RESEARCH & DEVELOPMENT

In-situ Determination of Emulsion Application Rates for Tack Coats and Surface Treatments

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16. Abstract

Emulsions are used as tack coats to bond asphalt concrete layers and as a bonding agent for aggregates in chip seals. The rate of emulsion application is critical to the performance of both tack coats and chip seals. It has been demonstrated that field EARs can be highly variable, which is not captured using current measures for quality control (QC). Comprehensive QC of emulsion application should include provisions for assessment of (1) transverse variability in EARs, (2) the quantity of emulsion absorbed by the paving surface to enable proper adjustment of the target EAR during construction, and (3) longitudinal variability in EARs along the length of paving.

The Tack Lifter was developed as a simple and efficient means for in-situ measurements of applied EARs and "effective" EARs, neglecting emulsion absorbed by the paving surface to improve QC measures. The Tack Lifter consists of a weight device, frame, and absorbent sheet. Following emulsion application by a distributor, the frame is applied to the surface of interest to seal the test area. The absorbent sheet is inserted into the frame and the weighted device is applied. Emulsion is absorbed into the sheet. The weight of emulsion combined with the sheet area is used to obtain a spot check of EAR. Tests can be applied directly to the paving surface provide a measure of effective EAR. Alternatively, tests can be applied to pans placed on the paving surface prior to emulsion application to provide a measure of the applied EAR. The difference between applied and effective EARs measured by the Tack Lifter allows for quantifying the rate by which a pavement absorbs applied emulsion. For maximum efficiency in measuring applied EARs in the field, elevated plates and a peel were developed. Elevated plates are placed on the roadway's lane center prior to arrival of the distributor. After emulsion application, elevated plates can be easily and efficiently removed from the roadway for Tack Lifter testing to minimize delays in construction operations. A comprehensive laboratory and field experimental program has been employed to develop and evaluate the Tack Lifter, which enabled development of a proposed practice for comprehensive QC of EARs.

Based on laboratory and field experiments, a proposed practice for QC of EARs has been developed. The practice includes three procedures: (1) ASTM D 2995 Test Method B for quality control of transverse variability in EARs each day prior to construction. (2) Tack Lifter tests applied in the wheel path to flat, steel pans and the paving surface on a test pavement section prior to construction and where significant changes in surface conditions are noted to allow for quantifying the rate by which the pavement absorbs emulsion and guide adjustment of the target EAR, (3) Tack Lifter tests conducted on elevated plates following removal from the roadway every 0.5 miles along the length of paving or where changes in grade or curvature are noted for assessment of longitudinal variability in applied EARs.

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EXECUTIVE SUMMARY

Emulsions are used as tack coats to bond asphalt concrete layers and as a bonding agent for aggregates in chip seals. The emulsion application rate (EAR) is critical to the performance of both tack coats and chip seals. It has been demonstrated that field EARs can be highly variable. Emulsion application can vary transversely across a pavement due to variability in emulsion output and fan patterns among distributor nozzles. Emulsion application can also vary longitudinally along the length of paving as a result of fluctuations in distributor speed and flow rates. In addition, the existing paving surface will absorb a fraction of emulsion applied which will be unavailable to act as a bonding agent for granite aggregate or asphalt concrete placed on top of the emulsion. Thus, it is important to differentiate between total EAR and "effective" EAR available for bonding. The importance of surface absorption is considered in many tack coat and chip seal design methods. However, specified adjustments to EARs to account for surface absorption lack experimental or theoretical basis.

Existing methods for quality control (QC) of EARs are very limited. The only standardized test procedure is ASTM D 2995, which targets calibration rather than in-situ measurements and does not allow for capture of the effective EAR. Thus, it is imperative to develop an improved method for in-situ measurement of EAR in the field along the length of paving to provide QC during construction. Improved QC of EARs will result in prolonged service life, decreased life cycle costs, and enhanced safety.

The Tack Lifter was developed as a simple and efficient means for in-situ measurements of applied EARs and effective EARs, neglecting emulsion absorbed by the paving surface to improve QC measures. The Tack Lifter consists of a weight device, frame, and absorbent sheet. Following emulsion application by a distributor, the frame is applied to the surface of interest to seal the test area. The absorbent sheet is inserted into the frame and the weighted device is applied. Emulsion is absorbed into the sheet. The weight of emulsion combined with the sheet area is used to obtain a spot check of EAR. Tests can be applied directly to the paving surface to provide a measure of effective EAR. Alternatively, tests can be applied to pans placed on the paving surface prior to emulsion application to provide a measure of the applied EAR. The difference between applied and effective EARs measured by the Tack Lifter allows for quantifying the rate by which a pavement absorbs applied emulsion.

A laboratory experimental program was implemented to evaluate the Tack Lifter, which considered varying surface types (asphalt concrete, chip seal, microsurfacings), textures (e.g., rough, smooth), emulsion types, applied EARs, and temperatures. Laboratory experiments established that the Tack Lifter absorbs 100% of emulsion applied to impermeable, steel pans. Results of Tack Lifter tests applied to paving surfaces indicate that the amount of emulsion absorbed by a pavement is influenced by surface type and texture. Rougher surface texture leads to a higher rate of emulsion absorption by the paving surface than smoother texture. Furthermore, the mechanisms of absorption can differ on the basis of surface type (e.g., asphalt concrete versus chip seal). In addition, it is important to recognize the absorption capacity of a paving surface is theoretically a fixed quantity. Thus, a greater percentage of applied emulsion

will be absorbed by the paving surface for low EAR applications (e.g., tack coat) as opposed to high EAR applications (e.g., chip seal). Results demonstrated emulsion absorption by a paving surface can be significant, and thus suggest it is critical to evaluate the amount of emulsion absorbed by a pavement prior to construction and adjust target the EAR accordingly.

Field experiments further validated use of the Tack Lifter and provided input to the development of a proposed practice for QC of EARs in the field. Field experiments were conducted to assess transverse and longitudinal variability in applied EARs and the rates by which pavements absorb emulsion. In addition to Tack Lifter tests, use of ASTM D 2995 Test Method A for QC of both longitudinal and transverse variability in EARs was tried in field experiments. While ASTM D 2995 was developed for the purpose of calibration prior to construction, it can also theoretically be implemented in-situ during construction. However, issues were encountered and this procedure is not recommended for implementation. The geotextile pads used in ASTM D 2995 Test Method proved to be difficult to handle and emulsion was often lost due to dripping from the pad edges. Furthermore, pads placed in the wheel path adhered to the distributor, precluding measurement of EARs in the wheel path.

Field experiments demonstrate that emulsion absorption by paving surfaces varies with surface texture and pavement type, confirming laboratory findings. Field investigations indicate emulsion absorption by pavements in the wheel path, (where performance is most critical), can be on the order of 0.05 gal/yd^2 and do not vary appreciably along the length of paving. These results imply that it is important to measure the quantity of emulsion absorbed by a pavement prior to construction and adjust target EARs accordingly. Note that field trials were limited to pavements containing granite aggregate. Future experiments on sections with differing aggregate type (e.g., limestone, lightweight) should be conducted to determine the impact of aggregate mineralogy on absorption.

The Tack Lifter was not found to be a suitable test method for QC of transverse variability in EARs due to potential to delay chip application. Field investigations suggest that transverse variability is relatively consistent along the length of paving, and hence, should be addressed prior to rather than during construction. Therefore, ASTM D 2995 Test Method B is recommended for QC of transverse variability in EARs. ASTM D 2995 Test Method B consists of measuring the emulsion output rate of individual nozzles, allowing for easy identification and corresponding adjustment of the source(s) of variability.

To allow for in-situ measurements of applied EARs at specific locations along the length of paving, elevated plates and a peel were developed for use in Tack Lifter testing. Elevated plates are placed on the roadway's lane center prior to arrival of the distributor. After emulsion application, elevated plates can be easily and efficiently removed from the roadway using the peel to minimize delays in construction operations. This is of particular importance in chip seal applications where aggregate application quickly follows emulsion application. Elevated plates can be transferred to a leveling table placed off of the roadway and subjected to Tack Lifter testing to determine the applied EAR. It is important to note that elevated plates must be placed in the center of the lane to avoid being crushed by the distributor. However, it is recommended that transverse variability in EARs and the rate by which a pavement absorbs emulsion be addressed prior to construction and hence, measurement of applied EARs in the lane center is deemed sufficient to assess longitudinal variability. Field investigations demonstrate the efficacy of using Tack Lifter tests to assess longitudinal variability in applied EARs. Results indicate applied EARs can vary over relatively short segments of road. Investigations also suggest changes in curvature and / or grade may impact variability in applied EARs. Hence, it is recommended that applied EARs be measured every 0.5 miles along the length of paving and at locations where significant changes in grade and / or curvature are noted.

Based on laboratory and field experiments, a proposed practice for QC of EARs has been developed. The practice includes three procedures: (1) ASTM D 2995 Test Method B for QC of transverse variability in the applied EAR. (2) Tack Lifter tests applied in the wheel path to flat, steel pans and the paving surface on a test pavement section to quantify the rate by which the pavement absorbs emulsion and correspondingly, guide adjustment of the target EAR, (3) Tack Lifter tests conducted on elevated plates following removal from the roadway for assessment of longitudinal variability in the applied EAR.

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1. INTRODUCTION

1.1 Research Needs and Significance

Emulsions are used as tack coats to bond asphalt concrete layers and as a bonding agent for aggregates in chip seals. The rate of emulsion application is critical to the performance of both tack coats and chip seals. In tack coats, emulsion application rate (EAR) affects the bond between two asphalt concrete layers. Improper tack coat application rates can lead to delamination and hence, inadequate load transfer between layers. In chip seals, EAR largely governs aggregate loss and bleeding. It has been demonstrated that field EARs can be highly variable, which is not captured using current measures for quality control (QC). Thus, it has become imperative to develop an improved method for in-situ measurement of EAR in the field along the length of paving to provide QC during construction. Improved QC of EARs will result in prolonged service life, decreased life cycle costs, and enhanced safety.

Emulsion application can vary transversely across a pavement due to variability in emulsion output and fan patterns among distributor nozzles. Emulsion application can also vary longitudinally along the length of paving as a result of fluctuations in distributor speed and flow rates. In addition, the existing paving surface will absorb a fraction of emulsion applied which will be unavailable to act as a bonding agent for aggregate or asphalt concrete placed on top of the emulsion. Thus, it is important to differentiate between total EAR and "effective" EAR available for bonding. The importance of surface absorption is considered in many tack coat and chip seal design methods (e.g., McLeod 1969). However, specified adjustments to EARs to account for surface absorption lack experimental or theoretical basis. Therefore, comprehensive QC of emulsion application should include provisions for assessment of (1) transverse emulsion variability, (2) longitudinal emulsion variability, and (3) the quantity of emulsion absorbed by the paving surface to enable proper adjustment of the target EAR during construction.

Currently, very few methods exist for QC of EARs. The most common method, (which is currently used by NCDOT), consists of measuring the change in the volume of emulsion in the distributer tank before and after paving. This method only provides a measure of the total quantity of emulsion applied over the length of paving and therefore does not allow for capturing variability along the length of paving. Also, by the time the measure is taken, construction is finished on the roadway. Thus, improved QC measures to capture EARs at specific locations along the length of paving are necessary.

1.2 Research Objectives

The objectives of this project were:

1. To identify issues in determining emulsion application rates in the field.
2. To develop a recommended field test for determination of emulsion application rates at specific locations along a roadway for quality control purposes

1.3 Report Organization

The report is organized into 10 chapters and three appendices. Chapter 1 presents the research needs and objectives. Chapter 2 provides a summary of the results of the literature review. Chapter 3 introduces the Tack Lifter as a means for practical and efficient in-situ measurement of emulsion application rates. Chapter 4 provides a summary of laboratory experiments. Chapter 5 presents a summary of field experiments, including recommendations for QC of emulsion absorption by the pavements and longitudinal variability in applied EARs. Chapter 6 presents recommendations for QC of transverse variability in applied EARs. Chapter 7 summarizes the findings and conclusions. Recommendations for future endeavors are provided in Chapter 8. Chapter 9 provides an implementation and technology transfer plan. Chapter 10 provides a list of cited references. Appendix A provides the full literature review. Appendix B contains the proposed practice for QC of EARs based on results presented. Appendix C provides details pertaining to the selection of the sorbent sheet and weight of the Tack Lifter.

2. RESULTS OF LITERATURE REVIEW

The literature review sought to identify existing methods for QC of EARs. In addition, the significance of EAR on the performance of both chip seals and tack coats was investigated along with a review of emulsion distributors and corresponding sources of /variability in field EARs. A brief summary of the results of the literature review is presented herein. The complete, comprehensive literature review is provided in Appendix A.

2.1 Importance of Emulsion Application Rate on Performance

Tack coats are essential for load transfer between pavement layers and thus constitute a critical component of a pavement structure. The tack coat type and application rate are important design considerations. Tack coat failure can occur in two modes: tensile and shear, which can lead to a variety of distresses, including slippage cracking, top-down cracking, premature fatigue cracking, pothole development, and complete delamination. Excessive EARs cause slippage and delamination whereas insufficient EARs can lead to lack of adhesion between layers (Leng et al. 2008, Mohammad et al. 2010, Hakimzadeh et al. 2012).

Performance of pavement surface treatments, such as chip seals, is also known to be significantly affected by EAR. Excessive emulsion application causes bleeding which diminishes skid resistance. Insufficient emulsion application leads to aggregate loss which often results in windshield damage in the short term and raveling of the surface in the longer term. Gurer et al. (2012) conducted a field study of the performance of five chip seals and found that deterioration was highly correlated to how closely actual in-situ emulsion application rates were relative to the target application rate. Furthermore, Kim et al. (2011) conducted a series of laboratory studies using simulated traffic loading which demonstrated the significance of EAR on chip seal performance.

2.2 Sources of Emulsion Application Rate Variability

It has been demonstrated that field EARs can be highly variable (Gurer et al. 2012, West et al. 2005). Emulsion distributor nozzle size, nozzle pattern, distributor pressure, tank temperature, and spray bar height can all affect the accuracy of emulsion application (Gransberg et al. 2005). It is imperative that all of these factors be calibrated regularly to minimize discrepancies between prescribed and actual EARs. However, a survey conducted in 2005 revealed that 25% of agencies in the U.S. do not require calibration (Gransberg et al. 2005).

2.3 Importance of Emulsion Absorption by the Paving Surface

The existing paving surface will absorb a fraction of emulsion applied which will be unavailable to act as a bonding agent for aggregate or asphalt concrete placed on top of the emulsion. Thus, it is important to differentiate between the applied EAR and "effective" EAR available for bonding. The importance of surface absorption is considered in many tack coat and chip seal design methods. This is reflected in NCDOT's guidelines for tack coat application rates detailed in Table 1. Surface absorption is also considered in many chip seal design methods, including the McLeod method (McLeod 1969**)** for which specifications for adjustment of the target EAR based on visual observation of surface conditions are given in Table 2. It can be seen that corrections can be significant, with adjustments up to 0.06 gal/yd^2. While current design procedures recognize the importance of emulsion absorption by the paving surface and provide provisions for corresponding adjustment of the target EAR, adjustments lack theoretical or experimental basis.

Table 1 NCDOT Tack Coat Application Specification

Existing Surface	Target Rate (gal/yd^2)
New Asphalt	0.04 (+/- 0.01)
Oxidized or Milled	0.06 (+/- 0.01)
Concrete	0.08 (+/- 0.01)

Table 2 McLeod Method's Qualitative Existing Pavement Surface Correction Factor (Source: McLeod 1969)

Existing Pavement Surface Texture	Correction (in gal/yd^2)
Black, flushed asphalt surface	-0.06
Smooth, nonporous surface	-0.03
Slightly porous, oxidized surface	0.00
Slightly pocked, porous, oxidized surface	+0.03
Badly pocked, porous, oxidized surface	+0.06

2.4 Existing Methods for Quality Control of Emulsion Application Rates

Very few measures exist for QC of in-situ EARs. Mohammad et al. (2012) conducted an international survey to identify the methods currently used for QC of EAR. The majority of respondents indicated that the change in volume of emulsion in the distributor before and after paving is the only measure used for QC, obtained either through a dipstick reading or volume gauge. Additionally, 27% of respondents reported use of the change in tank weight before and after paving as their QC measure and 18% reported that no QC measure is taken.

The only national standardized procedure which allows for capturing transverse and longitudinal EAR variability is ASTM D 2995: Standard Practice for Estimating Application Rate of Bituminous Distributors (ASTM D2995, 2009). However, only 2% of the participants in Mohammad et al.'s (2012) survey indicated use of ASTM D 2995 for QC EAR. ASTM 2995 includes provisions for two test methods. In the first, the distributer applies emulsion to a standard size tarp placed on the roadway. The tarp is weighed before and after emulsion application to determine EAR. Tarps can be aligned transversely or longitudinally to study the location dependence of emulsion application rate. In the second method, containers are placed directly under each nozzle and distributer releases emulsion for a set amount of time to determine transverse EAR variability. However, the procedure targets calibration at the start of application rather than use along the length of paving because the procedure is relatively time consuming and cumbersome. Caltrans (2009) also has a test specification for EAR QC, "California Test 339" which is essentially a modified version of ASTM D 2995 in which specifications of acceptances are based on residual asphalt rather than EAR.

Figure 1 Depiction of ASTM D 2995 Method A (Source: West et al. 2005)

Figure 2 Depiction of ASTM D 2995 Method B (Source: Krugler et al. 2009)

Several studies have noted issues with ASTM D 2995. Mohammad et al. (2012) reported that the procedure is a “lengthy process and required multiple calibration runs to ensure accuracy and uniformity of tack coat application”. Muench and Moomaw (2008) expressed concern that water can be lost from the emulsion prior to weighing the ASTM D 2995 tarps, making the measurement inaccurate.

Researchers from Spain developed a laboratory prototype device to measure “effective” EARs, considering absorption by the existing surface (Raposeiras et al. 2013). The device consisted of a polypropylene geotextile affixed to a steel plate which was pressed onto a pavement surface after emulsion application. The geotextile absorbed the non-absorbed emulsion on the pavement surface allowing for measurement of the “effective” emulsion application rate. Raposeiras et al. (2013) tried their procedure using several emulsion types, target application rates, and application surfaces with differing macro-textures. They were able to correlate the macro-texture of the existing surface to the amount of emulsion absorbed by the geotextile. However, the study was limited and did not include field testing.

2.5 Summary with Inference on Issues in Determining Emulsion Application Rates in the Field

The importance of EAR on the performance of surface treatments and tack coats has been clearly demonstrated by previous research. However, few methods exist for QC. Existing methods are summarized in Table 3. Based on the literature review, it is evident that the ability to capture transverse variability, longitudinal variability, and “effective” (i.e., non-adsorbed) EAR are critical aspects of EAR QC and hence, the ability of existing methods to perform these tasks is indicated in Table 3. It is evident that very few methods exist to capture the aforementioned factors and none of the identified QC measures can capture all measures of interest. It is inferred that this is largely related to the challenges associated with in-situ measures of EAR. In the case of chip seal construction, aggregate application quickly follows emulsion application and hence, there is very little time available for in-situ EAR measurements. For tack coats, there is a greater delay between the time of emulsion application and that of the subsequent layer of material. However, measurements still may be challenging as emulsions may break rapidly following application. Furthermore, in-situ measurements leave bare spots on the roadway and hence, require patching after the QC test is complete. Thus, there is a need for an improved QC framework.

Table 3 Summary of Existing Methods for Quality Control of EAR

Method	Ability to Quantify Longitudinal Variability?	Ability to Quantify Transverse Variability?	Ability to Quantify "Effective" EAR
Visual Inspection	No	No	No
Weight difference	No	No	No
Volume difference	No	No	No
Dipstick reading before and after paving	No	No	No
ASTM D 2995	Yes	Yes	No
Caltrans 339	Yes	Yes	No
Raposeiras et al. (2013)	Yes	No	Yes

3. TACK LIFTER FOR IN-SITU DETERMINATION OF EMULSION APPLICATION RATES

3.1 Tack Lifter Concept and Device

The literature review highlights the need for a simple and efficient test method to obtain in-situ measurements of EARs during field construction. The "Tack Lifter" has been developed herein to meet this need. A summary of the Tack Lifter is provided herein. Detailed test procedures and device specifics are provided in Appendix B. The Tack Lifter consists of a simple, weighted device that is placed on top of a super-absorbent, foam sheet applied to a paving surface or plate. The absorbent sheet soaks up emulsion applied to either the pan, plate or pavement. The weight of emulsion absorbed by the sheet, combined with the known sheet area, is used to obtain a local EAR measurement. When applied directly to the paving surface, the device measures the effective EAR on the pavement, neglecting emulsions absorbed into the paving surface. When applied to a plate placed on the paving surface prior to emulsion application, the device measures the total applied EAR. The specific components of the "Tack Lifter" are shown in Figure 3 and Figure 4, which include:

1. **Weighted device with handle**: The total weighted device mass is 33 lb (15 kg). The weighted device includes a base and handle (11 lb) plus removable weights (11 lb each). It was determined that 33 lb was the optimal weight because adding weight beyond 33 lb did not lead to significant reduction in variability or absorption. Details pertaining to the experiments and corresponding results used to select the device weight are provided in Appendix C. The weighted device base foot print is 5 in by 5 in. The 5 in by 5 in footprint was selected so that tests could be conducted within the wheelpath if desired.

2. **Sheet**: A super-absorbent sheet is placed on the surface of interest following emulsion application upon which the weighted device is placed. The sheet utilized in Tack Lifter Testing is characterized as "super-absorbent, super-cushioning, polyurethane foam". The sheet has a density of 1.8 lb/ft^3, firmness of 0.6 psi, and absorbs 100% of emulsion applied to

a smooth, non-porous surface. The sheet was selected after evaluating a number of candidate materials. Sheet dimensions are 5 in by 5 in with 0.5 in thickness. Details pertaining to the evaluation of candidate sheet materials are provided in Appendix C.

3. **Frame**: To prevent absorption of emulsion outside of the sheet area, a frame is applied to the paving surface following emulsion application but before sheet application to seal the surface. The frame is comprised of steel and includes a rubber, pliable gasket along the edges applied to the paving surface. The gasket conforms to the surface texture, sealing the area of interest from intrusion of additional emulsion. The inner dimensions of the gasket are 5.25 in by 5.25 in to allow a small gap for placement of the Tack Lifter sheet.

4. **Flat Pan**: To allow for measurement of applied EAR in the wheel path only. Following emulsion application, the frame, sheet, and weighted device are plated on the pan to allow for measurement of the applied EAR. Flat pans should be comprised of steel and have a dimension of 8 in by 8 in. The thickness of the pan can vary but is recommended to be no more than 0.25 in.

5. **Elevated Plate**: For tests conducted to determine the applied EAR at specific locations along the length of paving, an elevated plate is placed on the paving surface prior to emulsion application. Following emulsion application, the elevated plate is removed from the paving surface prior to application of the frame, sheet, and weighted device. The elevated plate has a 7 in bt 7in footprint with a 3/8" high lip to prevent loss of emulsion and ½" long legs to allow insertion of the peel.

6. **Peel**: The peel is used to easily remove the elevated plate from the paving surface when making applied EAR measurements. The peel allows for efficiently removal of plates from the paving surface while keeping the plate level to minimize emulsion flow during transit.

