached. Despite similar maximum loads from both testing options, a 5-lb weight is recommended to comply better with the manufacturer’s recommendation and to minimize glue squeezed out from the sides of the specimens.

The other issue observed was that the 10-lb weight recommended to ensure intimate contact between the specimen and the OT plates caused some glue to squeeze out. The squeezed out glue accumulates and hardens along the contact area between the perimeter of the specimen and the OT plates. This additional glue is not always uniform. To achieve uniformity, the glue along the perimeter of the specimens was removed with a razor immediately after the 5-lb weight was applied to the specimen. Figure 5 compares typical results obtained from monotonic loadings of the 55D (medium) synthetic specimen with and without removing the excess glue. The two load-displacement curves are initially similar. However, a change in the slope of the specimen with glue on sides was observed at around 0.01 in. in displacement. One difference that was observed was the change in the slope of the specimen glued on the sides around 0.01 in. in displacement. It was visually verified with a magnifying scope that the change in the slope could be attributed to the failure of the glue along the sides of the specimen. Additionally, the specimens with the excess glue not removed failed at a greater displacement than the clean-sided specimens (0.04 in. as opposed to 0.02 in.). Based on these observations, the removal of the excess glue is desired to uniformly glue the specimens.
Gluing Method

The earlier version of the gluing method (called the “Version 2009” hereafter) of OT test protocol consisted of covering the gap between the base plates with adhesive tape to prevent the accumulation of glue. The adhesive tape and the accumulated hardened glue were removed with a hacksaw. This process was perceived as operator-dependent and a possible source of variability in the OT results. In the current (called the “Version 2014”) protocol, the spacer bars are used instead of adhesive tape to remove the excess glue that accumulates between the OT plates after mounting the specimen. This new method seems more practical because the accumulated glue is removed easily while the glue is still fresh. The uniformity of the glued area due to the use of the tape and the ease of removing the glue with the space bars are both desirable. Thus, an alternative method was considered that could potentially provide both benefits. In the alternative method (called the “Proposed Method”), the tape is covered with a thin layer of petroleum jelly and placed on top of the spacer bar. The removal of the tape after the removal of the spacer bar is easy and the unglued portion of the specimen is uniform.

The three gluing methods were compared using synthetic specimen 90A (Very Soft) under an opening displacement of 0.025 in and loading time of 5 sec, as specified by the cyclic OT test. Figure 4 illustrates typical load-deformation curves obtained from the three gluing methods. The differences in the maximum loads and the shapes of the hysteresis loops indicate that the method of gluing will impact the OT results. The load-displacement response from the proposed method is slightly different than both the 2009 and 2014 versions. The slopes of the loading portion of the last two versions are steeper than the proposed protocol because the proposed protocol visually provided the “cleanest” and most uniform gap. The application of tape seems to improve the consistency of the glued area.

![FIGURE 4 Comparison of hysteresis loops from three gluing methods.](image)

This comparison indicates that the glued area must be consistent to improve the repeatability in the results. Based on these preliminary results, a modified gluing method was designed to minimize the influence of the glued area. Figure 7a presents the materials required to glue and mount the specimens to the OT plates under the proposed process.
The proposed gluing process consists of the following steps:

1. Ensure the base plates and spacer bars are clean and free of any dirt or epoxy from any previous uses.
2. Mount and secure the base plates to the mounting jig. Insert the spacer bar between the plates. Apply a small amount of petroleum jelly on the spacer bar to facilitate its removal (Figure 7b).
3. Draw a line along the middle of the trimmed specimen to guide the placement of the tape (Figure 7c).
4. Place a piece of 4-mm-wide tape along the middle of the trimmed specimen to cover the gap. Apply a small amount of petroleum jelly between the tape and the specimen to facilitate the tape removal once the specimen is mounted onto the base plates (Figure 7d).

5. Prepare two containers each containing 8 g of the two-part epoxy (Figure 7e). Prepare the epoxy only for one specimen in one batch.

6. Evenly spread the glue in each container on one side of the trimmed specimen (see Figures 7f and 7g).

7. Glue the specimen to the base plates while ensuring that the specimen is centered and aligned with the edges of the base plates.

8. Add a 5-lb weight on top of the specimen to ensure intimate contact between the specimen and the base plates (Figure 7h).

9. Remove the excess glue accumulated on the perimeter of the mounted specimen with a razor (Figure 7i).

10. Remove the tape and then the spacer bar carefully to prevent the specimen from moving (Figures 7j and 7k).

11. Allow the epoxy to cure for sufficient bonding strength as per the manufacturer’s recommendations, usually overnight (Figure 7l).

Figure 8 demonstrates the repeatability of the proposed gluing method with a 90A (soft) synthetic specimen. The load-displacement curves from the three trials are very similar. As compared to the last two gluing methods, the proposed gluing method helps to delimitate the contact area between the specimens and the OT plates by removing the glue on the sides of the specimens. Similarly, the application of the tape and space bars as proposed improves the removal of the glue accumulated between the OT plates.

![Figure 8 Consistency of modified gluing method.](image)

**Performance Using Proposed Gluing Method**

In addition to the study carried on the specimen preparation process using synthetic specimens, OT tests were carried out with HMA specimens to comparatively evaluate the performance of the OT results using the proposed specimen preparation vs. the Version 2014 method. A dense-graded mix was investigated under this study. Five similar specimens were tested for each testing option such that the specimens’ air voids were the only parameter that varied. The performance of the OT results using the version 2014 preparation method was evaluated first. The load-displacement
curves for the first and second loading cycles from this activity are shown in Figures 9a and 9b, respectively. Three out of the five specimens performed similarly. Figure 9c displays the displacement time histories captured by an LVDT placed on top of the specimens. The displacement recorded by the LVDT were also not fully consistent. The differences in the maximum load and hysteresis loop may be caused by the inconsistency of the specimen glued area.