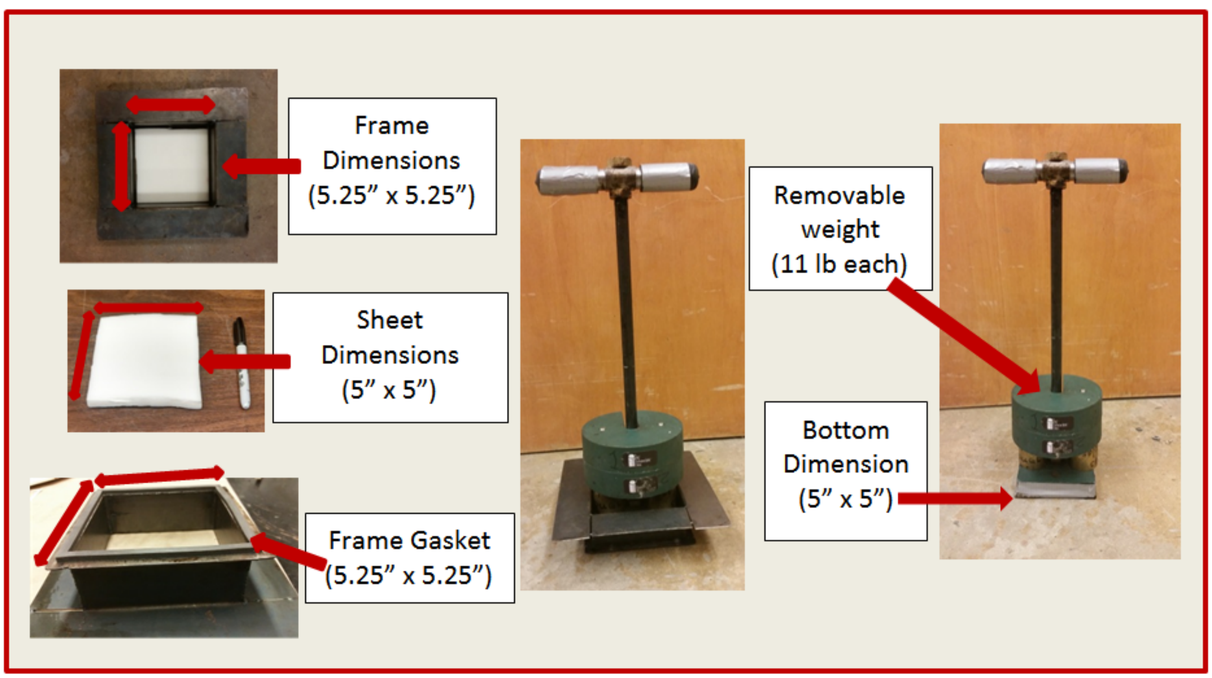

Figure 3 Tack Lifter components.

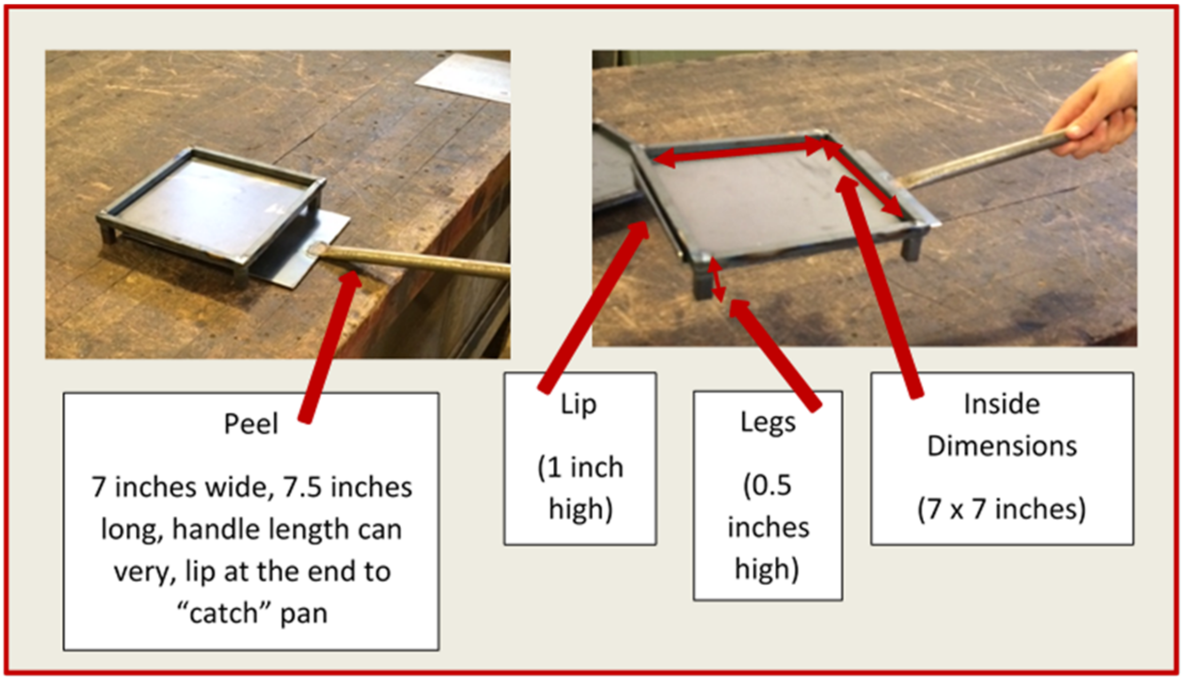

Figure 4 Elevated plate components.

3.2 Tack Lifter Procedure for Measurement of the Rate by which a Pavement Absorbs Emulsion

The difference in results of Tack Lifter tests conducted on a steel pan placed on the roadway prior to emulsion application (i.e., indicative of the applied EAR) and tests conducted on the adjacent paving surface (i.e., indicative of the effective EAR) can be used to determine the rate by which the pavement absorbs emulsion. The procedure used to measure the rate by which a pavement absorbs emulsion is depicted in Figure 5 and summarized herein. The detailed procedure is provided in Appendix B, Test Method B. First, a steel pan is placed on the paving surface prior to the arrival of the emulsion distributor (Figure 5(a)). Immediately following emulsion application, frames are placed on the pan (while still in place) and on the paving surface directly in front of the pan (Figure 5(b)). Next, pre-weighed sheets are placed in the center of each frame (Figure 5(c)). The weighted device is placed on top of each sheet for 30 seconds to allow for emulsion absorption (Figure 5(d)). Note that 30 seconds was found to allow sufficient time for maximum emulsion absorption. The sheets are then removed from the paving surface and weighed to determine the mass of emulsion absorbed (Figure 5(e)). Mass of emulsion absorbed is converted to EAR using the emulsion density and area of the sheet. The emulsion absorbed by the sheet place on the paving surface provides the effective EAR and the emulsion absorbed by the sheet placed on the pan provides the applied EAR. Thus, the difference between applied and effective EARs provides rate of emulsion (gal/yd^2) absorbed by the paving surface.

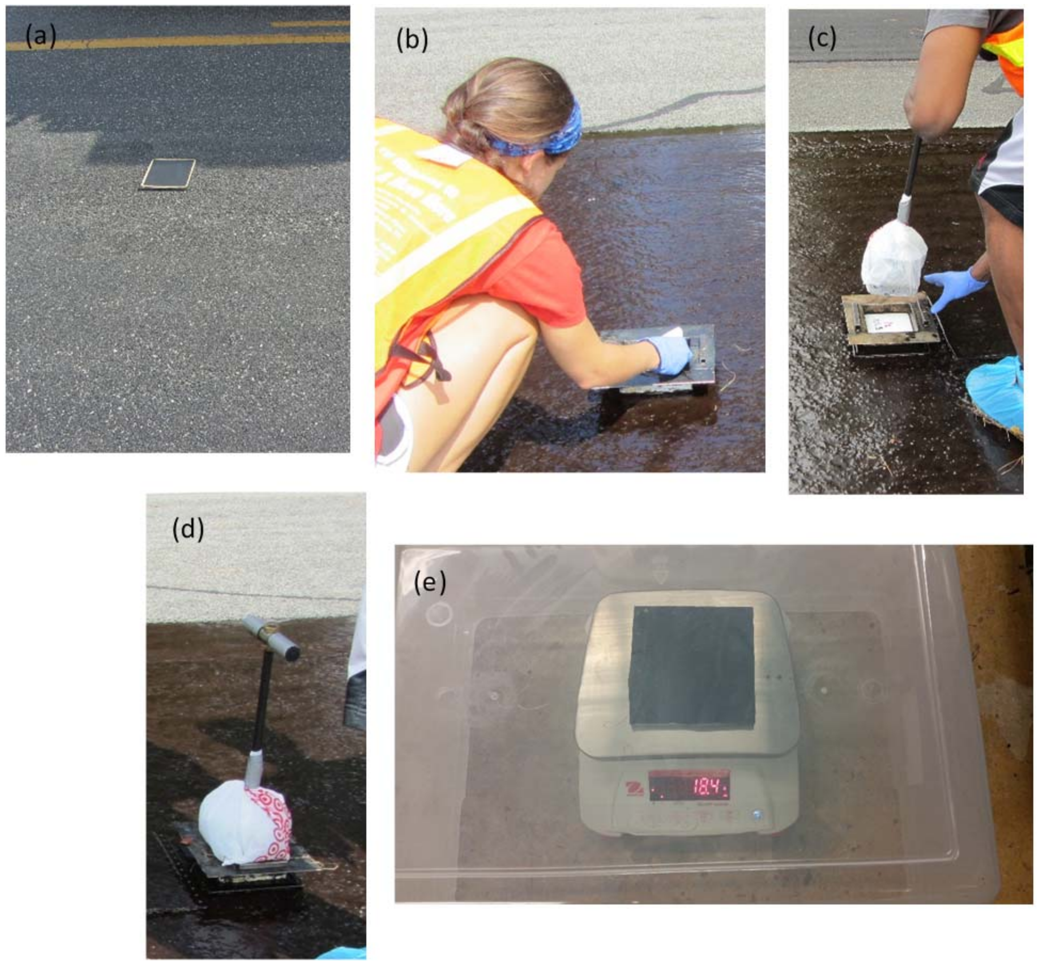

Figure 5 Tack Lifter testing in the field on the surface, including steps (a) placement of pan before paving, (b) placement of the sheet after the frame to the surface, (c) placement of the Tack Lifter on the sheet (d) Tack Lifter testing and (e) weighing of Tack Lifter sheet

Note that flat pans are recommended for use in Tack Lifter tests used to evaluate emulsion absorption by the paving surface. As will be detailed later in the report, it is ultimately recommended that measurements of absorption be conducted in the wheel path prior on a test section prior to paving. Pavements undergo the most damage in the wheel paths and hence, achieved the desired effective EAR in the wheel path is most critical. Testing in the wheel path requires use of flat pans because distributor wheels would crush the legs on the elevated plates.

3.3 Tack Lifter Procedure for Measurement of the Applied EAR

To obtain in-situ measurements of the applied EAR during construction, Tack Lifter tests are conducted on an elevated plate placed on the paving surface prior to emulsion application. A brief overview of the test procedure is provided herein. The detailed procedure is provided in Appendix B, Test Method C. To minimize delays in aggregate application (in chip seal applications), elevated plates are placed on the paving prior to emulsion application and then quickly removed from the paving surface after emulsion application using the peel. Tack Lifter tests are then conducted off of the paving surface on a leveling table, allowing construction operations to proceed without delay. The procedure conducted once the elevated plate is on the level table follow that used to measure EARs as detailed in the previous section. Correspondingly, the procedure for measurement of applied EAR using the Tack Lifter is depicted in Figure 6. Following emulsion application, the peel is placed under the elevated plate as shown in Figure 6(a). Next, the peel is lifted while keeping the plate as level as possible as shown in Figure 6(b). The peel is used to transport the elevated plate to a level table on the side of the roadway as shown in Figure 9(c). Steps (a) through (c) only take 10 to 15 seconds and thus, delays in aggregate spreading following emulsion application during chip seal construction are minimal. The Tack Lifter frame, sheet, and weighted device are then placed on top of the elevated plate as shown in Figure 6(d). The Tack Lifter sheet is subsequently removed and weighed to determine the applied EAR as shown in Figure 6(e).

Figure 6 Tack Lifter testing in the field using elevated plates, including steps (a) placement of peel under elevated plate, (b) lifting elevated plate, (c) placement of elevated plate on level table and (d) Tack Lifter testing and (e) weighing of Tack Lifter sheet

Note that use of flat steel pans was also considered for measurement of EARs during construction. However, in order to remove the flat steel pans from the paving surface, they must be tilted, which leads to flow of the emulsion on the pan. Therefore, the elevated plate and peel were developed to allow for easier removal from the pavement. The only limitation of the elevated plate method is that the plate must be placed in the lane center as wheels would crush the legs of the plate. However, findings of the research herein indicate that transverse variability of EAR should be checked prior to construction, (which will be discussed later in Chapters 5 and 6) and thus, measuring EARs along length of paving at a single transverse location is not perceived to be problematic.

4. LABORATORY EVALUATION OF THE TACK LIFTER

4.1 Laboratory Evaluation of Tack Lifter Applied to Steel Pan for Determination of Applied Emulsion Application Rates

Verification that the Tack Lifter has the capability to absorb all emulsion applied to a steel pan was conducted by applying emulsion to a smooth, impermeable steel pan surface in the laboratory and then applying the Tack Lifter device. Preliminary Tack Lifter trials on a pan were conducted using three emulsion types: CRS-2, CRS2-L, and CRS-1H. Testing was conducted using an EAR of 0.25 gal/yd^2 for CRS-2 and CRS-2L emulsions to represent a typical chip seal EAR, whereas an EAR of 0.06 gal/yd^2 was used for testing the CRS-1H emulsion, representative of a typical tack coat EAR. Testing was conducted at 25°C (77°F). The weight of emulsion on the surface was monitored during application in order to control the EAR. EARs measured using the Tack Lifter are presented in Figure 7(a). Results demonstrate close agreement between the applied and measured EARs, especially considering there could be minor non-uniformity in actual emulsion application. Thus, it is concluded that the Tack Lifter absorbs 100% of emulsion applied to a smooth surface. This conclusion is supported by the photograph in Figure 7(b), which shows a steel pan after emulsion application and subsequent Tack Lifter testing. These results suggest that Tack Lifter tests applied to a steel pan can be used to measure applied EARs in the field. Furthermore, results suggest the difference between results of Tack Lifter tests applied to steel pans and paving surfaces can be attributed to emulsion absorption into the paving surface.

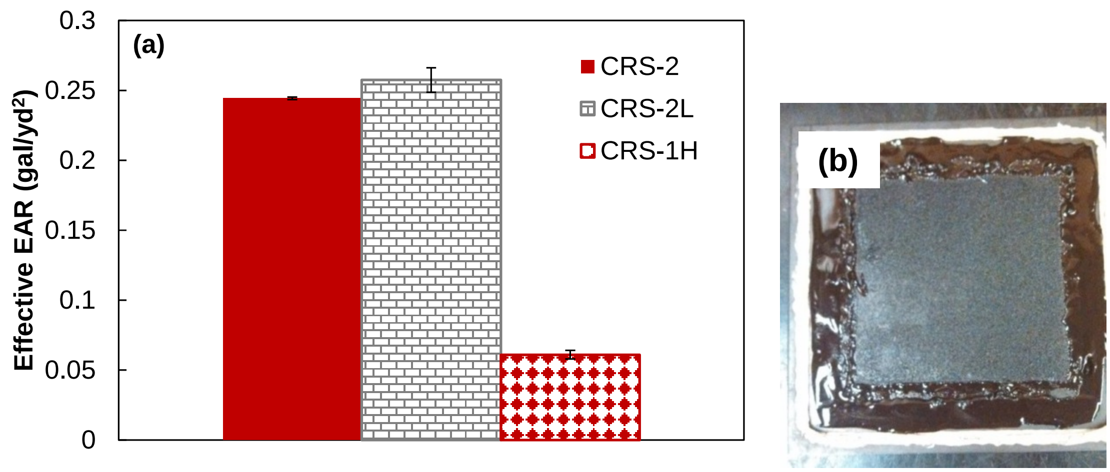

Figure 7 (a) Tack lifter measured EARs on pan (b) Photo of pan after Tack Lifter test.

4.2 Laboratory Evaluation of Tack Lifter Applied to Paving Surfaces for Determination of Effective Emulsion Application Rates

4.2.1 Experimental Plan

A set of laboratory experiments were conducted to evaluate the ability of the Tack Lifter to capture effective EARs and study the influence of various factors on emulsion absorption by pavements. Table 1 summarizes the experimental plan. The experimental plan included assessment of three surface types: Hot-mix Asphalt (HMA), microsurfacings, and chip seals with varying textures. For HMA and chip seal surfaces, surfaces with varying textures were obtained as indicated in Table 4. Three emulsion types were evaluated: CRS-2, CRS-2L, and CSS-1H. Four EARs were considered to reflect both typical chip seal and typical tack coat conditions: 0.35, 0.25, 0.08, and 0.04 gal/yd^2. In addition, a limited number of experiments were conducted at varying temperature conditions. Note that in all tests, emulsion conditioned at 60°C and thus, temperatures listed reflect the temperature of the application surface, not the emulsion. The experimental plan included two components: (1) surface texture measurements and (2) Tack Lifter testing. For each condition, between 2 and 6 replicates were conducted, depending on the availability of samples.

Table 4 Laboratory Experimental Plan

<table>
<tr><th>Surface Type</th><th>HMA Smooth</th><th>HMA Rough</th><th>Microsurfacing</th><th>Chip Seal Trafficked, Bled</th><th>Chip Seal Trafficked, Unbled</th><th>Chip Seal Un-trafficked</th></tr>
<tr><td rowspan="3">Target EARs</td><td rowspan="2">0.08 gal/yd^2 (CSS-1H)</td><td>0.04 gal/yd^2 (CSS-1H) (25°C)</td><td rowspan="3">0.08 gal/yd^2 (CSS-1H and CQS-1H) (25°C)</td><td rowspan="3">0.25 gal/yd^2 (CRS-2L) (15°C, 25°C, and 35°C)</td><td rowspan="2">0.25 gal/yd^2 (CRS-2L) (25°C)</td><td rowspan="2">0.25 gal/yd^2 (CRS-2L & CRS-2) (25°C)</td></tr>
<tr><td>0.08 gal/yd^2 (CSS-1H) (25°C)</td></tr>
<tr><td>0.25 gal/yd^2 (CRS-2L)</td><td>0.25 gal/yd^2 (CRS-2L) (25°C)</td><td>0.35 gal/yd^2 (CRS-2L) (25°C)</td><td>0.35 gal/yd^2 (CRS-2L) (25°C)</td></tr>
</table>

4.2.2 Surface Texture Characterization

Prior to Tack Lifter testing, the surface texture of each specimen was quantified using a laser developed by NCSU and the standard sand patch method (ASTM E 965). The sand patch method quantifies surface texture using Mean Texture Depth (MTD) which is calculated based on the diameter of a circle formed by spreading a known volume (V) of sand over the paving surface, spreading it using a circular motion with a flat disk, and measuring the diameter at four different radial locations. Four replicates are conducted on each surface. The average of all measurements of the diameter (D) is used to calculate Mean Texture Depth (MTD) shown in Equation 1.

$$MTD = \frac{4V}{\pi D^2} \tag{1}$$

The laser profilometer quantifies surface texture by measuring the distance between a laser sensor and the pavement surface at varying longitudinal and transverse locations (Adams and Kim 2014). The stationary profilometer includes a point laser with adjustable resolution. For this study, a laser scan area of 100 mm (3.9 in) by 100 mm (3.9 in) was utilized for all surfaces with 0.5 mm (0.02 in) resolution (Im, 2013). Scanning time was approximately six minutes. Surface texture is quantified from laser results using Mean Profile Depth (MPD) defined in Equation 2 as specified in ASTM E1845-09: Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth (ASTM E1845, 2009). Reported MPD values correspond to the average MPD of each line of scanning.

$$MPD = \frac{(\text{Peak Level 1st}) + (\text{Peak Level 2nd})}{2} - \text{Average Level} \tag{2}$$

The compiled correlation between sand patch and laser surface texture results for all surfaces analyzed (HMA, microsurfacings, and chip seals) is presented in Figure 8. It can be seen that there is a strong correlation between laser and sand patch results, with an R^2 of 0.94. Furthermore, there is little difference in the magnitude of texture depth measured using the laser and sand patch methods. On average, the sand path MTD is approximately 10% higher than the laser MPD. The advantages of the laser are that it does not involve operator variability and allows for analyzing a larger area than the sand patch test as the dimensions of the scan area can be changed unlike the sand patch in which the area measured is a function of the amount of sand and the surface texture. In other words, MPD is measured from a set scan area (in our case 100mm by 100mm) and in the sand patch the area over which texture is measures is dictated by the diameter of the sand patch. However, the sand patch has significant practical advantages over the laser. It is standardized and much quicker to perform in the field than the laser.

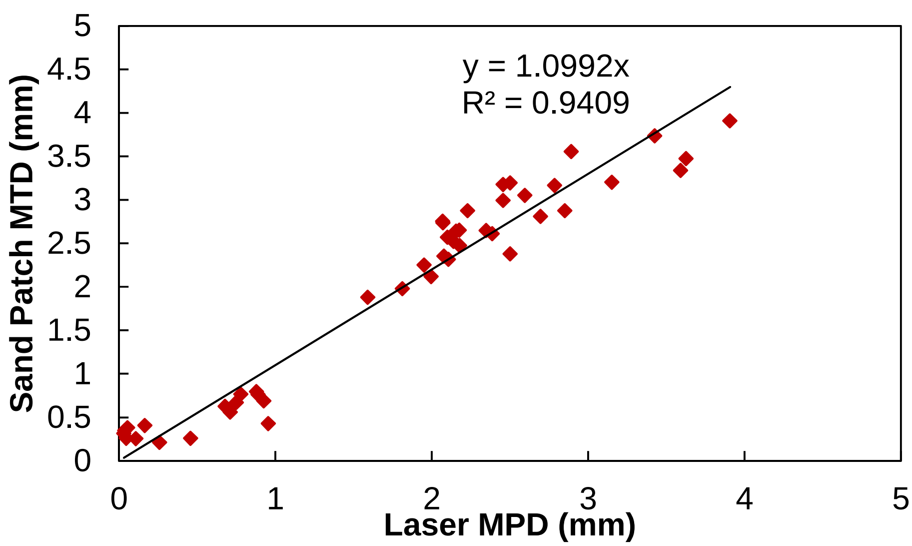

Figure 8 Correlation between sand patch and laser results

The laser takes approximately six minutes to scan a sample. In contrast, based on the research teams' experience, the sand patch test, including replicates, can be conducted in less than five minutes. In addition, the laser requires relatively expensive instrumentation compared to the sand patch method and requires post processing using a computer whereas the sand patch results can quickly be analyzed in the field. Therefore, the research team deems the sand patch method advantageous for routine use in the field over the NCSU laser to quantify surface texture. Thus, subsequent surface texture results presented reflect sand patch test results except in cases where only laser measurements were made.

4.2.3 Tack Lifter Testing

Prior to emulsion application, specimen areas were measured and the corresponding mass of emulsion required to reach the target EAR was calculated. Emulsion was applied as uniformly as possible. For tack coat EARs, a paint sprayer (Figure 9(a)) was used to apply emulsion uniformly. For chip seal EARs, emulsion was spread as evenly as possible with the aid of a brush. Following emulsion application, Tack Lifter testing was conducted as quickly as possible. Tack lifter sheets were weighed immediately after removal from the application surface to minimize the possibility for water loss. The Tack Lifter sheet is pliable and thus conforms to the large, outward macro-texture of surfaces, but does not penetrate surface pores as evident by samples photographs following testing in Figure 9(d) and (e).

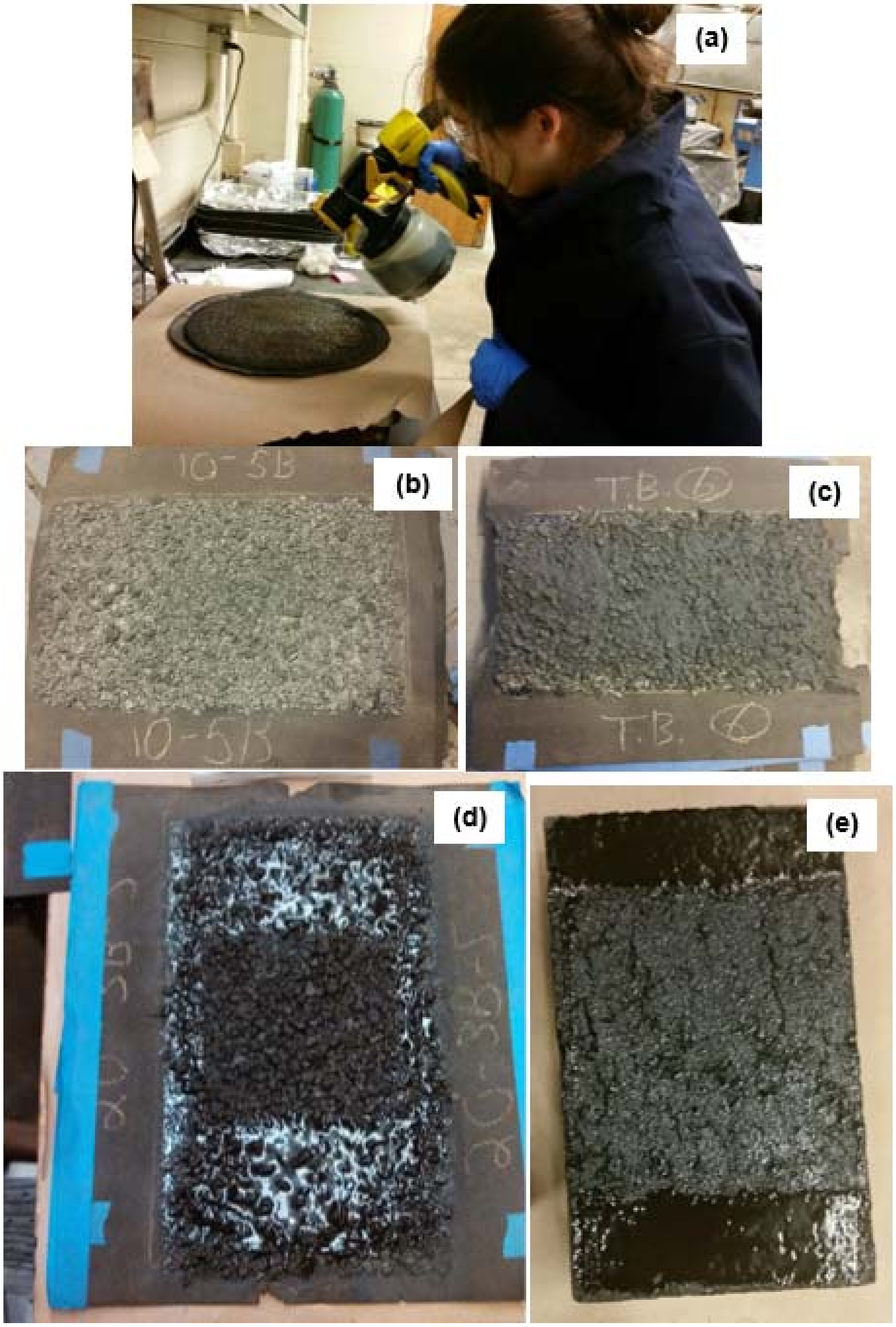

Figure 9 (a) Paint sprayer emulsion application, (b) Trafficked, un-bled chip seal sample prior to testing, (c) Trafficked, bled chip seal sample prior to testing, (d) Chip seal surface after testing, and (e) HMA surface after testing.

4.2.4 Results

4.2.4.1 Effect of Surface Texture on Tack Lifter Results

To evaluate the effect of surface texture on "effective" EARs measured by the Tack Lifter, tests were conducted on varying surfaces using typical EARs for tack coats and chip seals. To reflect typical chip seal emulsion application, a CRS-2L was applied on HMA and chip seal surfaces at a target EAR of 0.25 gal/yd^2. To reflect typical tack coat application, a CSS-1H emulsion was applied to HMA surfaces at a target EAR of 0.08 gal/yd^2.

Figure 10(a) and (b) show results of CRS-2L emulsion applied to surfaces of varying texture at a target application EAR of 0.25 gal/yd^2. Figure 10(a) shows the comparison between surface texture and the percentage of applied emulsion absorbed by the Tack Lifter sheet (i.e., percentage of emulsion not absorbed by the surface). Error bars are included to indicate variability of surface texture among samples in a given category and in measured Tack Lifter emulsion absorption. The error bars displayed are the standard error. Standard error is calculated by dividing the standard deviation by the square root of the number of samples. It should be noted that in some cases emulsion absorbed by the Tack Lifter exceeds 100%, which can be attributed to slight non-uniformity in emulsion application. Figure 10(b) shows the comparison between “effective” EAR measured by the Tack Lifter and the actual applied EAR for CRS-2L at 0.25 gal/yd^2 EAR. Error bars are included to demonstrate inherent variability in the applied EARs and Tack Lifter effective EARs. Trends in Tack Lifter results amongst chip seal surface types match intuition: a higher MPD (i.e., rougher texture) leads to greater emulsion absorbed by the surface. Smaller differences between applied and Tack Lifter effective EARs exist for bled surfaces than un-bled trafficked or un-trafficked surfaces, which matches expected trends as bled surfaces contain few bare aggregate surfaces and surface pores and thus, are not anticipated to absorb a significant amount of emulsion. Furthermore, un-trafficked samples show evidence of higher surface absorption compared to un-bled trafficked samples which matches expectations. Un-trafficked surfaces contain a significant amount of bare aggregate surfaces and pores between aggregate particles which are not significantly embedded into the existing emulsion residue and thus, give significant opportunity for the applied emulsion to be absorbed and consequently unavailable for bonding to materials applied on top of the emulsion (e.g., additional layer of aggregate).

Trends in Tack Lifter results among rough and smooth HMA surfaces in Figure 10(a) and (b) also match expected trends with rougher texture leading to higher differences between applied and Tack Lifter measured effective EARs. It should also be noted that it is not possible to directly compare trends in surface absorption among chip seals and HMA surfaces. Results indicate that the MPDs of the HMA surfaces are significantly lower those of chip seal surfaces (i.e., HMA surfaces are smoother). However, the amount of emulsion absorbed by HMA is comparable to chip seals. Inherent differences between the mechanisms of emulsion absorption in chip seal an HMA surfaces preclude direct comparison between surface texture and Tack Lifter results of the two surface types. Chip seal surfaces consist of a single layer of aggregate embedded in emulsion residue. Emulsion can be absorbed into the surface of bare aggregate surfaces or into voids between embedded aggregate. In contrast, HMA is a mixture of aggregate and asphalt with air voids. While HMA surfaces are smooth compared to chip seals, surface porosity offers significant opportunity for emulsion absorption compared to chip seals which do not contain surface pores.

The results of CSS-1H emulsion applied to HMA surfaces of varying texture at a target applied EAR of 0.08 gal/yd^2 are shown in Figure 10(c) and (d). Figure 10(c) shows the comparison between surface texture and the percentage of applied emulsion absorbed by the Tack Lifter. Figure 10(d) shows the comparison between "effective" EAR measured by the Tack Lifter and the actual applied EAR. Error bars are included to demonstrate variability in surface textures amongst specimens, applied EARs, and measured effective EARs. Note that precise application of low EARs, such as 0.08 gal/yd^2, is very difficult in the laboratory. Correspondingly, it can be noted that applied EAR results for a target EAR of 0.08 gal/yd^2 are closer to 0.09 gal/yd^2 on average. Results demonstrate rougher HMA surface texture leads to a lower effective EAR. These results indicate the Tack Lifter could be used as a tool to identify how applied EARs should be adjusted to account for surface absorption.

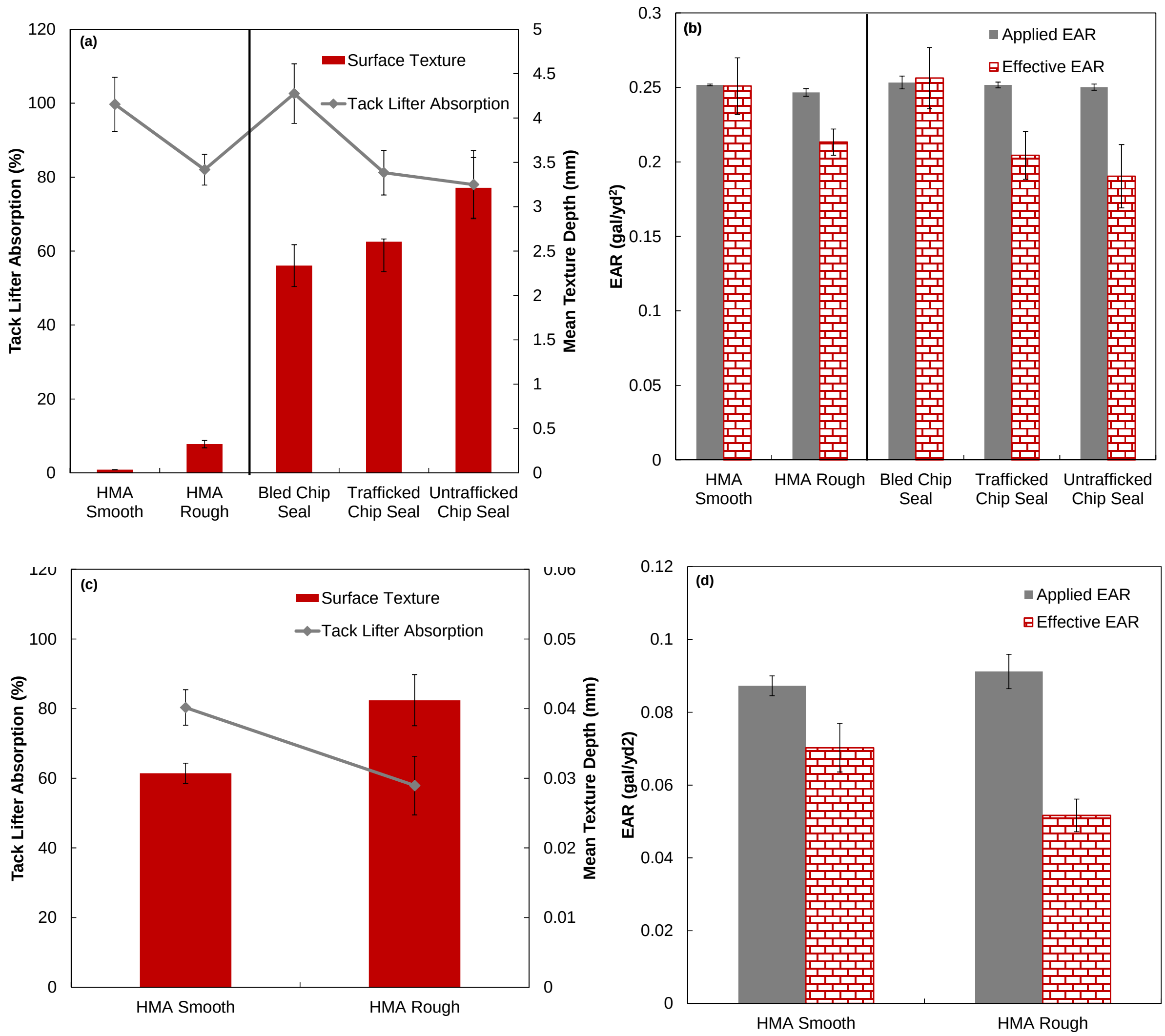

Figure 10 Effect of surface texture on Tack Lifter results for 0.25 gal/yd^2 EAR: (a) comparison between surface texture and Tack Lifter emulsion absorption, (b) comparison between applied and effective EARs, and for 0.08 gal/yd^2 EAR: (c) comparison between

surface texture and Tack Lifter emulsion absorption, (d) comparison between applied and effective EARs.

Note that microsurfacing surfaces were also evaluated because an abundant supply of samples was available from past research efforts at NCSU. However, results were only used for limited analyses and hence, are not presented in this section. The MTD values of all microsurfacing specimens were all similar, precluding assessment of surface texture effects on Tack Lifter results for microsurfacings. Microsurfacings do not represent a typical application surface to which emulsion would be applied. Microsurfacing surfaces include a very fine gradation and are un-compacted and thus, surface void structure differs from typical HMA and hence, results of microsurfacing, HMA, and chip seals could not be compared. Thus, microsurfacing specimens were only used in the context of studying the effect of emulsion type on absorption by the paving surface to EAR.

4.2.4.2 Effect of Emulsion Application Rate on Tack Lifter Results

To allow for assessment of the sensitivity of Tack Lifter results to EAR, a series of Tack Lifter tests with varying applied EARs were conducted on rough HMA surfaces, un-bled trafficked and un-trafficked chip seal samples, which represent conditions of the two surface types that offer greatest opportunity for emulsion absorption. Both tack coat and chip seal applications are common on HMA surfaces. Hence, typical conditions for both applications were considered. Target applied EARs of 0.04 gal/yd^2 and 0.08 gal/yd^2 reflect typical tack coat EARs, whereas 0.25 gal/yd^2 reflects a typical chip seal EAR. CSS-1H emulsion was used for tack coat EARs, whereas CRS-2L was used for the chip seal EAR. A comparison between applied and Tack Lifter measured effective EARs for varying EARs applied to rough HMA surfaces are presented in Figure 11(a). Results indicate the difference between applied and effective EARs decreases as applied EAR increases, which matches expected trends. Use of a lower EAR will allow a greater percentage of the total emulsion applied to be absorbed into the surface. It should be noted at the lower EARs of 0.08 and 0.04 gal/yd^2 of the applied EAR differs somewhat from the target. Precise application of low EARs in the laboratory is difficult due to the small quantity of emulsion applied.

To evaluate the effect of applied EAR on effective EAR on chip seal surfaces, Tack Lifter tests were conducted using CRS-2L emulsion applied to both un-bled trafficked and un-trafficked chip seal samples at two rates: 0.25 gal/yd^2 and 0.35 gal/yd^2. A comparison between applied and Tack Lifter effective EARs is shown in Figure 11(b). Results indicate that an applied EAR of 0.35 gal/yd^2 leads to a lower difference between measured and effective EAR for a given chip seal surface condition than an applied EAR of 0.25 gal/yd^2. Results match intuitions as the surface absorption is fixed. Thus, a surface will become saturated at a lower percentage of the applied emulsion as the applied EAR increases.

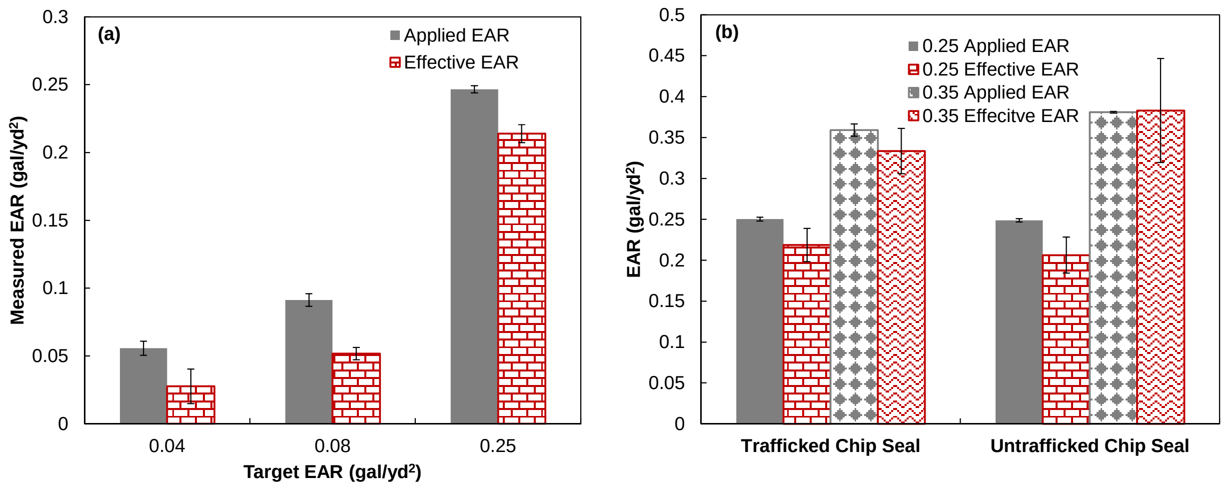

Figure 11 (a) Effect of EAR on the difference between applied and effective EARs for rough HMA surfaces, and (b) Effect of EAR on the difference between applied and effective EARs for typical chip seal surfaces.

4.2.4.4 Effect of Emulsion Type on Tack Lifter Results

To evaluate the effect of emulsion type on surface absorption, a comparison was made between Tack Lifter results of CRS-2L and CRS-2 applied to un-trafficked chip seal samples at a target applied EAR of 0.25 gal/yd^2 to reflect a typical chip seal EAR. In addition, CSS-1H and CQS-1H emulsion s were applied to microsurfacing samples at a target EAR of 0.08 gal/yd^2 to reflect a typical tack coat EAR. Emulsion viscosity may affect the amount of emulsion absorbed by a surface. Higher viscosity emulsions are less likely to penetrate surface pores. Results of the application of two emulsion types to chip seal samples are presented in Figure 12(a). Results indicate little difference between the percentages of applied emulsion absorbed by the Tack Lifter for the two emulsion types. Results of the application of two emulsions at a typical tack coat EAR to microsurfacing samples are shown in Figure 12(b). The average amount of emulsion absorbed by the Tack Lifter sheet is higher for the CSS-1H emulsion. However, the error bars from testing the two emulsion overlap and thus, there is no significant difference between results of the two emulsion types.

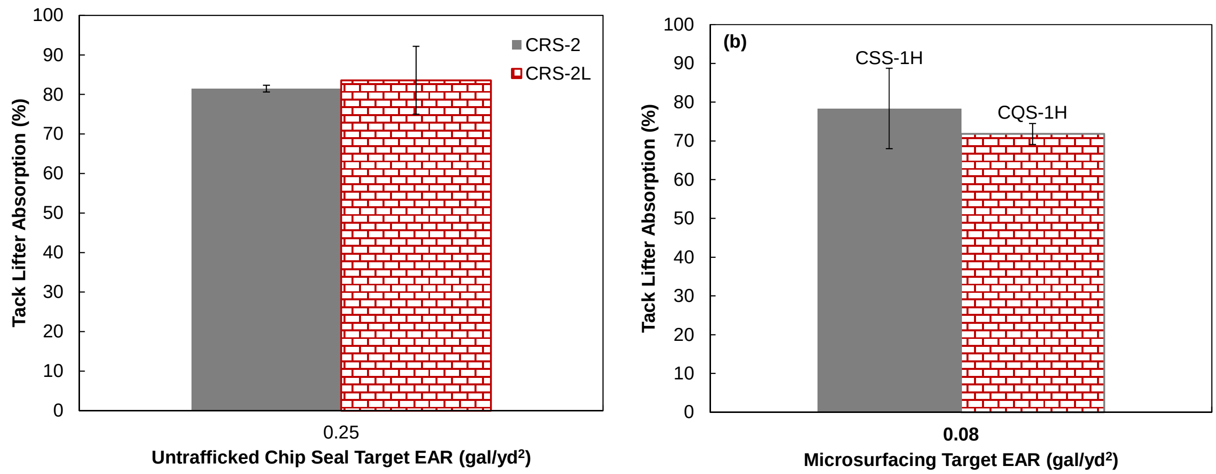

Figure 12 (a) Effect of emulsion type on untrafficked chip seal samples applied at 0.25 gal/yd^2 and (b) Effect of emulsion type on microsurfacings applied at 0.08 gal/yd^2

4.2.4.4 Effect of Temperature on Tack Lifter Results

To evaluate the effect of temperature on "effective" EARs measured by the Tack Lifter, CRS-2L emulsion was applied to trafficked chip seal samples conditioned at three temperatures: 15°C, 25°C, and 35°C. Note the temperature of the applied emulsion was 60°C in all instances and only the temperatures of the application surfaces differed. The target EAR was 0.25 gal/yd^2. Results are show in Figure 13. Results indicate that as the application surface temperature increases, the amount of emulsion absorbed by the paving surface increases somewhat (and hence, effective EAR measured by the Tack Lifter decreases. This is intuitive as the higher temperature of the application surface will lead to less of a temperature drop of the emulsion upon application and thus, allow emulsion to seep into the surface more freely. Note that the effect of temperature study was relatively limited and thus, merits further investigation in future research efforts.

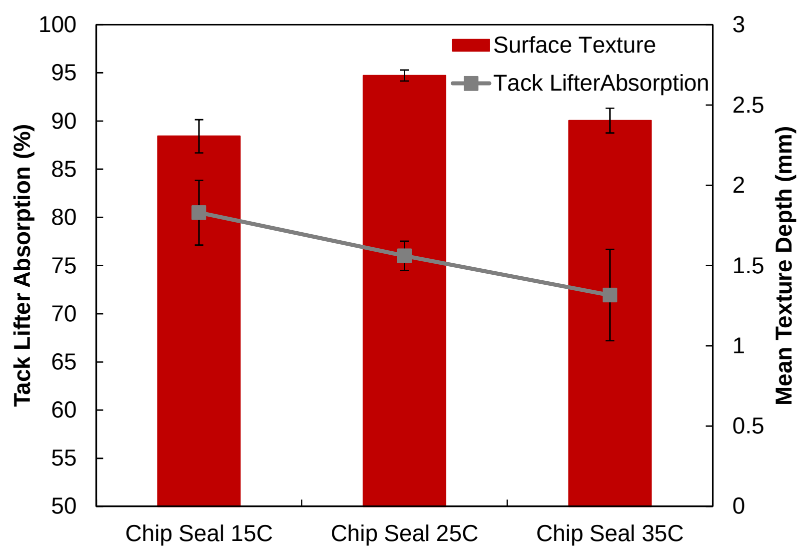

Figure 13 Chip seal samples at various temperatures showing tack lifter absorption and surface texture

5. TACK LIFTER FIELD TRIALS

5.1 Comparison between ASTM D2995 Test Method A and Tack Lifter

5.1.1 Summary of Experiments

Initial field experiments were conducted to compare the use of the Tack Lifter to that of ASTM D 2995 Method A for measurement of EARs at specific locations along the length of paving. Note that the intent of the standardized procedure detailed in ASTM D 2995 is calibration of the emulsion distributor along a short section of paving. However, the ASTM D 2995 Method A pads can also theoretically be placed specific locations along the length of paving to obtain spot checks of EAR. Two field trials were conducted to assess use of the Tack Lifter versus ASTM D 2995 Test Method A pads for in-situ measurements of EAR in the field. In the first field trial, ASTM D 2995 results were compared to “effective” EAR measurements obtained by applying the Tack Lifter sheets to the paving surface. In the second field trial, Tack Lifter tests applied to pans placed on the paving surface prior to emulsion application were used as an additional measure of applied EARs. Recall that the Tack Lifter sheet absorbs 100% of emulsion applied to a steel plan as detailed in Chapter 4.1. In each field experiment, EAR measurements were conducted at two locations along the length of paving.