![Hysteresis Loop](image)

**FIGURE 9** Results for version 2014 gluing method a) First cycle hysteresis loop, b) Second cycle hysteresis loop, and c) Displacement of top LVDT.

Figures 10a and 10b show the load-displacement curves for the first and second loading cycles when the specimens were prepared using the proposed specimen preparation, respectively. These load-displacement curves are more repeatable and consistent than those shown in Figures 9a and 9b. The specimen with the higher maximum load for the first cycle also exhibited higher maximum load for the second cycle. Figure 10c shows the displacement time histories captured by an LVDT placed on top of the specimens. The displacements recorded by the LVDT were
still less consistent than the load displacement curves. This may be due to geometric dissimilarity of the applied load since, strictly speaking, the specimens are not subjected to a pure tension.

![Load-Displacement Curves](image)

**FIGURE 10** Results for proposed gluing method a) First cycle hysteresis loop, b) Second cycle hysteresis loop, and c) Displacement of top LVDT.

Table 1 summarizes the statistical information of a number of parameters extracted from the OT tests performed using the proposed and version 2014 specimen preparations. Apart from the number of OT cycles, several other parameters such as the maximum load from the first cycle, the corresponding displacement at the maximum load, and the total area under the first hysteresis loop (dissipated energy) were documented. The COV values obtained from the proposed specimen preparation were relatively smaller as compared to the similar results from the version 2014.
### TABLE 1 Summary of Results Obtained from both Gluing Methods

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<th>Gluing Method</th>
<th>Parameter</th>
<th>Number of OT Cycles</th>
<th>Max Load, lbs</th>
<th>Displacement at Max Load, in.</th>
<th>Hysteresis Loop Area</th>
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<tr>
<td>Version 2014</td>
<td>Average</td>
<td>274</td>
<td>409</td>
<td>0.020</td>
<td>10</td>
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<tr>
<td></td>
<td>Std. Dev.</td>
<td>140</td>
<td>99</td>
<td>0.003</td>
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<td></td>
<td>COV</td>
<td>51%</td>
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<td>16%</td>
<td>22%</td>
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<tr>
<td>Proposed</td>
<td>Average</td>
<td>300</td>
<td>467</td>
<td>0.014</td>
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<tr>
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<td>Std. Dev.</td>
<td>95</td>
<td>21</td>
<td>0.002</td>
<td>1</td>
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<tr>
<td></td>
<td>COV</td>
<td>32%</td>
<td>4%</td>
<td>12%</td>
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Despite the decrease in the variability in the number of OT cycles to failure from the proposed specimen preparation, the stated goal of acceptable variability, defined by TxDOT as COV ≤ 20%, could not be achieved. Considering the more consistency of the other parameters, especially the maximum load and the dissipated energy (i.e., the area within the hysteresis loop), further work is on the way to estimate the cracking resistance of HMA mixes from these and similar alternative parameters.

### SUMMARY and CONCLUSIONS

The sources of variability of the results from the OT tests can be categorized as material-related, test-related, or analysis-related. The objective of the paper was to report on the results of a study to evaluate the specimen preparation and to propose means of reducing some aspects of the test-related variability, when feasible. A laboratory evaluation of synthetic specimens was first performed to eliminate the material-related variability. The results obtained from testing synthetic specimens were used to improve the gluing process of OT specimens. HMA specimens were then tested using the proposed improvements to partially demonstrate their validity and practicality. Key findings and conclusions obtained during this study are presented in Table 2. The proposed modifications in Table 2 provide more consistent results. However, the number of OT cycles estimated with the standard 93% load reduction method still resulted in higher variability than desired.

### ACKNOWLEDGEMENTS

The authors are grateful to the Texas Department of Transportation for the help and support provided. The authors would like to especially thank Ms. Gisel Carrasco and Mr. Robert Lee from the Flexible Pavement Branch for all their guidance in this study. The authors would also like to thank the undergraduate research assistants that worked on the laboratory testing.
### TABLE 2 Key Findings and Conclusions from Operational Parameters Investigated

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<td><strong>Glue Type</strong></td>
<td>Glue strength:</td>
<td>The implementation of a glue with a higher strength yielded a higher maximum load and a more linear load-displacement curve. Visual microscopic inspection indicated less internal damage to the bond between the specimen and OT plates when stronger glue is used. To reduce the probability of failure of the OT specimens at the specimen-OT plate’s interface, it is recommended a glue with higher strength to gain reliably a strong bond between the specimen and the OT plates.</td>
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<tr>
<td></td>
<td>• 2500 psi</td>
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<tr>
<td></td>
<td>• 4400 psi</td>
<td></td>
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<tr>
<td><strong>Gluing Method</strong></td>
<td>• Version 2009</td>
<td>A consistent gluing method is essential to cover more uniformly the specimen’s surface that is in contact with the OT plates. The proposed gluing method, which uses of the greased tape and spacers along with the removal of the glue located on the sides of the OT specimen, is recommended to ensure a more consistent and uniform gluing process</td>
</tr>
<tr>
<td></td>
<td>• Version 2014</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Proposed Method</td>
<td></td>
</tr>
<tr>
<td><strong>Weight on Top of Specimen</strong></td>
<td>• 10-lb Weight</td>
<td>Reducing the weight placed on top of the specimens during the curing time helps minimizing the squeezing of the glue and achieving a thicker glue film (as strongly recommended by the glue manufacturer) to provide a stronger and uniform bond between the specimen and the OT plates.</td>
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<td>• 5-lb Weight</td>
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### REFERENCES