Table 5 Summary of Field Trials completed for ASTM D2995 and Tack Lifter Comparison

Location	Date	Existing Surface Condition	Target EAR (gal/yd^2)	Remarks
Granville County, NC	8-27-14	Asphalt concrete with moderate block cracking and raveling	0.35	Windy day
Zebulon, NC	9-17-14	Chip seal (7 years old) with high roughness	0.35	Additional Results in Appendix C

The experimental layouts for each location of testing are depicted in Figure 14 and Figure 15 for the first and second field trials, respectively. In the first field trial, two ASTM D 2995 pads and two Tack Lifter tests applied to the surface were used for EAR measurements. Note that the Tack Lifter sheets were applied to the right and left of the ASTM D 2995 sheets in the first field trial which could impact trends if transverse variability in emulsion application exists. In the second field trial, the Tack Lifter tests were conducted in the same transverse location as the ASTM D 2995 geotextile pad was placed and hence, results are directly comparable. Also note that these field trials preceded the development of the elevated plates and thus, a flat steel pan was used and the Tack Lifter was applied to the pan while still in place on the roadway. Photos of the existing surface conditions corresponding to the two field trials are provided in Figure 16.

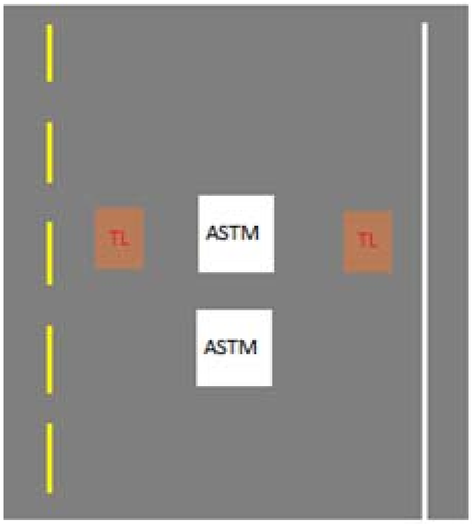

Figure 14 Experimental layout for 8/27/14 field trial

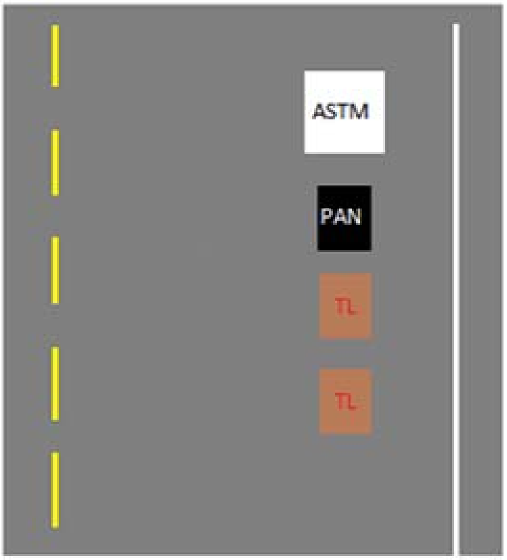

Figure 15 Experimental layout for 9/17/14 field trial

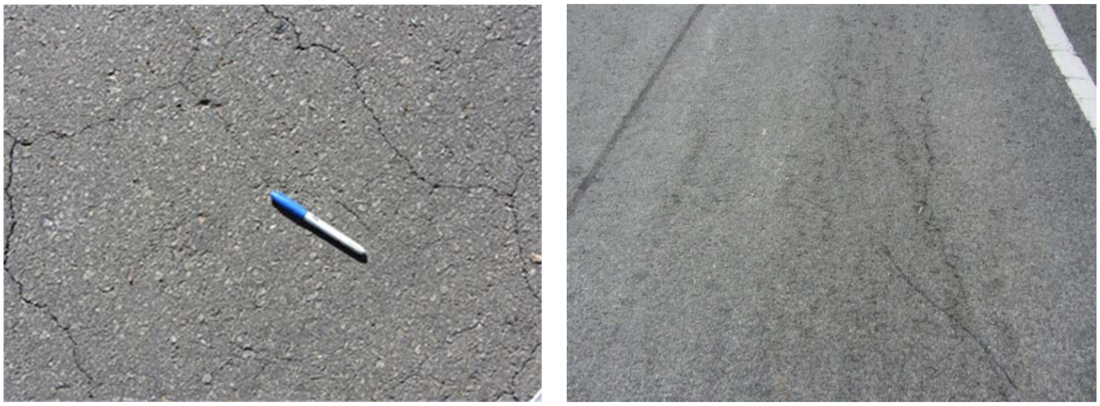

Figure 16 (a) Surface condition of 8/27/14 field trial and (b) Surface condition of 9/17/14 field trial

5.1.2 Field Trial Conducted on 8/27/14

Results from the first field experiment are shown in Figure 17. Results indicate that use of ASTM D 2995 Method A pads for EAR measurement is not reliable because measurements made on adjacent pads (in the same transverse location) are highly variable. There are several possible sources of variability in ASTM D 2995 Method A tests. The pads are relatively large (12”x12”) and difficult to handle. Emulsion is easily lost while transporting pads from the paving surface to the scale for weighing via dripping from the pad edges. In addition, it was windy during field construction, which forced debris from the side of the roadway (e.g., sand, pine needles) onto the ASTM D 2995 pads, compromising measurements. In contrast, Tack Lifter results applied to the paving surface appear reasonable. Measured “effective” EARs are somewhat lower than the target application EAR of 0.35 gal/ yd^2. It is anticipated that a portion of the applied emulsion will be absorbed into the pores of the paving surface and thus, “effective” EAR measurements appear reasonable. Furthermore, results are less variable than those of the ASTM D 2995 Method A results even though the Tack Lifter “replicate” results contained embedded variability associated with transverse variability in surface texture and/or emulsion application since the tests were conducted at different transverse locations. Also note that the Tack Lifter sheets have a much higher absorption capacity than the ASTM D 2995 Test Method A geotextile pads and thus, dripping of emulsion is not of concern. The relatively small size of the Tack Lifter sheets (5”x5”) also makes them much easier to handle than the ASTM D 2995 Test Method A pads.

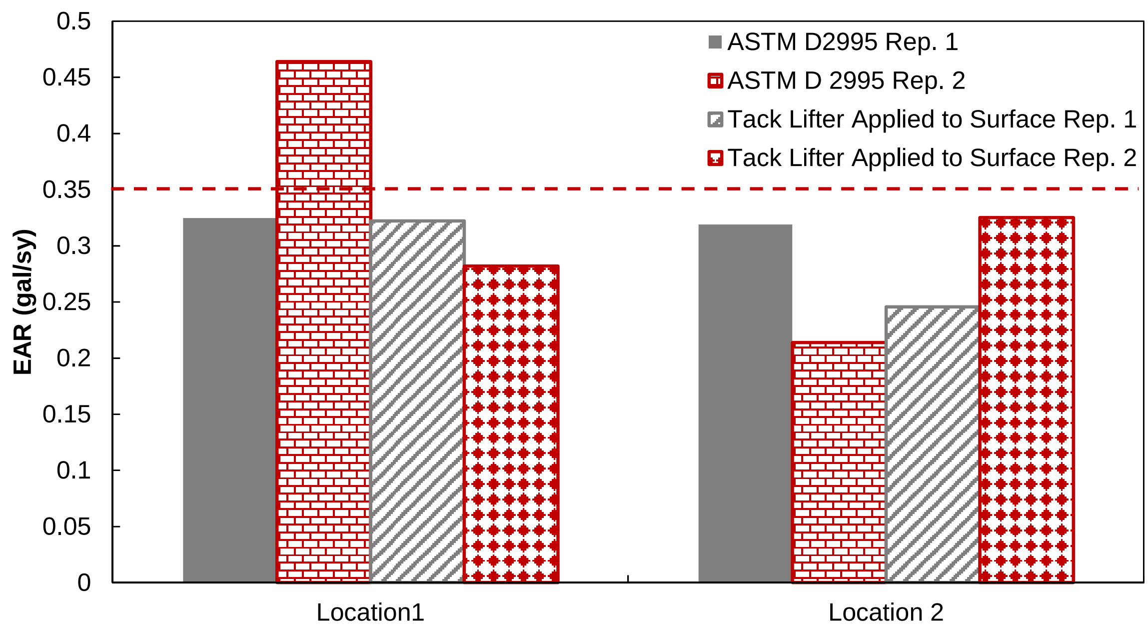

Figure 17 Comparison between results of ASTM D 2995 and Tack Lifter applied to paving surface (8/27/14)

Figure 18 provides a photo of the paving surface after Tack Lifter testing. It can be seen that the Tack Lifter removes all surface emulsion as evident by the visible macro surface texture. This provides promising evidence the Tack Lifter sheet absorbs all of the asphalt emulsion on the paving surface, neglecting emulsion absorbed into the micro pores and bare aggregates contained on the paving surface.

Figure 18 Paving surface after Tack Lifter application

In addition to the aforementioned drawbacks of ASTM D 2995 Method A, significant bare spots are left in the roadway. Figure 19 provides a photo with evidence of the bare spots left behind from application of ASTM D 2995 pads following aggregate application and light sweeping. Note that the Tack Lifter tests also leave spots requiring repair but the area influenced (5”x5”) is much lower than the ASTM D 2995 Test Method A (12”x12”).

Figure 19 Bare spots left by the ASTM D 2995 Test Method A

5.1.3 Field Trial Conducted on 9/17/14

The second field trial allowed for more direct comparison between ASTM D 2995 Test Method A and Tack Lifter results applied to both a pan and the paving surface because the tests were conducted a single transverse location. Furthermore, tests were aligned very closely longitudinally and thus, longitudinal EAR variability is not anticipated to impact results. Results of the second field trial are shown in Figure 20. All test methods indicate a higher EAR was applied at the second location of testing compared to the first. ASTM D 2995 results indicate higher applied EAR values than those of Tack Lifter tests applied to pans at both testing locations. However, the ASTM D 2995 results greatly exceed the target EAR and thus, results are questionable. Debris adhering to the ASTM D 2995 pads could possibly explain trends. The Tack Lifter results applied to the paving surface indicate lower "effective" EARs than those applied based on Tack Lifter tests applied to pans placed on the paving surface prior to emulsion application. This matches expected trends as the paving surface is anticipated to absorb a portion of the applied emulsion. Furthermore, error bars indicate relatively consistent results among Tack Lifter test replicates, providing promising evidence of the potential for the test to be implemented for QC.

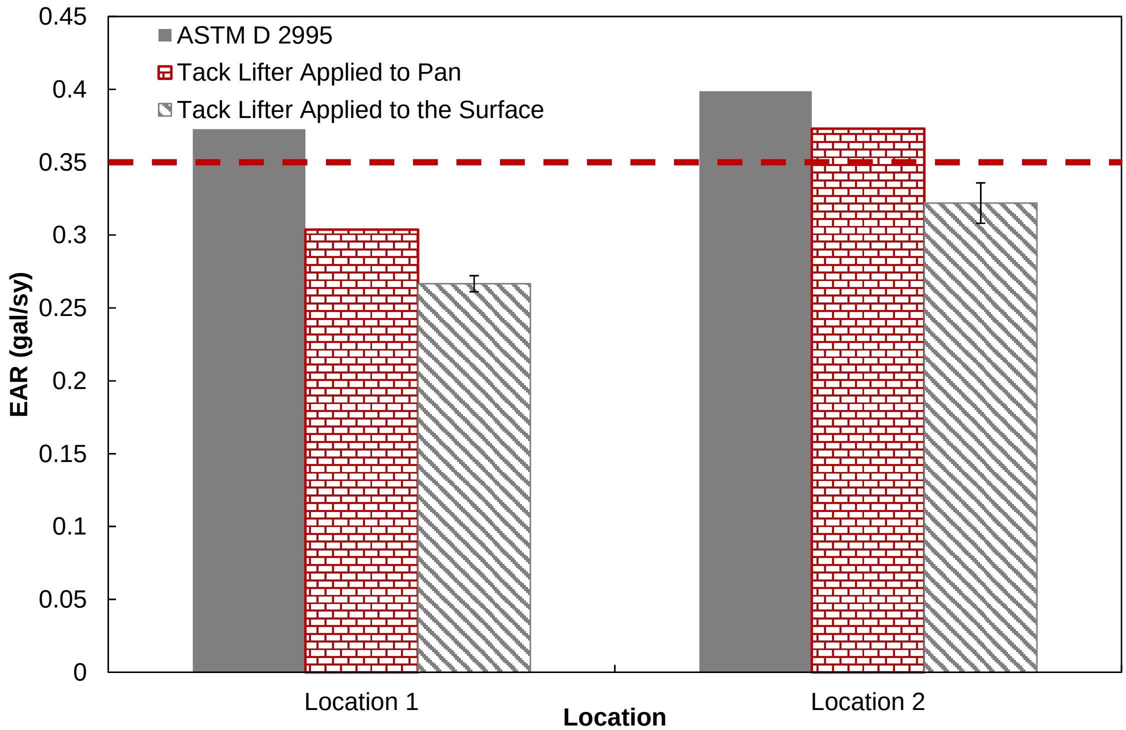

Figure 20 Comparison between results of ASTM D 2995, Tack Lifter applied to pan, and Tack Lifter applied to paving surface (9/17/14)

5.2 Assessment of Emulsion Absorption by Pavements

5.2.1 Summary of Field Experiments

Laboratory experiments and preliminary field investigations indicate emulsion absorption by the pavements can be captured using comparisons between Tack Lifter tests applied to the paving surface following emulsion application and Tack Lifter tests applied to steel pans placed on the paving surface prior to the application of emulsion. If the rate at which a pavement absorbs asphalt emulsion can be captured, the target EAR during construction can be adjusted to compensate. Laboratory investigations indicate that surface texture impacts the rate by which a pavement absorbs emulsion. Thus, three field experiments were conducted to compare the rate by which emulsion is absorbed by the paving surface at locations of varying surface texture. A summary of the three field experiments is provided in Table 6. Field experiments included Tack Lifter testing on pans placed on the paving surface prior to emulsion application by the distributor and Tack Lifter tests conducted on the paving surface. In addition, the Sand Patch Test (ASTM E 965) was used to quantify surface texture at each site of Tack Lifter testing in an effort to relate observed trends in emulsion absorption by the paving surface to the existing surface condition. Figure 21 provides a photo of Sand Patch testing in the field.

Figure 21 Sand patch testing in the field

Table 6 Summary of Field Experiments to Evaluate Emulsion Absorption into Paving Surfaces Using the Tack Lifter

Location	Date	Existing Surface Condition	Target EAR (gal/yd^2)	Remarks
Vance County, NC	5-26-15	Existing chip seal exhibiting raveling and cracking in the wheel paths	0.25	
Warren County, NC	6-23-15	Existing asphalt concrete pavement, exhibiting raveling and cracking	0.30	Very hot day
Franklin County, NC	8-10-15	Existing chip seal, exhibiting cracking and raveling	0.30	

5.2.2 Field Trial Conducted on 5/26/15

Field construction corresponding to the field trial conducted on 5/26/15 consisted of the application of a chip seal to an existing chip seal surface. The emulsion utilized was of designation CRS-2L and the target EAR was 0.25 gal/ yd^2. The existing chip seal surface consisted of smooth, moderately bled conditions in the wheel path and cracking and raveling outside of the wheel path. A photo of the pavement prior to the application of the new chip seal is provided in Figure 22. Surface texture measurements were made using the sand patch test prior to emulsion application. EAR measurements included Tack Lifter tests applied to the paving surface and to pans placed on the paving surface prior to emulsion application. The latter allows for measurement of the total applied EAR as the Tack Lifter absorbs 100% of emulsion applied to a steel pan. Testing was conducted at three locations along the length of paving, herein after referred to as Locations 1, 2, and 3. Due to the observed transverse variability in surface texture, testing was conducted at two transverse sites for each location of EAR measurement, with the exception of Location 1 where three spots were evaluated due to excessive bleeding observed at the pavement edge. Sites are designated as (a) to indicate wheel path test sites or (b) to indicate lane center test sites. Figure 23 depicts the layout of tack lifter testing for each location, showing both spots of tack lifter testing. The "X" corresponds to the third spot of tack lifter testing at Location 1, designated (c). Note that a single pan was placed at each location of testing and thus, transverse variability in emulsion application may impact observed trends when comparing results of Tack Lifter tests applied to the paving surface and pan. Table 7 provides a summary of the different longitudinal locations and transverse sites of testing with corresponding visual observations of surface conditions.

Figure 22 Surface condition of 5/26/15 field experiment

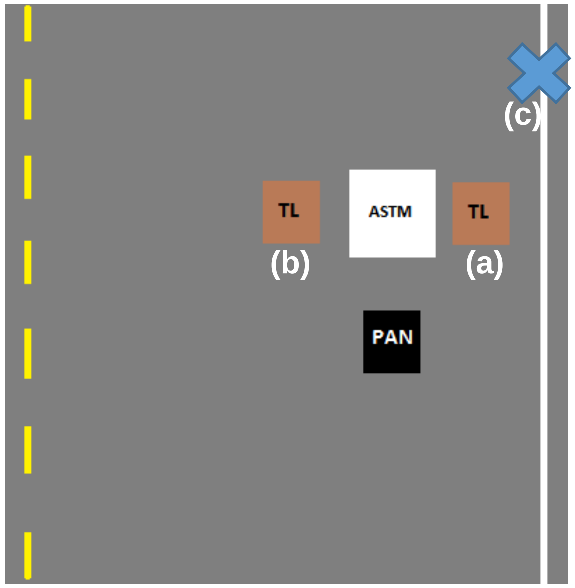

Figure 23 Experimental layout for 5/26/15 field trial

Table 7 Description of Testing Sites Corresponding to Field Trial Conducted on 5/26/15

Label	Longitudinal Location	Transverse Site	Surface Description
1A	1	Wheel Path	Smooth (Worn but not bled)
1B	1	Lane Center	Rough with raveling
1C	1	Lane Edge	Heavily Bled
2A	2	Wheel Path	Rough with raveling
2B	2	Lane Center	Bled

Results of the 5/26/15 field trial are shown in Figure 24. Figure 24 (a) shows the comparison between surface texture and the percentage of applied emulsion absorbed by the Tack Lifter sheets applied to the paving surface at the different sites of testing. Note that the percentage of emulsion absorbed by the Tack Lifter was determined through comparison to Tack Lifter results conducted on the steel plans placed on the paving surface prior to emulsion application. Results in Figure 24 (a) demonstrate an inverse trend between mean texture depth (MTD) and the percentage of applied emulsion absorbed by the Tack Lifter as expected. For the three testing sites with low MTD (1A, 1C, and 2B), the Tack Lifter sheet applied to the paving surface absorbed 100% of emulsion applied, implying the paving surface was impervious and did not absorb emulsion. Note that some values are even slightly higher than 100% which can be attributed to transverse variability in emulsion application and inherent variability in experimental measurements. At locations of rough texture (1B, 2A), it can be seen that absorption levels fall below 100%, indicating the existing pavement absorbed a portion of the applied emulsion. These trends are further supported by Figure 24 (b), which shows the comparison between results of Tack Lifter tests applied to the surface (i.e., effective EAR measurements) and those applied to the pan placed on the paving surface prior to emulsion application (i.e., applied EAR measurements). Tack Lifter tests applied to pans indicated that the applied EAR was very close to the target EAR of 0.25 gal/ yd^2 at the first two locations of testing.

Results indicate negligible differences between pan and paving surface Tack Lifter measurements for sites of low texture (1A, 1C, and 2B) but for sites of high roughness, the "effective" EAR is significantly lower than that applied. For the location of highest texture, results indicate the paving surface absorbed more than 20% of the applied emulsion, suggesting it is important to adjust the target EAR to account for absorption when emulsion is applied to surfaces with high roughness.

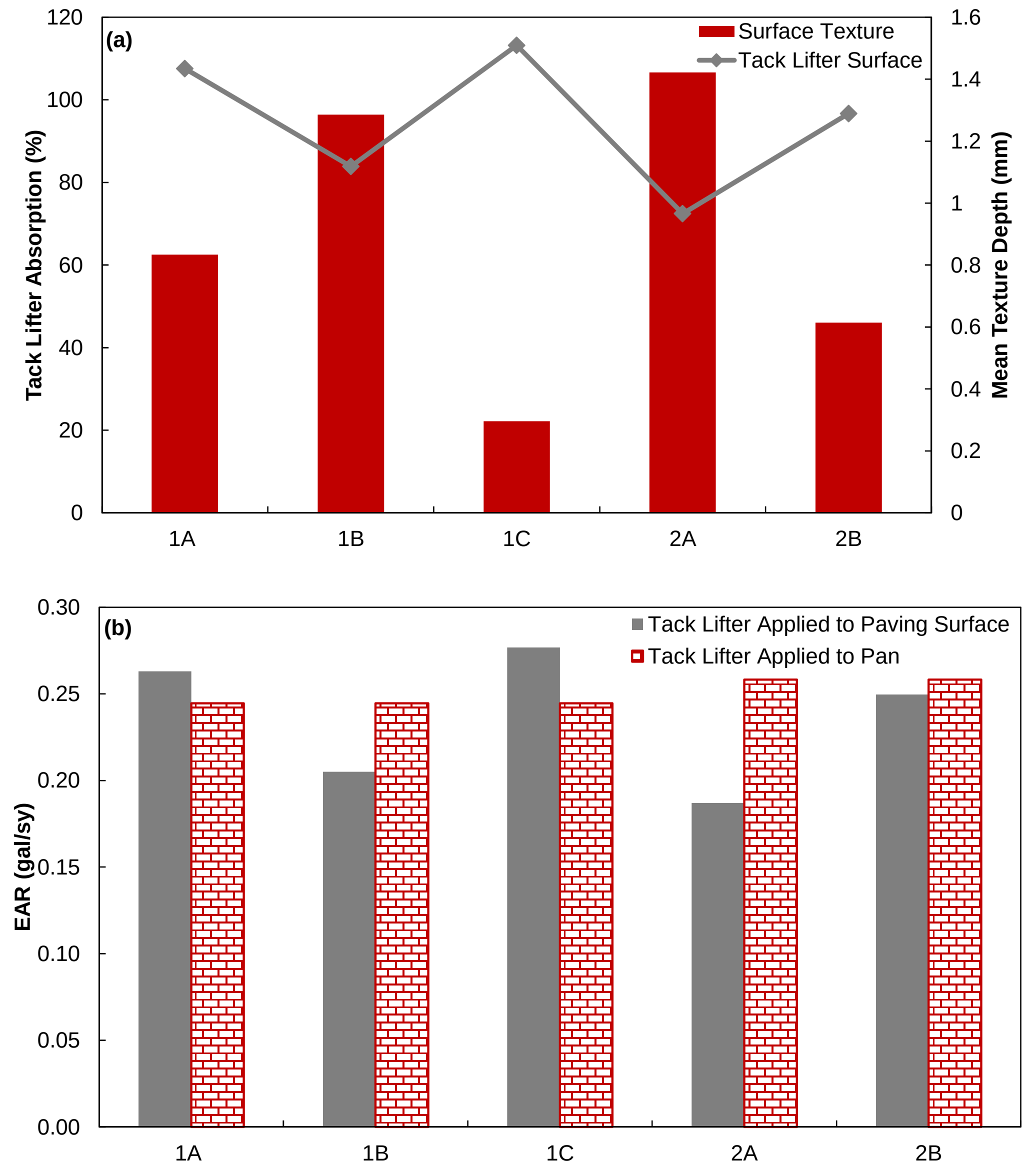

Figure 24 5/26/15 Field Trial Results: (a) Comparison between surface texture and the percentage of applied emulsion absorbed by Tack Lifter tests conducted on the paving surface (b) Comparison between results of Tack Lifter tests applied to the paving surface and pans

5.2.3 Field Trial Conducted on 6/23/15

The field trial conducted on 6/23/15 consisted of applying a CRS-2L emulsion at a target rate of 0.30 gal/yd^2 to an existing asphalt concrete pavement in Warren County, NC. The existing pavement exhibited alligator cracking and a rough texture in the wheel paths with relatively smooth texture in the center of the lane. A photo of the existing pavement condition is provided in Figure 25. The field trial included several experiments: (1) ASTM D 2995 Test Method A, (2) Tack Lifter tests applied to the paving surface, and (3) Tack Lifter tests conducted on a pan placed on the paving surface prior to emulsion application. Testing was conducted at three locations along the length of emulsion application, numbered one through three. For Location 1, EAR was only measured in the wheel path. For Locations 2 and 3, testing was conducted in both the (a) wheel path and (b) lane center, which displayed significantly different surface texture. The experimental layout used for each location of testing is depicted in Figure 26. (Note that for the first location, the lane center test (b) was omitted). To avoid the possible influence of transverse variability in comparing measurements of applied and effective EAR, measurements with each method were made at the same transverse location, with close spacing longitudinally. Surface texture measurements were made using the sand patch test prior to emulsion application. Table 8 provides a summary of the different longitudinal locations and transverse sites of testing with corresponding visual observations of surface conditions.

Figure 25 Surface condition of 6/23/15 field experiment

Figure 26 Experimental layout for 6/23/15 field trial

Table 8 Description of Testing Sites Corresponding to Field Trial Conducted on 6/23/15

Label	Longitudinal Location	Transverse Site	Surface description
1A	1	Wheel Path	Cracking, some raveling
2A	2	Wheel Path	Cracking, some raveling
2B	2	Lane Center	Relatively smooth, low severity cracking/raveling
3A	3	Lane Wheel Path	Cracking, some raveling
3B	3	Lane Center	Relatively smooth, low severity cracking/raveling

Results of Tack Lifter tests are displayed in Figure 27. Note that ASTM D 2995 Test Method A results were omitted because measurements were compromised due to difficulties in implementing the procedure. The sheets placed in the wheel path often adhered to the emulsion distributor wheels which precluded measurement of the applied EAR. The results that were obtained from ASTM D 2995 Test Method A consistently indicated an applied EAR of 0.25 gal/yd^2, which is significantly lower than both the target EAR and Tack Lifter results. The large size of the ASTM D 2995 Test Method A pads made them difficult to handle and emulsion dripped from the edges of the sheets during transit to the scale, which explains the erroneously low EAR measurements.

Figure 27(a) shows the comparison between surface texture at the different spots of Tack Lifter testing and the percentage of applied emulsion absorbed by the Tack Lifter tests applied to the paving surface. Note that the percentage of emulsion absorbed by the Tack Lifter was determined through comparison to Tack Lifter results conducted on the steel plans placed on the paving surface prior to emulsion application. Results in Figure 27(a) demonstrates an inverse trend between MTD and the percentage of applied emulsion absorbed by the Tack Lifter as expected. The only exception to this trend is the last site of testing, denoted “3B,” which shows low roughness and relatively low absorption by the Tack Lifter applied to the paving surface. It is speculated this outlier reflects water loss from the Tack Lifter sheet prior to weighing. Site 3B was the last test conducted and experienced the greatest delay in sheet removal from surface to weighing. In addition, the ambient temperature exceeded 35°C (95°F) at the time of this last measurement and thus, conditions were severe.

Figure 27(b) shows the comparison between Tack Lifter results applied to the surface (i.e., effective EAR measurements) and those applied to the pan placed on the paving surface prior to emulsion application (i.e., applied EAR measurements). Results indicate the applied EAR was consistently close to the target of 0.30 gal/yd^2 based on results of Tack Lifter tests applied to pans. Results indicate negligible differences between pan and paving surface Tack Lifter measurements for locations of low texture (with the exception of the last spot). For cracking locations of higher MTD, results indicate approximately 0.06 gal/yd^2 of emulsion is absorbed by the surface, indicating significant adjustment in applied EAR is needed in cracked locations to overcome emulsion loss to surface absorption.

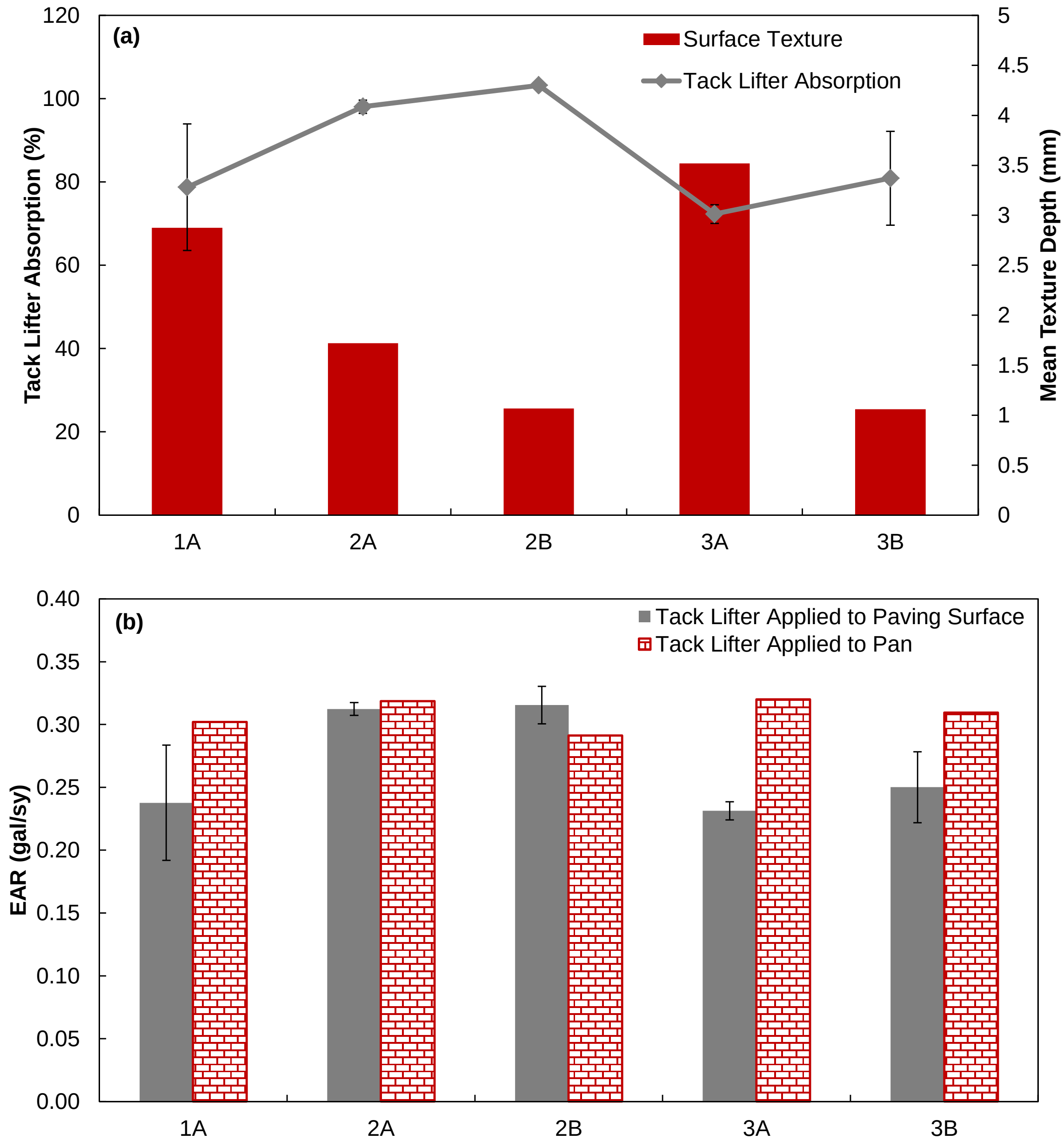

Figure 27 6/23/15 Field Trial Results: (a) Comparison between surface texture and the percentage of applied emulsion absorbed by Tack Lifter tests conducted on the paving surface (b) Comparison between results of Tack Lifter tests applied to the paving surface and pans

5.2.4 Field Trial Conducted on 8/10/15

The field trial conducted on 8/10/15 followed a similar approach to the previous two field trials. Construction consisted of the application of a chip seal to an existing chip seal surface. The target EAR was 0.30 gal/yd^2 and a CRS-2L emulsion was utilized. Tack Lifter testing was conducted at three locations along the length of paving, numbered one through three. The test layout for each location is shown in Figure 28. Tack Lifter testing was conducted both in (a) the wheel path and (b) lane center. Tack Lifter testing was conducted both on the paving surface and on a pan placed on the paving surface prior to emulsion application. In addition, surface texture was measured prior to the application of emulsion. The pavement did not exhibit as much distress as those in the previous field trials with the exception of Location 2, which was bled. A summary of the individual test sites is provided in Table 9.

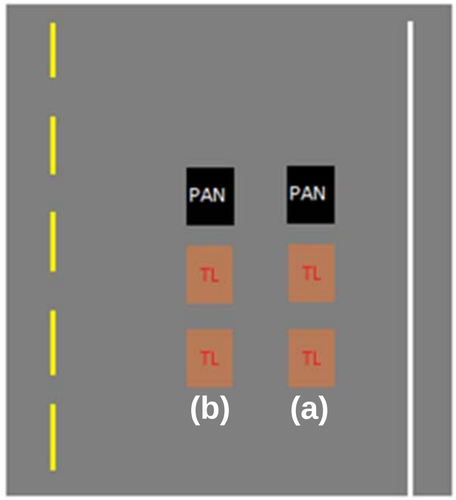

Figure 28 Experimental layout for 8/10/15 field trial

Table 9 Description of Testing Sites Corresponding to Field Trial Conducted on 8/10/15

Label	Longitudinal Location	Transverse Site	Surface Condition
1A	1	Wheel Path	Rough
1B	1	Lane Center	Rough
2A	2	Wheel Path	Light Bleeding, low severity cracking/raveling
2B	2	Lane Center	Light Bleeding, minimal distress
3A	3	Wheel Path	Rough
3B	3	Lane Center	Rough

Figure 29 shows the results of the 8/10/15 field trial. The results generally match expected trends, indicating rougher surface texture leads to lower emulsion absorption by the Tack Lifter (and hence, greater absorption by the paving surface). Consistent with previous field trials, absorption by the Tack Lifter was calculated using the Tack Lifter pan measurement as a reference of total emulsion applied. Results indicate that up to 20% of the applied emulsion was absorbed by the paving surface. The only testing site which does not match expected trends is 2A. Location 2A was a bled section. However, Location 2A indicates relatively low emulsion absorption by the Tack Lifter which contradicts expectations. Note that the "pan" Tack Lifter results shown in Figure 29(b) for Location 2A indicate unusually high EAR results, which could be the source of unexpected trend in Figure 29(a). Figure 29(b) shows the comparison between Tack Lifter results applied to the paving surface and the pan placed on the paving surface prior to emulsion application. The Tack Lifter results applied to the pan indicate variability in the applied

EAR ranging from 0.27 gal/yd^2 to 0.36 gal/yd^2. Tack Lifter tests applied to the paving surface indicates variation in the "effective" EAR ranging from 0.26 gal/yd^2 to 0.32 gal/yd^2.

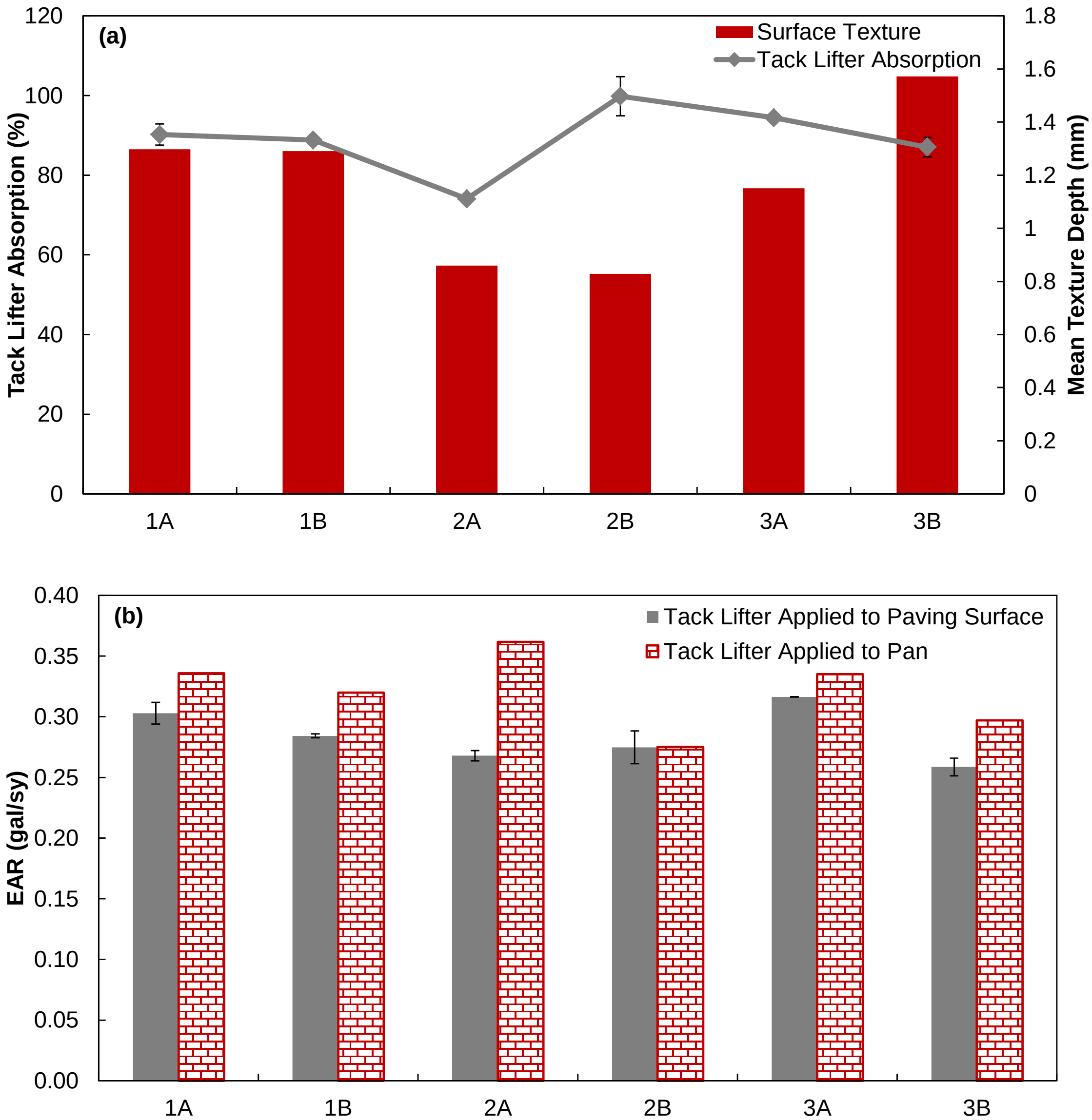

Figure 29 8/10/15 Field Trial Results: (a) Comparison between surface texture and the percentage of applied emulsion absorbed by Tack Lifter tests conducted on the paving surface (b) Comparison between results of Tack Lifter tests applied to the paving surface and pans

5.2.5 Summary and Recommendations for Implementation for Assessment of Pavement Absorption Rate

Laboratory and field investigations provide promising evidence that the Tack Lifter tests applied to a paving surface provide measurements of the effective EAR on the paving surface, neglecting absorbed emulsion. Thus, the difference between the EAR measured using Tack Lifter tests applied to the paving surface and adjacent steel pans placed can be used to determine the quantity of emulsion absorbed by the paving surface. Experimental results indicate the quantity of emulsion absorbed by a paving surface can differ significantly depending on the surface type (e.g., asphalt concrete versus chip seal) and texture. Absorbed emulsion is not available for bonding to material placed on top of the emulsion. Therefore, the target EAR during construction should be increased by the emulsion absorption rate of the pavement in order to improve quality. It is recommended that Tack Lifter tests be conducted on a test strip of roadway prior to the start of construction to allow such adjustments. Testing should be conducted in the wheel path because the wheel path is the area subjected to traffic loading and hence, most susceptible to distress. Testing in the wheel path necessitates the use of flat rather than elevated plates because the emulsion distributor wheels would crush elevated plate legs. However, use of flat plates is not deemed problematic because Tack Lifter tests can be conducted directly on the flat pans after emulsion application without removal from the roadway because there are not the time constraints imposed by testing during construction. Measurements of the emulsion absorption by the pavement should be repeated if significant changes in surface texture are noted along the length of paving and the target applied EAR should be adjusted accordingly. A detailed procedure recommended for evaluating the rate by which a pavement absorbs emulsion is provided in Appendix B, Test Method B.

According to aforementioned procedure, the rate by which emulsion was absorbed into the pavement in the wheel path was determined for the field trials conducted on 6/23/15 and 8/10/15. Results are presented in Figure 30. Results represent the average and corresponding standard error determined from the three locations of testing along the length of paving. For both field trials, results indicate the pavement absorbed approximately 0.05 gal/yd^2 of the applied 0.30 gal/yd^2. These results suggest the target EAR (assuming no absorption) should have been adjusted by 0.05 gal/yd^2 to account for emulsion lost to absorption into the existing pavement. Results indicate standard errors of approximately 0.015 gal/yd^2, based on measurements made at different longitudinal locations. Due to the relatively small variability in rates of absorption along the length of paving, testing at the starting location of construction only is deemed sufficient, unless significant changes in pavement surface conditions are observed.

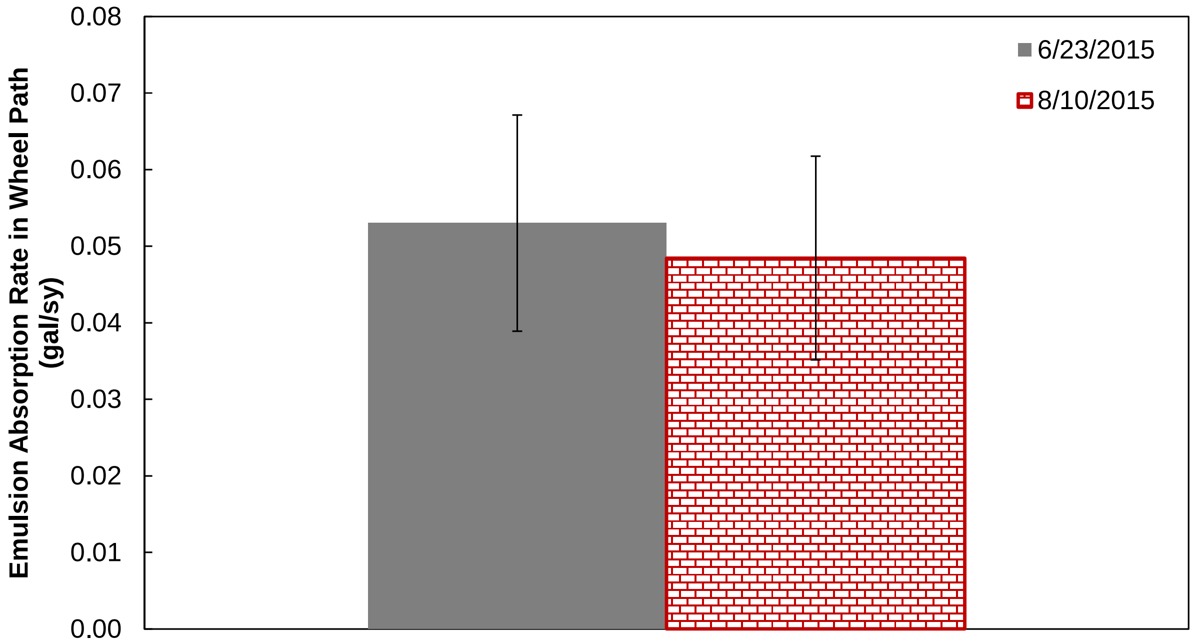

Figure 30 Emulsion absorption rate in wheel path for field trials conducted on 6/23/15 and 8/10/15

It is important to note that the absorption capacity of a pavement surface is theoretically a fixed quantity, which is supported by laboratory experimental results presented in Chapter 4. This implies that at lower applied EAR, (such as in a tack coat application), a higher percentage of the applied emulsion will be absorbed by the paving surface. For example, if a surface has the ability to absorb 0.02 gal/yd^2 of emulsion and the applied EAR is 0.04 gal/yd^2, 50% of the emulsion will be absorbed into the pavement. However, if emulsion is applied to the same pavement at a rate of 0.25 gal/yd^2, only 8% of applied emulsion will be absorbed into the paving surface. These trends imply quantifying the rate at which a pavement absorbs emulsion is particularly important in tack coat and fog seal applications where applied EARs are relatively low compared to chip seals.

5.3 Assessment of Transverse EAR Variability using the Tack Lifter

5.3.1 Summary of Field Experiments

To comprehensively evaluate transverse variability in EARs using the Tack Lifter test, tests would need to be conducted across the entire width of a pavement lane. The small size of the Tack Lifter sheets (5 in by 5 in) would necessitate a large number of tests to cover the entire width of a pavement lane which is infeasible. Tack Lifter tests must be conducted efficiently after emulsion application to avoid possible influence of emulsion breaking and curing and thus, testing the large number of specimens required to cover the pavement width would not be possible. However, Tack Lifter tests applied to pans were conducted at two transverse locations (wheel path and lane center) during the 6/23/15 and 8/10/15 field trials detailed in Chapter 5.2, which allows for a preliminary study of study transverse variability in EAR application along the length of paving.

5.3.2 Field Trial Conducted on 6/23/15

The comparison between the EARs measured using Tack Lifter tests applied to pans placed in the wheel path and lane center at Locations 2 and 3 of the 6/23/15 field trial are presented in Figure 31. Recall that Location 1 of the 6/23/15 field trial only included Tack Lifter testing at a single transverse location and hence results are omitted herein. Results indicate relatively little transverse variability in EARs between the locations of testing, with the emulsion output in the lane center consistently, slightly lower than in the wheel path.

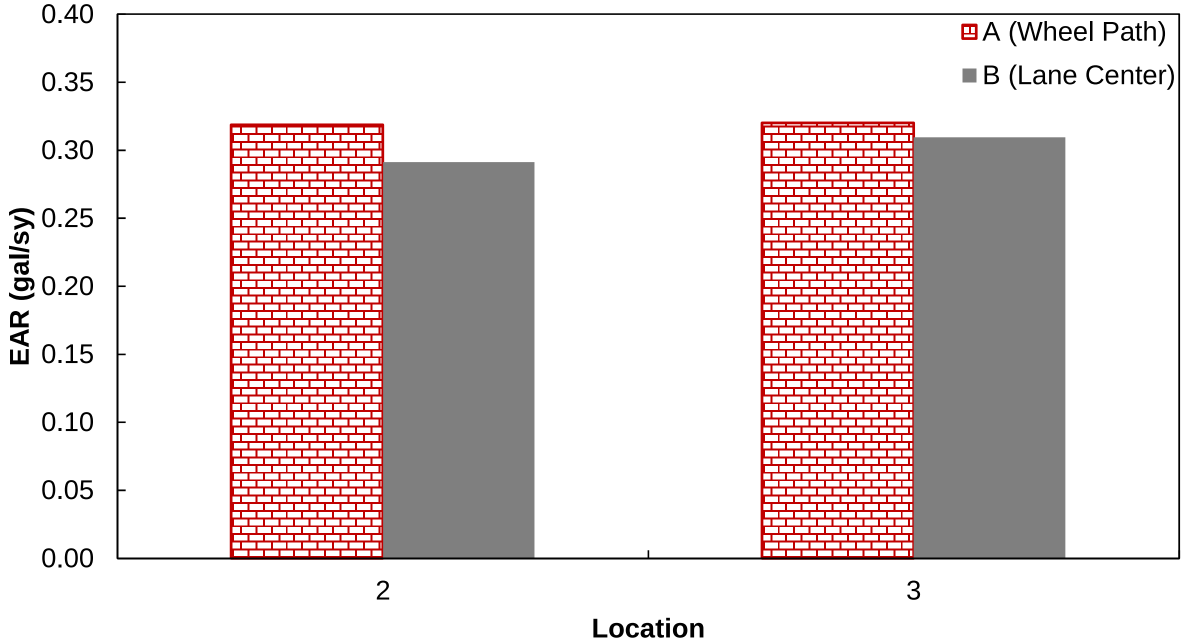

Figure 31 Assessment of transverse EAR variability in 6/23/15 field trial

5.3.3 Field Trial Conducted on 8/10/15

The comparison between the EARs measured using the Tack Lifter applied to pans placed in the wheel path and lane center at the three locations of testing in the 8/10/15 field trial are presented in Figure 32. Similar to the field trial on 6/23/15, results indicate that the EAR in wheel path is consistently lower than the lane center. The results of the 8/10/15 field trial indicate slightly higher discrepancies between EARs in the wheel path and lane center than in the 6/23/15 field trial with a maximum transverse difference between applied EARs of 0.08 gal/yd^2.

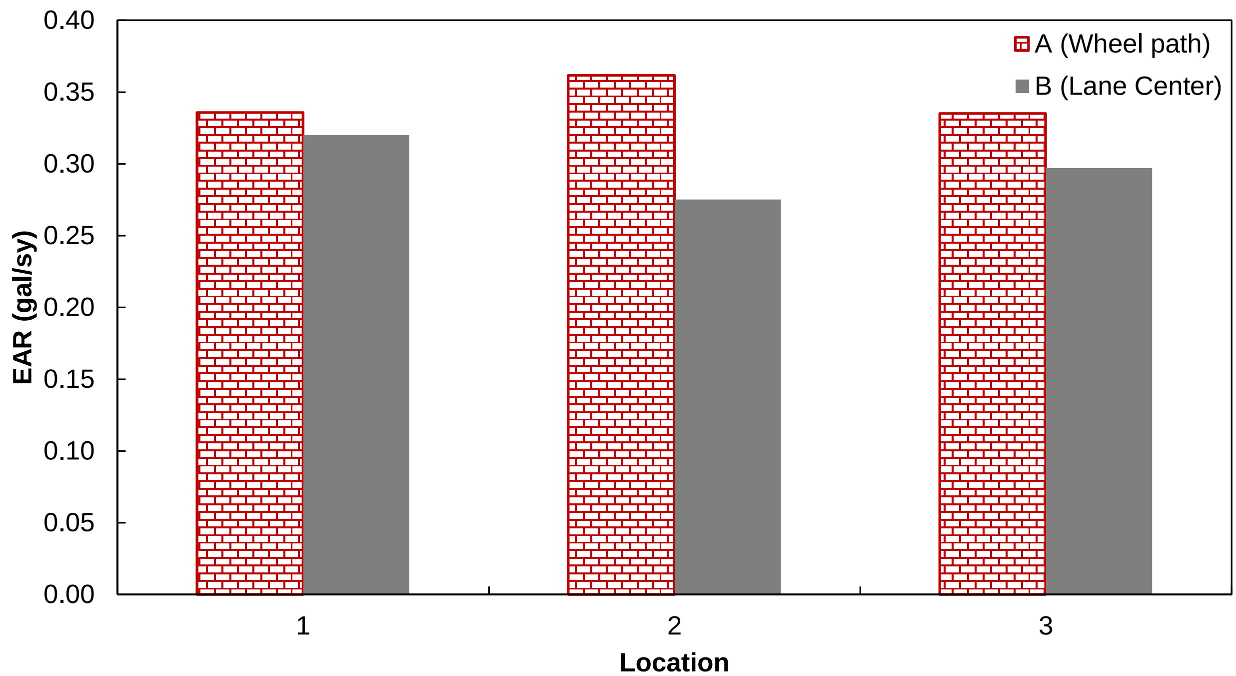

Figure 32 Assessment of transverse EAR variability in 8/10/15 field trial

5.3.3 Summary and Recommendations for Implementation of the Tack Lifter in Transverse Variability Assessment

The investigations of transverse EAR variability using the Tack Lifter presented, albeit relatively limited, suggests consistent trends in transverse variability along the length of paving. Thus, results suggest that transverse variability should be evaluated and remedied prior to construction for improved QC. ASTM D 2995 provides well developed provisions for such measures. Due to the time constraints during construction and relatively consistent trends in transverse variability at different locations along the length of paving, it is deemed unnecessary and impractical to conduct in-situ measures of transverse EAR variability along the length of paving. An evaluation of ASTM D 2995 Test Method A for assessment of transverse EAR variability with recommendations for implementation is provided in Chapter 6.

5.4 Assessment of Longitudinal EAR Variability using Tack Lifter Tests Applied to Elevated Plates

5.4.1 Summary of Field Experiments

Results presented in Chapter 5.2 which compare results of Tack Lifter tests applied to the paving surface and pans suggest that it is critical to assess determine the amount of emulsion absorbed by the paving surface to guide appropriate adjustment of target EARs. However, Tack Lifter tests conducted on pans and paving surfaces in past chip seal field trials delayed aggregate application by one to two minutes. Testing involves placing the Tack Lifter on the paving surface (or pan) for 30 seconds and then removing the Tack Lifter weighted device, sheets, and pan. This delay is not problematic for tack coat applications but for chip seals in which aggregates are applied shortly after emulsion application, minimizing delays is critical. Furthermore, it is anticipated that Tack Lifter tests conducted prior to construction operations will allow for appropriate adjustments of EARs based on surface absorption. It is not anticipated that it is feasible to continually adjust the applied EAR based on periodic Tack Lifter during construction.

In a first effort to enable quick in-situ measures of EAR for assessment of longitudinal variability, quick removal of the flat steel pans that were used in past field trials from the paving surface immediately after emulsion application was tried. Pans were transferred to a table placed off of the roadway for subsequent Tack Lifter testing to minimize delays. Note that in the previously presented field trials, the pan was left in place on the roadway and the Tack Lifter was transported and applied to the pan in place. Conducting Tack Lifter tests on the side of the roadway has efficiency gains. However, in order to remove the flat steel pans from the paving surface, they must be tilted, which leads to movement of the emulsion on the pan. Thus, the elevated plates and peel detailed in Chapter 3 were developed to allow efficient in-situ measurements of applied EARs at specific locations along the length of paving. The peel, (similar to a pizza peel), enables easy removal of elevated plates from the paving surface within 10 to 15 seconds of emulsion application, minimizing delays in aggregate application during chip seal construction. Elevated plates are transferred to a leveling table placed off of the roadway for Tack Lifter testing, as detailed in Chapter 3. The only limitation of the elevated plate method is that the plate must be placed in the lane center because emulsion distributor wheels would crush the legs of the plate. However, it is recommended that transverse variability of EAR be checked prior to construction as discussed in Chapter 5.3 and thus, measuring EARs along length of paving at a single transverse location is not perceived to be problematic. Furthermore, placement of the plates in the lane center is anticipated to have the least impact on the quality of the resultant chip seal. The plates leave a small, bare area which must be patched. The wheel path is where loading and hence, distress is concentrated and thus, minimizing patching requirements in the wheel path is deemed beneficial to the performance of the pavement.

Three field trials were conducted using elevated plate tests to evaluate longitudinal variability in applied EARs. A summary of the field trials is provided in Table 10. In each field trial, EAR measurements were made at four locations, roughly equally spaced along the length of paving. At each location of EAR measurement, an elevated plate was placed on the paving surface prior to emulsion application in the center of the lane. In addition to use of the elevated plates, flat steel pans were also placed at each location prior to emulsion application to allow for comparison to elevated plates in terms of ease of use and quality of measurements. Following emulsion application, both elevated and flat steel plates were removed from the paving surface as efficiently as possible and placed on a level surface for Tack Lifter testing.

Table 10 Summary of Field Trials to Assess Longitudinal Variability in Applied EARs

Location	Date	Target EAR (gal/yd^2)	Approximate Length of Paving (miles)
Franklin County, NC	9-9-15	0.30	1.5
Warren County, NC	9-11-15	0.30	0.6
Franklin County, NC	9-23-15	0.30	1.6

5.4.2 Field Trial Conducted on 9/9/15

In the initial field trial, the height of the legs on the elevated plates was 1" with a 3/8" lip around the plate. Construction consisted of the application of a chip seal to a 1.5 miles of rural road. CRS-2L emulsion was utilized with a target application rate of 0.30 gal/yd^2. Testing was conducted at four locations spaced roughly 0.4 miles apart. At each location, both flat pans and elevated plates were placed on the roadway prior to emulsion application and transferred off of the roadway for Tack Lifter testing following emulsion application. The elevated plates proved to be easy to remove from the roadway while keeping level. The flat plates proved to be more problematic, requiring tilting to dislodge from the paving surface which may have compromised results. The only problem encountered with the elevated plates was that they moved slightly after the distributor passed, which led to partial coverage of the flat plates at Locations 3 and 4 of testing. This was remedied by lowering the height of the elevated plates to 0.5" in subsequent field trials. The use of shorter legs allowed the plates to stay in place during emulsion application. Results are presented in Figure 33, with omission of flat plate results at Locations 3 and 4. Elevated and flat plates provided similar measurements of applied EAR at Locations 1 and 2. Elevated plate results indicate relatively little variability in EAR along the length of paving with the minimum EAR measured equal to 0.27 gal/yd^2 and the maximum 0.32 gal/yd^2. Note that the minimum EAR measured corresponded to a testing location within a sharp curve in the roadway, which perhaps is a situation in which accurate emulsion application by the distributor is more challenging.

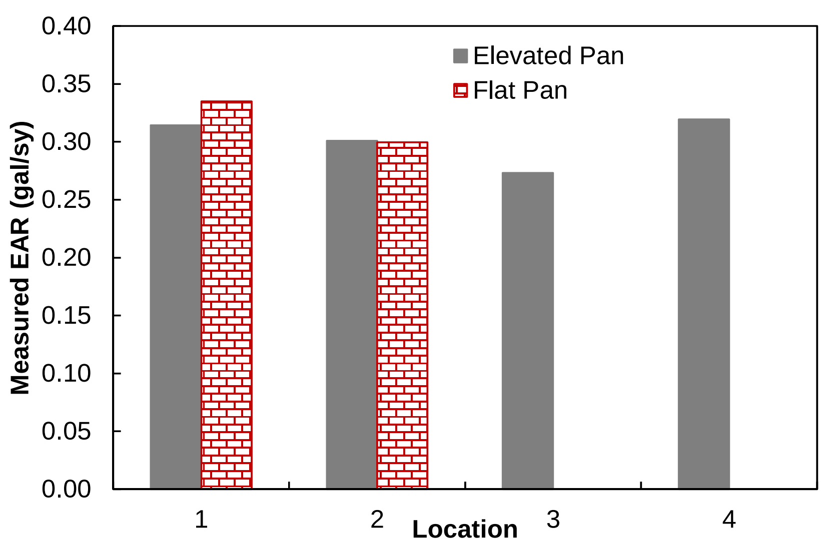

Figure 33 Measured EAR's for September 9, 2015 in Franklin County

5.4.3 Field Trial Conducted on 9/11/15

The second field trial with the elevated plates consisted of the application of chip seal to a relatively short length of roadway, 0.6 miles long. Construction consisted of applying a chip seal to an existing asphalt concrete pavement using a CRS-2L emulsion applied at a target EAR of 0.30 gal/yd^2. EAR measurements were made at four locations along the length of paving, spaced roughly 0.15 miles apart using both elevated and steel plate methods. Here, the heights of legs on the elevated plates were lowered to 0.5" as previously discussed. Flat pans proved to be very difficult to remove from the paving surface which led to loss of pans at testing Locations 2 and 4. Results are presented in Figure 34. Results indicate some variability in flat and elevated plate measurements. As discussed, flat pans required tilting to remove from the paving surface and thus are deemed less accurate than elevated plate measurements. Elevated plate measurements indicate that applied EARs were generally lower than the target EAR of 0.30 gal/yd^2. Measured EARs varied from 0.25 gal/yd^2 to 0.30 gal/yd^2. Note that EAR variability is deemed relatively high despite the relatively short length of paving.

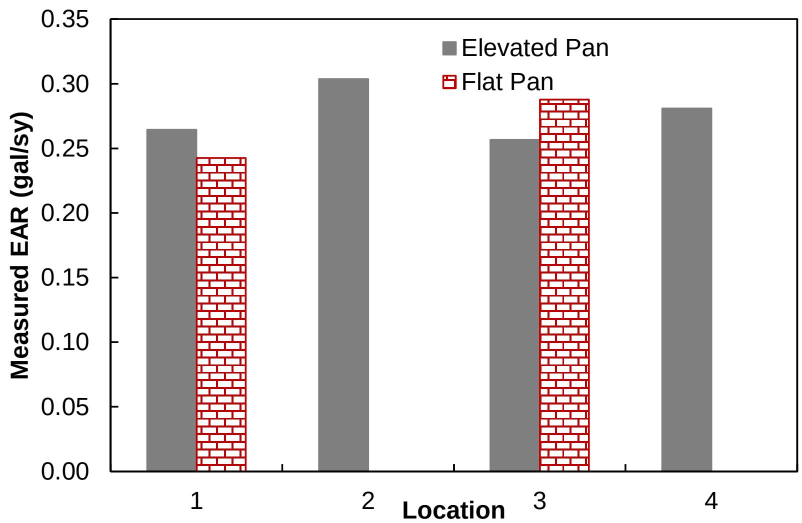

Figure 34 Measured EAR's for September 11, 2015 in Franklin County

5.4.4 Field Trial Conducted on 9/23/15

The third elevated plate field trials consisted of the construction of a chip seal on a 1.5 mile stretch of roadway in Person County. Emulsion application consisted of a target EAR of 0.30 gal/yd^2 using CRS-2L emulsion. EAR measurements were made at four locations spaced roughly 0.4 miles apart along the length of paving. The elevated plate was lost at the third location of testing due to tilting / flow of emulsion. Results are presented in Figure 35. Considerably higher variability in EAR along the length of paving was observed in this field trial than past trials. Results demonstrate that EAR varied from roughly 0.23 gal/yd^2 to 0.35 gal/yd^2 along the length of paving based on elevated plate results, indicating the EAR increased as paving progressed. The flat pan results are consistently lower than the elevated plate results. A few factors may have influenced results of this field trial and may have contributed to the higher variability observed than past field trials. Conditions were windy during construction which led to fast emulsion breaking. Note that flat pan measurements were always made after the elevated plate measurement and thus, the windy conditions could have led to partial breaking of the emulsion on the flat pans prior to Tack Lifter testing. One possible remedy to the partial breaking of the emulsion before Tack Lifter testing could be to have two Tack Lifters and scales to aid in quickness of measurements. However, this is not feasible for non-research applications.

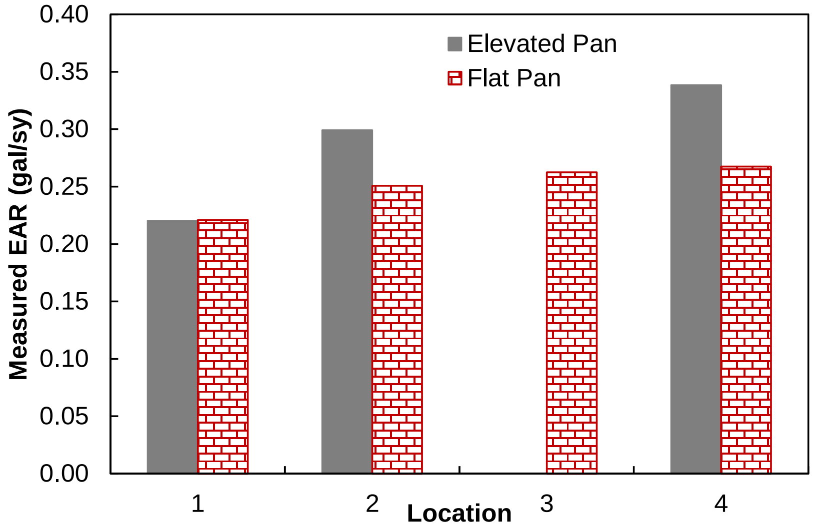

Figure 35 Measured EAR's for September 23, 2014 in Person County

5.4.5 Summary and Recommendations for Implementation of Elevated Plates

The results presented indicate that Tack Lifter tests applied to elevated plates are capable of providing quick spot checks of the applied EAR at the center of a lane. Results suggest variability in the applied EAR can exist over relatively short sections of roadway. Therefore, it is recommended that elevated plates be placed at 0.5 mile increments along the length of paving to allow for adequate capture of longitudinal variability in applied EARs. Note that testing at more frequent intervals is deemed impractical due to time constraints during field construction operations, particularly in chip seal applications. In addition to the placement of elevated plates at 0.5 mile increments along the length of paving, it is recommended that plates be placed and tested at critical locations such as changes in grade or curvature. Elevated plates should be placed on the roadway shortly prior to emulsion application to avoid accidental crushing by roadway traffic or construction personnel. The detailed procedure recommended for QC of longitudinal variability in EARs is provided in Appendix B, Test Method C. It is important to note that the recommended procedure using Tack Lifter tests applied to elevated plates only allows for assessing longitudinal variability in applied EARs at the center of the lane. However, as previously discussed, transverse variability is relatively consistent along the length of paving and hence, it is recommended that transverse variability in EARs be assessed and resolved prior to construction. Furthermore, it is recommended that the rate by which a pavement absorbs emulsion be measured prior to construction and hence, measurement of applied EARs to assess longitudinal variability is deemed sufficient.

6 ASTM D 2995 FOR QUALITY CONTROL OF TRANSVERSE VARIABILITY IN EMULSION APPLICATION RATES

6.1 Summary of ASTM D 2995

As discussed in Chapter 2.4, ASTM D 2995 specifies two procedures for assessing transverse variability of emulsion application, which can be used to ensure the distributor nozzles are functioning properly prior to construction. In Test Method A, pre-weighed pads are placed on the roadway in front of the distributor. Pads are aligned to cover the entire width of emulsion application. Emulsion is applied and then the pads are removed from the roadway and weighed in order to assess transverse EAR variability. In Test Method B, containers are placed under each nozzle and emulsion is sprayed into the containers for a set period of time. Bags are placed in the containers and affixed to nozzles using rubber bands to ensure no overlap in nozzle output into each container. The amount of emulsion deposited into each container is then used to assess transverse variability.

ASTM D 2995 Test Method A, in theory, is easiest to implement in the field. Caltrans specifies a protocol equivalent to Test Method A for measuring transverse variability. However, Test Method B allows for evaluation of individual nozzles which would allow for easier detection of the source of problems (e.g., which nozzle is malfunctioning or clogged). TXDOT specifications include provisions for routine assessment of transverse variability using a test procedure equivalent to ASTM D 2995 Test Method B. ASTM D 2995 Test Method B is not an “in-situ” measure and hence, was outside the scope of rigorous evaluation in this study. Therefore, efforts herein focused on evaluating use ASTM D 2995 Test Method A for measuring transverse variability in applied EARs.

6.2 Summary of Experiment to Evaluate ASTM D 2995 Test Method A

To conduct ASTM D 2995 Test Method A in the field, nine pre-weighed geotextile pads were affixed to the pavement surface using duct tape. ASTM D 2995 Test Method A also calls for the placement of butcher paper on top of the pads in the wheel path, which is supposed to be removed by the distributor wheels, leaving the pads on the pavement. However, windy conditions prohibited use of the butcher paper which would not stay in place. Photos of the pads on the roadway before and after emulsion application are shown in Figure 36. It can be seen in Figure 36 (b) that the pads and emulsion distributor were not perfectly aligned to completely capture transverse variability. The pad placed closest to the edge of the roadway was only partially covered by the spray of emulsion and there was additional emulsion sprayed towards the lane center past the last pad. In addition, the third pad from the edge of the pavement, (which was in the wheel path), was folded upon contact with the distributor wheels. Nevertheless, the results obtained were analyzed.

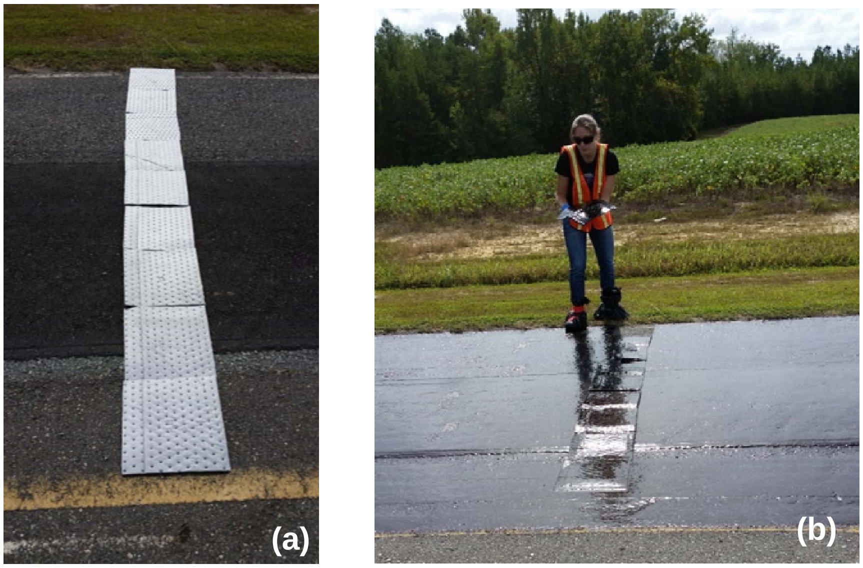

Figure 36 ASTM D 2995 Test Method A for assessment of transverse EAR variability: (a) pads on roadway prior to emulsion application, (b) pads being removed from roadway after emulsion application

6.3 Results of ASTM D 2995 Test Method A

Results of the transverse variability study using ASTM D 2995 Test Method A are shown in Figure 37. Note that Location 1 is the location closest to the pavement edge and increasing location number indicates closer proximity to the lane center. The target EAR was 0.25 gal/yd^2. It can be observed that Location 1 results indicate a low measured EAR which makes sense as the pad was only partially covered by the spray of emulsion. Thus, no conclusions regarding transverse variability can be drawn from Location 1 results. No measurement could be made at Location 3 as the pad was lost due to folding upon contact with the distributor wheels. Locations 3 through 7, and Location 9 indicate relatively little transverse variability, with measured EARs between 0.24 gal/yd^2 and 0.27 gal/yd^2. The measured EAR at Location 8 is substantially lower than the EARs measured at other transverse locations. However, Location 8 was in the wheel path and hence, the pad may have been disturbed from contact with the distributor wheel and thus, the measurement is not considered reliable.

In addition to the issues associated with interactions between pads and distributor wheels and relative alignment of the pads and emulsion distributor, there are several other noteworthy issues associated with the procedure. The pads are difficult to remove from the roadway and transfer to scale. The pads are flimsy and emulsion can drip from the edges during transport.

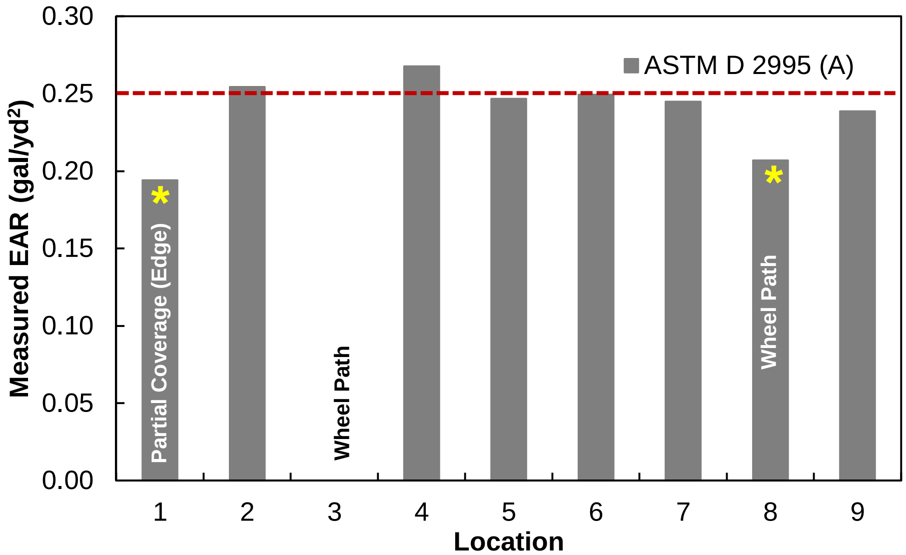

Figure 37 Results from ASTM D 2995 Test Method A

6.4 Summary and Recommendations for Transverse Variability Assessment

Issues were encountered when conducting ASTM D 2995 Test Method A tests in the field. Given these issues and the fact that ASTM D 2995 Test Method B allows for measuring emulsion output of individual nozzles, it is recommended that ASTM D 2995 Test Method B be implemented to assess transverse variability in EARs rather than Test Method A. TXDOT specifications stipulate that the output rate of individual nozzles should not vary more than 10% from the mean. If variability exceeds the 10% criterion, adjustments / re-calibration are necessary. The proposed practice for QC of EARs, provided in Appendix B, includes provisions for ASTM D 2995 Test Method B to assess transverse variability. It is recommended that transverse variability be assessed each day before the start of construction and TXDOT specification criteria are proposed in the developed practice.

7. FINDINGS AND CONCLUSIONS

The following summarizes the primary findings and conclusions of this study:

- Very few methods exist in the literature for QC of EARs. None of the methods identified in the literature was developed specifically to quantify EARs in-situ, at specific locations along the length of paving.
- Three components must be addressed for comprehensive QC of EARs in the field: (1) assessment of transverse variability in applied EARs prior to construction, (2) adjustment of the applied EAR to account for emulsion absorption by the paving surface, and (3) assessment of longitudinal variability in applied EARs at specific locations along the length of paving.
- Use of ASTM D 2995 Test Method A was evaluated for assessing both longitudinal and transverse variability in EARs. Issues were encountered and procedure is not recommended for implementation. The geotextile pads used in ASTM D 2995 Test

Method A proved to be difficult to handle and emulsion was often lost to dripping from the pad edges. Furthermore, pads placed in the wheel path adhered to the distributor, precluding measurement of EARs in the wheel path.

- The Tack Lifter was developed as a simple and efficient means for in-situ measurements of applied EARs and "effective" EARs, neglecting emulsion absorbed by the paving surface. The Tack Lifter consists of a weight device, frame, and absorbent sheet. Following emulsion application by a distributor, the frame is applied to the surface of interest to seal the test area. The absorbent sheet is inserted into the frame and the weighted device is applied. Emulsion is absorbed into the sheet. The weight of emulsion combined with the sheet area is used to obtain a spot check of EAR. Tests can be applied directly to the paving surface provide a measure of effective EAR. Alternatively, tests can be applied to pans placed on the paving surface prior to emulsion application to provide a measure of the applied EAR.
- The difference between applied and effective EARs measured by the Tack Lifter allows for quantifying the rate by which a pavement absorbs applied emulsion.
- Field and laboratory investigations indicate the amount of emulsion absorbed by a paving surface is influenced by surface type and texture. Rougher surface texture leads to a higher rate of emulsion absorption by the paving surface than smoother texture. Furthermore, the mechanisms of absorption can differ on the basis of surface type (e.g., asphalt concrete versus chip seal).
- Field investigations indicate emulsion absorption by pavements in the wheel path can be significant (on the order of 0.05 gal/yd^2). The target, applied EAR should be adjusted to account for emulsion lost to absorption. Field investigations were limited to pavements containing granite aggregate.
- It is recommended that Tack Lifter tests applied in the wheel path to flat, steel pans and the paving surface be conducted on a test section prior to construction to allow for quantifying the rate by which the pavement absorbs emulsion. Results can be used to guide adjustment of the target EAR. Field investigations indicate that the rate by which a pavement absorbs emulsion does not vary appreciably along the length of paving, given surface conditions are consistent. If significant changes in surface conditions (e.g., texture, cracking) are observed at intermediate locations along the length of paving, measurements can be repeated and the applied EAR can be adjusted accordingly.
- The Tack Lifter is not a suitable test method for QC of transverse variability in EARs. Field investigations suggest that transverse variability is relatively consistent along the length of paving, which suggests it should be addressed prior to rather than during construction. Evaluation of transverse variability of EARs at specific locations along the length of paving is deemed impractical and unnecessary.
- ASTM D 2995 Test Method B is recommended for QC of transverse variability in EARs each day prior to construction. ASTM D 2995 Test Method B allows for assessing the EAR of individual emulsion distributor nozzles, allowing for easy identification and corresponding adjustment of the source(s) of variability.
- Elevated plates and a peel were developed to allow for removal of test specimens from the roadway following emulsion application to minimize delays in construction operations. Elevated plates can be transferred to a leveling table placed off of the roadway and subjected to Tack Lifter testing to determine the applied EAR. Removing

plates from the roadway immediately after emulsion application allows for construction operations to progress more quickly than conducted tests on the roadway. In the construction of chip seals, aggregate application quickly follows the application of emulsion and thus, minimizing delays between emulsion and aggregate application is critical. In tack coat applications, there are not such tight time constraints. Elevated plates consist of steel plates with legs and a lip. The peel allows for removing elevated plates from the roadway, while keeping plates level.

- Tack Lifter tests conducted on elevated plates following removal from the roadway is recommended for assessment of longitudinal variability in applied EARs. It is important to note that elevated plates must be placed in the center of the lane to avoid being crushed by the distributor. However, it is recommended that transverse variability in EARs and the rate by which a pavement absorbs emulsion be addressed prior to construction and hence, measurement of applied EARs in the lane center is deemed sufficient to assess longitudinal variability.
- Field investigations indicate applied EARs can vary over relatively short segments of road and therefore, it is recommended that an elevated plate be placed every 0.5 miles along the length of paving to obtain a spot check of EAR. Investigations also suggest changes in curvature and / or grade may impact variability in applied EARs. Hence, it is also suggested that tests be conducted at critical locations where significant changes in grade or curvature are noted.

8. RECOMMENDATIONS

The following recommendations are proposed:

- The proposed practice for QC of EARs provided in Appendix B should be adopted to improve the performance of tack coats and surface treatments.
- Future research should seek to refine recommendations for testing frequency and number of replicates included in the proposed practice based on additional field testing.
- Future field experiments on sections with differing aggregate type (e.g., limestone, lightweight) should be conducted to determine the impact of aggregate mineralogy on absorption.
- Future research should identify how deviations from the target EAR affect the performance of tack coats and surface treatments, which could be used to guide definition of acceptable variability in EARs for QC.
- Future research should investigate mechanisms to reduce the weight of the Tack Lifter device for easier handling. For example, a pneumatic piston could be used to induce loading on the Tack Lifter sheet rather than the use of dead weights.
- Future research should explore the development of the relationship between surface type, texture, emulsion viscosity, applied EAR, and absorption rates via a large, comprehensive field experimental plan to eliminate the need for Tack Lifter testing to determine absorption.

9. IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

The primary product of this study is a proposed practice for QC of EARs (Appendix B). It is recommended that the developed practice be implemented in NCDOT specifications. The test methods included in the proposed practice for QC of EAR would be conducted by bituminous pavement maintenance personnel if adopted. Alternatively, if roadway construction is contracted, NCDOT inspectors would perform the QC tests. The practice includes three test methods to address: (1) transverse variability, (2) adjustment of target EAR to account for emulsion absorbed by the paving surface and (3) longitudinal variability. The practice includes detailed test procedures. Test procedures are relatively simple. However, training videos and / or classes can be developed to supplement the proposed practice document to train NCDOT personnel. Instrotek is interested in further developing and marketing the Tack Lifter device if it NCDOT anticipates considering it further. In addition, results will be disseminated through journal publications and conference presentations.

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APPENDIX A: LITERATURE REVIEW

A.1 Introduction

Asphalt emulsions are used as tack coats to bond hot-mix asphalt layers and as a bonding agent for aggregates in chip seals. The rate of emulsion application is critical to the performance of both tack coats and chip seals. It has been demonstrated that field emulsion applications rates can be highly variable, which is not captured using current measures for quality control. Thus, it has become imperative to develop a test method for determining emulsion application rate at specific locations along a roadway in order to provide quality control during construction. Improved quality control of emulsion application rates will result in prolonged service life, decreased life cycle costs, and enhanced safety.

The literature review herein is aimed at identifying existing methods for quality control of emulsion application rates. In addition, the significance of emulsion application rate in determining the performance of both chip seals and tack coats is investigated along with a review of emulsion distributors and corresponding sources of variability in field emulsion application rates. The literature search conducted highlights the importance of emulsion application rates in determining performance. However, a comprehensive search of existing literature also revealed that relatively few methods and documented literature exists on the topic of quality control of emulsion application rates. Furthermore, existing methods have significant short comings, which will be discussed and used to aid development of an improved quality control test in this project.

A.2 Importance of Emulsion Application Rate in Tack Coat Performance

Tack coats are essential for load transfer between pavement layers and thus are a critical component of a pavement structure. The tack coat type and application rate are important design considerations. NCDOT currently specifies tack coat application rates based on the condition of the existing pavement surface to which the tack coat is being applied (Table A.1) (NCDOT Best Practices for Tack Coats, 2012).

Table A.1 NCDOT Tack Coat Application Specification

Existing Surface	Target Rate (gal/yd^2)
New Asphalt	0.04 (+/- 0.01)
Oxidized or Milled	0.06 (+/- 0.01)
Concrete	0.08 (+/- 0.01)

The bonding between adjacent layers imposed by a tack coat is critical to ensure the system acts as a single layer. Tack coat failure can occur in two modes: tensile and shear as depicted in Figure A.1, which can lead to a variety of distresses, including slippage cracking, top-down cracking, premature fatigue cracking, pothole development, and complete delamination. Excessive emulsion application rates (EARs) cause slippage / delamination whereas insufficient EARs can lead to lack of adhesion between layers / debonding (Leng et al., 2008).

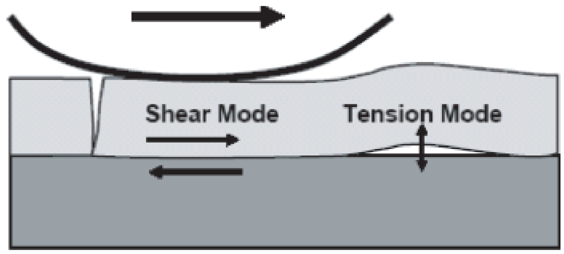

Figure A.1 Tack coat failure modes (Source: Raab and Partl 2004)

Hakimzadeh et al. (2012) studied the effect of tack coat application rate on both tensile fracture energy and shear strength of hot-mix asphalt interlayer systems. Results shown in Figures A.2 and A.3 demonstrate the significant impact EAR can have on both tensile and shear failure and thus, the importance of quality control.

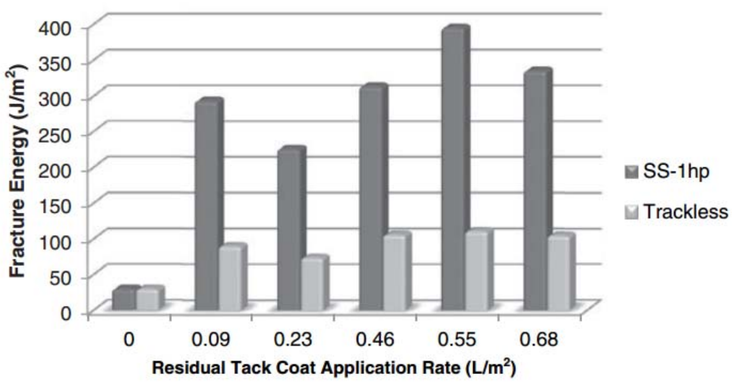

Figure A.2 Effect of tack coat application rate on tensile fracture energy (Source: Hakimzadeh et al. 2012)

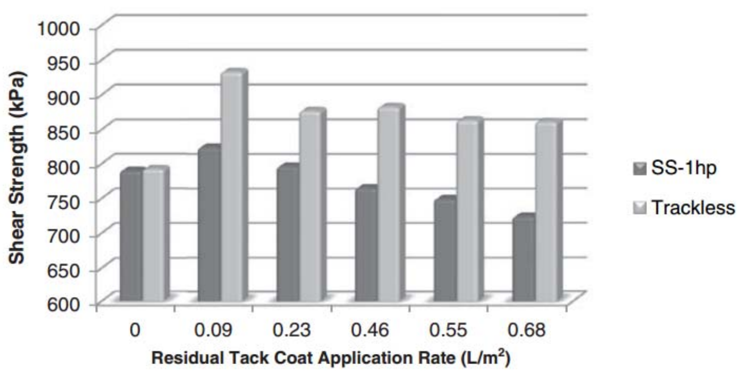

Figure A.3 Effect of tack coat application rate on shear strength (Source: Hakimzadeh et al. 2012)

Mohammad et al. (2010) also studied the effect of residual tack coat application rate on tensile and shear strength of hot-mix asphalt interlayer systems. Results presented in Figure A.4 demonstrate significant effect emulsion application rate can have on fracture resistance. In addition, the study by Mohammad et al. (2010) indicated errors in field emulsion application rates are often 30%, which based on their results could have a significant effect on performance, thus indicating the importance of quality control.

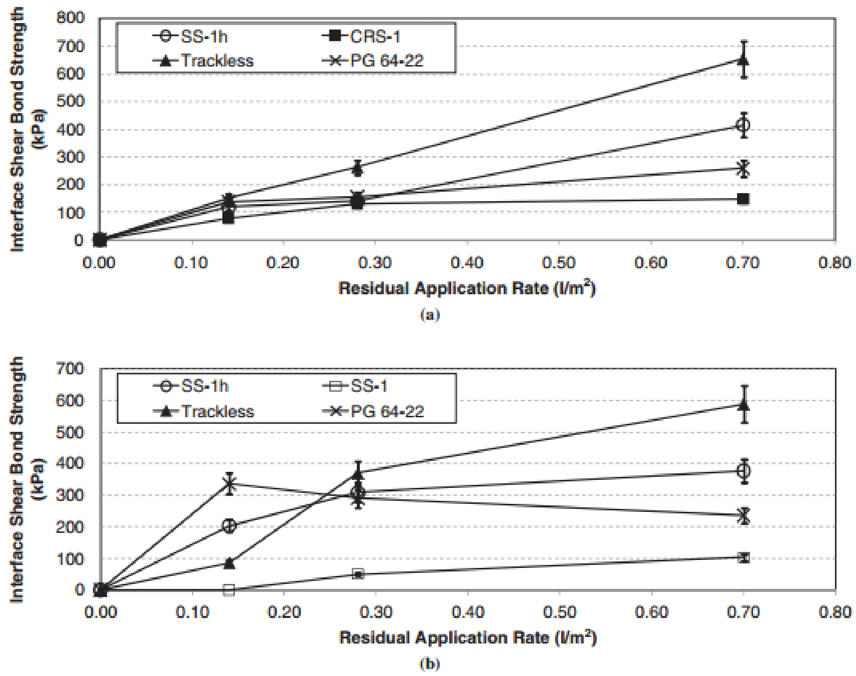

Figure A.4 Effects of emulsion residue application rate on (a) interfacial shear strength, and (b) interfacial shear strength (Source: Mohammad et al. 2010)

A.3 Importance of Emulsion Application Rate in Surface Treatment Performance

Performance of pavement surface treatments, such as chip seals, are also known to be significantly affected by EAR. Gurer et al. (2012) conducted a field study of the performance of five chip seals and found that deterioration was highly correlated to how closely actual in-situ emulsion application rates were relative to the target application rate. For two of the five sections, emulsion application rates were close to target but for the other three (Soma, Aksar, and Finike), field rates were found to be 30% different than the target. These three sections were found to have the poorest performance as evident by Figure A.5, which shows raveling deterioration indices for the sections. Note that a lower index indicates poorer performance.

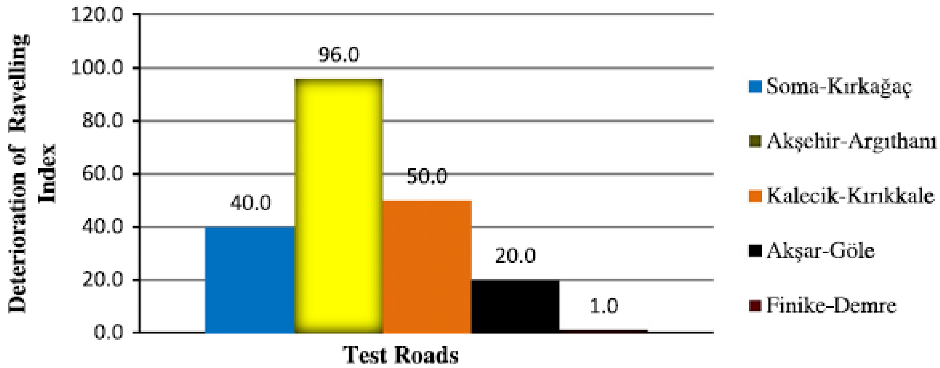

Figure A.5 Field observations of raveling performance (Source: Gurer et al. 2012)

Because surface treatment performance is known to be affected by EAR, surface treatment design methods include specifications for EAR. Emulsion application rate is a critical design parameter for chip seals. For example, the recently developed NCSU performance based chip seal mix design procedure developed during HWY-2008-04 project, (currently under validation and consideration by NCDOT), specifies selection of the EAR such that 50% aggregate embedment is achieved. This procedure assumes that the optimal EAR is achieved by filling the available voids under the surface profile of a single stone layer of ideal spherical aggregate particles as demonstrated in Figure A.6, which has been shown to give optimal performance (Kim et al. 2011).

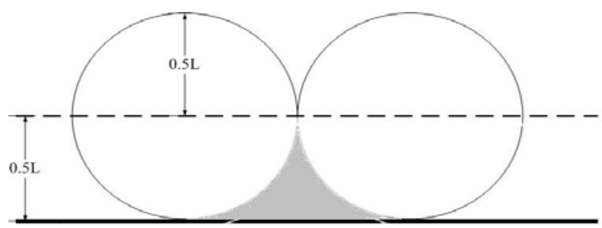

Figure A.6 Depiction of 50% embedment concept (Source: Kim et al. 2011)

To calculate the required EAR based on the 50% embedment concept, surface profile views of aggregates placed on a board are determined using a 3D laser profiler. Surface profile views are used to determine the total volume below the surface profile (red line in Figure A.7). The void volume (i.e., volume to be filled with emulsion) is determined by subtracting the volume of aggregate, determined using the known aggregate weight and the specific gravity, from the total volume in the surface profile (i.e., below line in Figure A.8). The EAR is then calculated by converting the total void volume to the corresponding weight of the emulsion using the specific gravity of the emulsion.

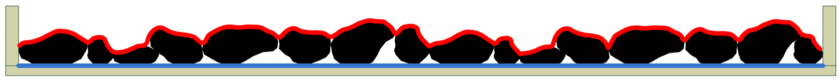

Figure A.7 Profile view obtained from the modified board test (Source: Kim et al. 2011)

Adjustments to the EAR are then made to account for emulsion absorption into the existing pavement surface and aggregate. In the NCSU chip seal design procedure, emulsion absorption into an existing pavement is determined using a surface profile of the existing roadway surface obtained from the laser profiler. In this method, it is assumed that all voids a reference line constructed as the average of all aggregate peaks will absorb emulsion. To account for aggregate absorption, the McLeod method is adopted, which suggests adding 0.02 gal/yd^2 of emulsion if the aggregate absorption is at or above 2%. No adjustments are necessary if aggregate absorption is below 2%.

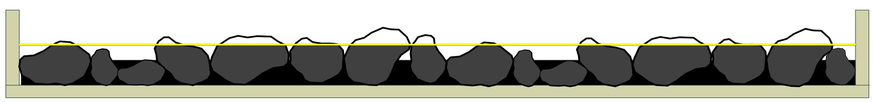

Figure A.8 Profile of existing asphalt surface (Source: Kim et al. 2011)

The importance of EAR in chip seal performance is highlighted in Figures A.8 and A.9, which show results of accelerated simulated traffic testing of chip seals in the Model Mobile Load Simulator (MMLS3). The design EAR based on the NCSU mix procedure was determined to be 0.2 gal/yd^2 for the chip seal results presented in Figures A.9 and A.10. It can be seen that bleeding drastically increases if the EAR exceeds 0.2 gal/yd^2 and that aggregate loss decreases with increasing EAR. Thus, it is imperative that emulsion application rates are precisely controlled to ensure adequate performance.

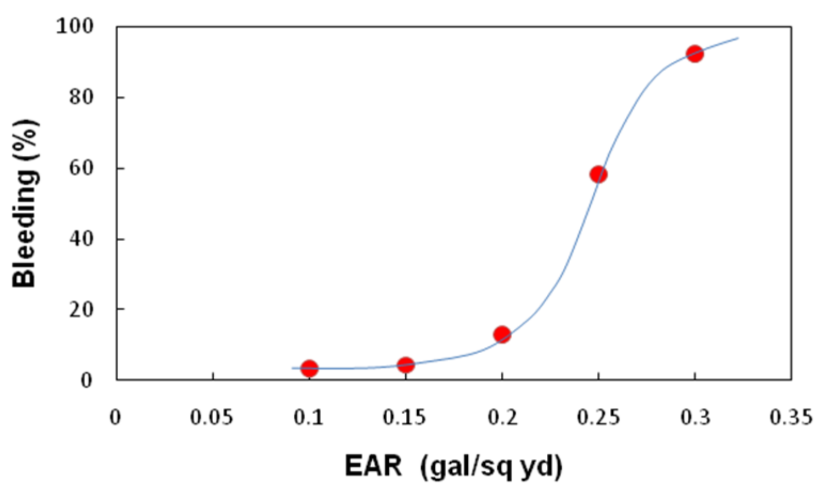

Figure A.38 Effect of EAR on bleeding (Source: Kim et al. 2011)

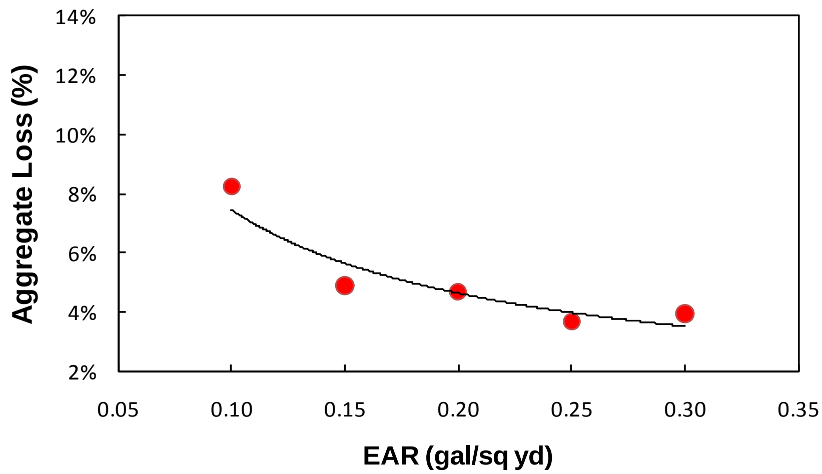

Figure A.10 Effect of EAR on aggregate loss (Source: Kim et al. 2011)

A.4 Emulsion Distributors

In developing a method for quality control of EAR, it is important to understand how emulsions are applied and what factors affect application rates. Results of a worldwide survey conducted by Mohammad et al. (2012) (Figure A.11) revealed that asphalt emulsions are typically applied using a conventional distributor with a spray bar. A few survey respondents reported use of hand wands and specially designed pavers with an emulsion tank and spray bar attached. Due to the overwhelming use compared to other technology for emulsion application, the discussion and proposed research herein will focus on conventional emulsion distributors.

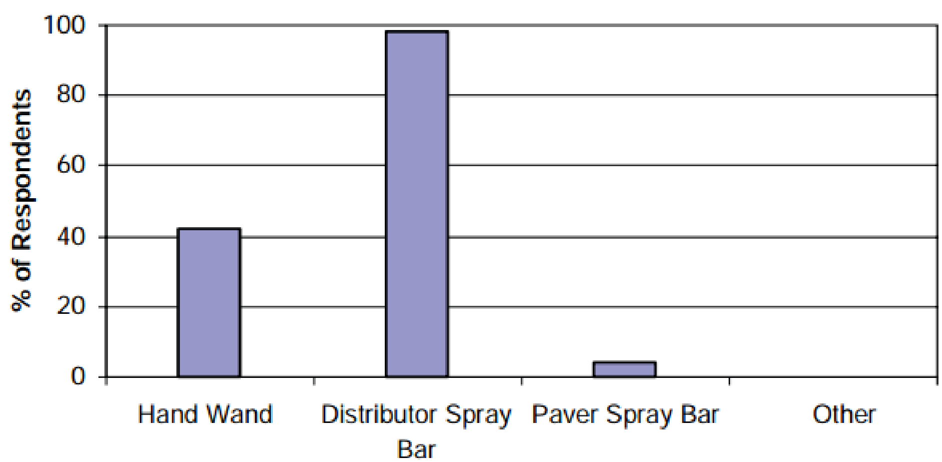

Figure A.39 Emulsion application technology (Source: Mohammad et al. 2012)

Emulsion distributors contain asphalt tanks affixed with a spray bar mounted to the truck chassis (Figure A.12). The general components of an emulsion distributor are as follows (Gransberg and James 2005; Shuler et al. 2011):

1. Insulated asphalt tank
2. Heating system and circulation pump
3. Spray bar and nozzles
4. Distributor controls and gauges

The insulated tank is required for storing emulsified asphalt at constant temperature. A heating system, typically comprised of burners, is used to heat the asphalt emulsion in the tank. A pump circulates the emulsion to maintain uniform temperature. The spray bar hosts a series of nozzles to allow for application of the emulsion onto the paving surface. Nozzles control the spray pattern and can be produced with varying size openings to allow for compatibility with different materials and spray requirements. The nozzles are all oriented at an angle to provide a fan-shaped pattern to provide full coverage and minimize transverse variability as shown in Figure A.13.

Figure A.40 Emulsion distributor (Source: Mohammad et al. 2012).

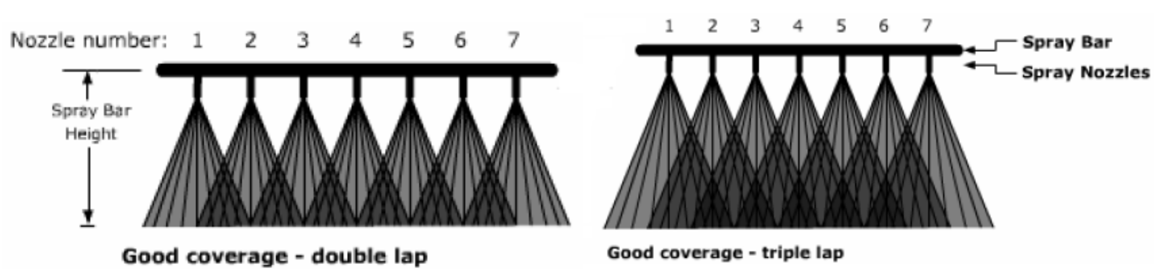

Figure A.13 Emulsion spray bar configuration (Source: Mohammed and Button 2005).

Typically, distributors include computerized systems with tachometers for precisely controlling / monitoring distributor speed, volume measuring devices to monitor the quantity of emulsion in the tank, pressure gauges, thermometer, and controls for adjusting pressure / rate, spray bar height, and spray bar width.

These systems typically adjust the pressure of the material to compensate for speed variation of the vehicle, and also allow the operator to quickly make adjust application rate adjust spray bar height and width, and shut off individual spray bar sections from the cab (Gransberg and James 2005). Gransberg and James (2005) conducted a survey to determine relative use of computerized and non-computerized distributors. Results presented in Figure A.14 demonstrate 37% use of non-computerized distributors in the U.S. Non-computerized distributors require synchronization of the truck speed/RPM, the asphalt pump pressure/discharge (gpm), and the bar height to obtain the required application rate, which is very tedious and difficult, often requiring multiple operators of a single distributor.

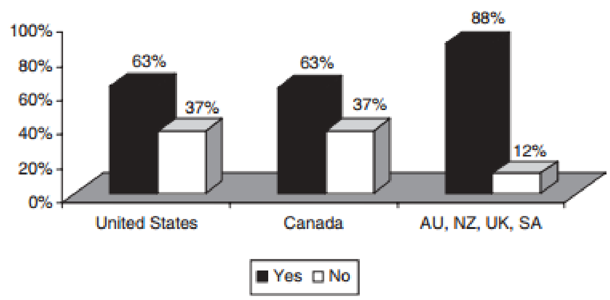

Figure A.14 Percentage use of automated (yes) versus non-automated (no) emulsion distributors (Source: Gransberg and James 2005).

A.5 Factors Affecting In-Situ Emulsion Application Rate

A number of factors influence emulsion application rate and thus, can lead to construction variability. A summary of key influencing factors follows (Mohammad et al. 2012):

1. Spray bar height: Spray bar height controls the distance between nozzles and the application surface and thus, is an important factor in determining EAR. As emulsion is applied, the tank becomes lighter which leads to a natural rise in the spray bar tank. It is important that emulsion distributors are equipped with a means to compensate for this rise.

2. Nozzle pattern: For uniform application, nozzles should be equally spaced and oriented at the same angle (Figure A.15). Discrepancies between individual nozzle angles gives rise to transverse variability in emulsion application rate. Nozzle angle settings are usually set between 15 and 30 degrees. Typically, nozzle spacing and angles are selected such that there is overlap in the spray pattern of individual nozzles (Figure A.13) to ensure full coverage and promote uniform film thickness.

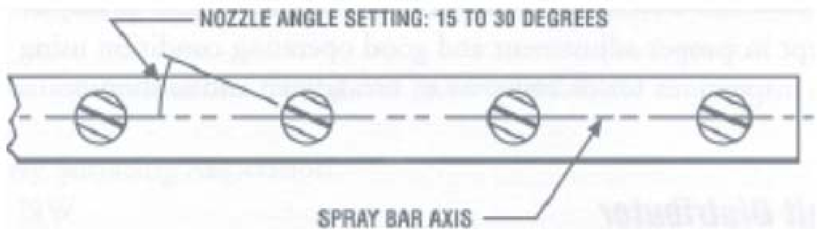

Figure A.15 Depiction of nozzle angle (Source: Mohammad et al. 2012).

3. Nozzle size: Selection of appropriate nozzle size is important. If a nozzle opening is too small, pressure can build up and nozzles can clog leading to poor coverage and uniformity.

4. Distributor pressure: Constant nozzle pressure needs to be maintained to minimize longitudinal variability in emulsion application rate over the length of paving. Pressure gauges must be fully operational and calibrated regularly for accurate regulation of pressure.

5. Temperature: The temperature within the emulsion tank must be precisely controlled and maintained to minimize variability in emulsion viscosity and to avoid premature breaking.

It is imperative that all of the above factors be calibrated regularly to minimize variability and discrepancies between prescribed and actual emulsion application rates. However, a survey conducted in 2005 revealed that 25% of agencies in North America do not require calibration (Gransbergand James 2005).

In addition, the existing pavement surface texture impacts the “effective” application rate. This is reflected in NCDOT’s guidelines for tack coat application rates (Table A.1). Surface absorption is also considered in some chip seal design methods, including the McLeod for which specifications for adjustments are given in Table 2. Depending on the category in which the existing surface is placed upon inspection, the appropriate correction factor from the McLeod method is then applied to the final design EAR. It can be seen that corrections can be significant (up to 0.06 gal/yd^2).

Table A.2 McLeod Method’s Qualitative Existing Pavement Surface Correction Factor (Source: McLeod 1969)

Existing Pavement Surface Texture	Correction (in gal/yd^2)
Black, flushed asphalt surface	-0.06
Smooth, nonporous surface	-0.03
Slightly porous, oxidized surface	0.00
Slightly pocked, porous, oxidized surface	+0.03
Badly pocked, porous, oxidized surface	+0.06

A.6 NCDOT’s Current Practice for Quality Control of Emulsion Application Rate

Based on NCDOT’s “Best Practices Field Guide” for tack coats, two methods are allowed for quality control of EAR. In Method 1, the flow meter on the distributer is checked before and after paving to determine the total number of gallons of emulsion applied. In Method 2, a calibrated dipstick in the distributor tank is used to check emulsion quantity before and after paving to determine the amount placed in the field (depicted in Figure A.16). Method 2 is only required once per year. Neither Method 1 nor 2 allows for capturing local variability in emulsion application rate.

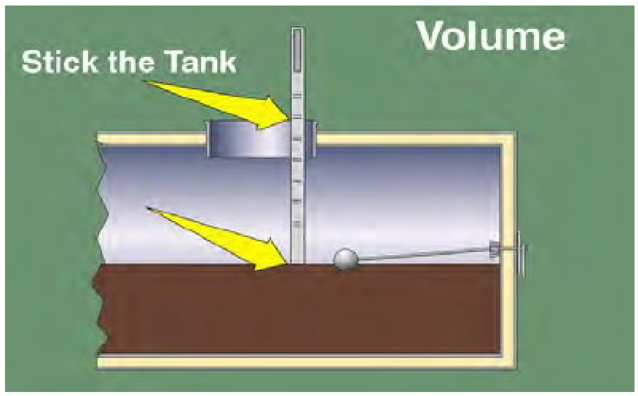

Figure A.16 Depiction of Method 2 (Source: Tack Coat Best Practices Field Guide 2012, NCDOT)

Additional measures to minimize deviation from target emulsion application rates specified in the best practices guide include requirements of calibration and check of set-point of:

(a) Temperature gauges
(b) Spray bar height (11-12 inches)
(c) Nozzle angle (set to 30 degrees)
(d) Application rate gauge (to ensure proper setting)
(e) Tank gauge (to check quantity)

A.7 Existing Methods for Quality Control of Emulsion Application Rate

Despite the significance of EAR in determining surface treatment and tack coat performance, very few measures exist for quality control of in-situ emulsion application rates. Mohammad et al. (2012) conducted an international survey to identify the methods that are currently being utilized for quality control of emulsion application rates. The results, based on 72 respondents, are provided in Figure A.17.

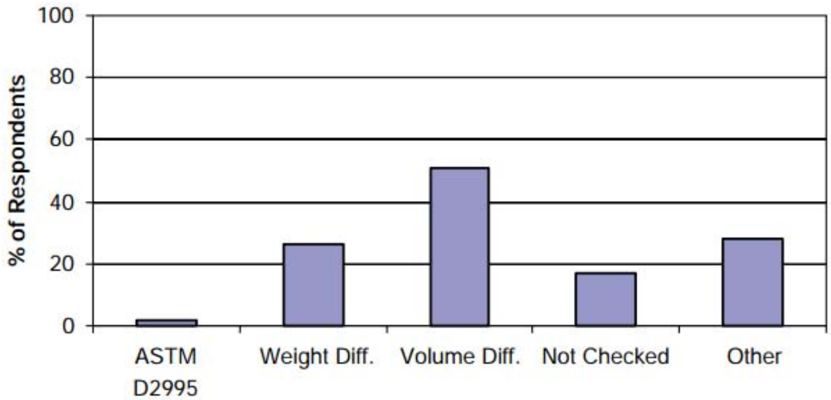

Figure A.17 Measures used for quality control of emulsion application rate (Source: Mohammad et al. 2012).

The majority of respondents indicated that the change in volume of emulsion in the distributor tank before and after paving is the only measure used to check application rate. Additionally, 27% of respondents reported use of the change in tank weight along the entire length of paving as their quality control measure and 18% reported that no quality control measure is taken. Only 2% of respondents reported use of *ASTM D 2995: Standard Practice for Estimating Application Rate of Bituminous Distributors,* which allows for spot checks of emulsion application rate to assess transverse and longitudinal variability even though it is a recommended by the Federal Highway Administration's "Chip Seal Application Checklist". Other methods reported included visual inspection of uniformity, meter on distributor, and dip-stick reading before and after paving.

ASTM D 2995 is the only standard procedure identified in the literature that is currently used by agents that allows for consideration of local variability in emulsion application rate. The procedure includes provisions for two test methods. The first consists of spot checks, in which the distributer applies emulsion to a standard size tarp placed on the roadway. The tarp is weighed before and after emulsion application to determine a spot rate. Tarps can be aligned transversely or longitudinally to study the location dependence of emulsion application rate (Figure A.18). In the second method (Figure A.19), containers are placed directly under each nozzle and distributer releases emulsion for a set amount of time. The emulsion volume in the containers can be used to estimate the application rate. Note that the second method can only check transverse variability.

Figure A.18 Depiction of ASTM D 2995 procedure 1 (Source: West et al., 2005)

Figure A.19 Depiction of ASTM D 2995 procedure 2 (Source: Krugler et al., 2009)

Caltrans (2009) has a specified test, “California Test 339” which is essentially a modified version of ASTM D 2995 in which specifications of acceptances are based on residual asphalt rather than emulsion application rate.

While ASTM D 2995 is currently in limited use, a few studies have sought to evaluate it. Based on results of a field study, West et al. (2005) stressed the importance of measuring in-situ application rates. West et al. (2005) used ASTM D 2995 to check transverse and longitudinal variability of emulsion application rate and found discrepancy between prescribed and in-situ rates, which the authors attributed to poor calibration of distributors. While West et al. (2005) found ASTM D 2995 to be effective, Mohammad et al. (2012) reported that the procedure is a “lengthy process and required multiple calibration runs to ensure accuracy and uniformity of tack coat application.” In addition, Muench and Moomaw (2008) questioned West’s findings that

ASTM D 2995 was effective, stating that, “West et al. (2005) reported application rates significantly different than target rates on 3 of 6 field projects measured by ASTM D 2995. Coincidentally, all 3 of these projects were CRS-2 emulsion tack coats, while those that most closely match target rates were straight paving grade asphalt tack coats (2 projects) and 1 special heavy application of a polymer modified emulsion…One possible cause may be that these emulsions lost water weight before they were weighed making the measurement inaccurate. It remains to be seen whether the mismatch between target and actual application rates is caused by improper/variable tack truck application rates or ASTM D 2995 measurement inadequacies.”

Tashman et al. (2006) also evaluated ASTM D 2995, with a slightly modified procedure consisting of measurement of emulsion application rate directly after application and residue rate after curing. Theoretical calculations of residual rates based on emulsion results were in disagreement with measured values and it was found that similar results for residual asphalt rate were obtained regardless of the target emulsion application rate, which led to questioning of the validity of the test.

Another criticism of ASTM D 2995 is that it does not allow for measure of absorption of the pavement surface (Raposeiras et al. 2013). Researchers from Spain (Raposeiras et al. 2013) developed a prototype device to measure the effective emulsion application rate, considering absorption by the existing surface. The device used, shown in Figure A.20, consisted of a non-woven polypropylene geotextile was affixed to a steel plate which was pressed onto a pavement surface with emulsion applied. The geotextile absorbed the non-absorbed emulsion on the pavement surface allowing for measurement of the “effective” in-situ emulsion application rate. In order to reduce variability and increase effectiveness, a standard weight of 20kg was applied to the 250mm by 250mm steel plate (leading to a pressure of 3.14kPa) for 5 minutes. In their study, the amount of emulsion absorbed by weight difference at 20°C was used to quantify the effective emulsion rate on the surface. In addition, a10mm thick polypropylene foam was placed between the steel plate and geotextile to allow for accommodating surface imperfections. It was found that if the load application time was longer than 5 minutes, the emulsion begins to break and the geotextile is not able to absorb the broken emulsion. However, one criticism of the study is that the control device was tested at only 20°C, which is not a realistic temperature during field construction.

Figure A.20 Depiction of Rasposeiras et al. (2013) test device

Raposeiras et al. (2013) tried their procedure on several emulsion types, target application rates, and application surfaces with differing macro-textures (quantified using a modified sand patch test using ophitic filler). They were able to correlate the macro-texture of the existing surface to the amount of emulsion absorbed by the geotextile. The results show that the percentage of emulsion absorbed by the geotextile is highly related to the surface macro-texture of the samples where the emulsion is applied and is also sensitive to emulsion application rate but not emulsion type. Based on the results, the authors concluded that their developed device can be used to measure the "effective" rate of emulsion acting as a bonding agent.

A.8 Summary and Implications of Reviewed Literature

The importance of emulsion application rate in determining the performance of surface treatments and tack coats has been clearly demonstrated by previous research. Despite this known importance, few methods exist for quality control. Thus, there is a need for development of a simple, easy to use test method to precisely determine in-situ emulsion application rates. Existing methods are summarized in Table A.3. Based on the literature review, it is evident the ability to capture local variability, consider surface absorption, and measure both emulsion and residual asphalt rates are all of significance and hence, the ability of existing methods to perform these tasks is included.

Table A.3 Summary of Existing Methods for Quality Control of EAR

Method	Able to Capture Local Variability	Ability to Measure Residue Rate	Consider Surface Absorption
Visual inspection	No	No	No
Weight difference	No	No	No
Volume difference	No	No	No
Dipstick reading before and after paving	No	No	No
ASTM D 2995	Yes	No	No
Caltrans 339	Yes	Yes	No
Raposeiras et al. (2013)	Yes	No	Yes

The only standard procedure for obtaining spot checks of local variability is ASTM D 2995. While the procedure has potential to precisely measure emulsion application rate, the procedure imposes several short comings. First, users have noted the procedure is considered labor intensive and errors may often exist due to fast breaking / curing of emulsions. Second, it determines the total amount of emulsion applied, which does not allow for quantification of “effective” emulsion acting as a bonding agent versus that absorbed by the application surface. Raposeiras et al. (2013) developed a prototype device that may overcome limitations of ASTM D2995 by allowing for measuring “effective” EAR by accounting for absorption by surface emulsion is applied to. Furthermore, their study suggests by specifying and limiting time delay between measurement and emulsion placement, issues associated with breaking / curing can be avoided. The reviewed literature also suggests standard emulsion distributors are equipped with gauges for monitoring emulsion output and distributor speed, suggesting the potential opportunity for better utilization of existing equipment.

Based on the aforementioned factors, efforts will proceed in developing the “tack lifter” with the help of Instrotek, Inc. as suggested in the proposal. The recent study by Raposeiras et al. (2013) presents a similar concept to the tack lifter and thus, the findings of their study will be given careful consideration in proceeding research. As a parallel and secondary effort, further investigation of the opportunity to better utilize / specify distributor measurements to aid in quality control will be conducted.

APPENDIX B PROPOSED PRACTICE FOR QUALITY CONTROL OF EMULSION APPLICATION RATES

Proposed Practice for

Quality Control of Emulsion Application Rates

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1. SCOPE

1.1 This practice covers quality control of emulsion application rates (EARs) in tack coat and surface treatment applications. Quality control of EARs includes: (1) measurement of transverse variability, (2) adjustment of target EAR to account for emulsion absorbed by the paving surface and (3) measurement of longitudinal variability.

1.2 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.3 The values stated in inch-pound units are to be regarded as the standard.

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2. REFERENCED DOCUMENTS

2.1 *ASTM Standards*:

- D 2995-99, Standard Practice for Estimating Application Rate of Bituminous Distributors

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3. SUMMARY OF PRACTICE

3.1 *Test Method A*:

3.1.1 This test method follows ASTM D 2995 Test Method B. Elliptical containers are placed under each nozzle of an emulsion distributor. Emulsion is sprayed into the containers for a specified time. The volume of emulsion in each container is then measured. Comparison between the quantities of emulsion deposited into each container allows for assessment of transverse variability in emulsion application. If the emulsion output of any nozzle deviates more than 10% from the mean, adjustment is required to correct the problem and testing should be repeated.

3.2 *Test Method B*:

3.2.1 Flat, steel pans are placed on the surface of the roadway in front of the emulsion distributor in the wheel paths. The emulsion distributor is driven over the steel pans while spraying asphalt emulsion. Frames are placed on the pans and on the paving surface. Pre-weighed foam sheets are placed into each frame. A weighted device is placed on each foam sheet. The foam sheets are removed from the frames and re-weighed. The weight of emulsion absorbed by each sheet is determined by subtraction and converted to EAR using the known sheet area. The difference between average EAR measurements corresponding to sheets placed on pads and the paving surface is calculated and reported as the absorption rate. Absorbed emulsion is not available for bonding to material placed on top of the emulsion. Therefore, the target application EAR can be increased by the measured absorption rate in order to improve quality.

3.3 *Test Method C*:

3.3.1 Elevated, steel plates are placed on the surface of the roadway in front of the emulsion distributor in the lane center. Elevated plates should be spaced in 0.5 mile increments or whenever a change in curvature or grade is noted. The emulsion distributor is driven over the elevated plates while spraying asphalt emulsion. Each plate is transferred to a leveling table placed on the side of the roadway directly following emulsion application using a steel peel. A frame is placed on the plates. A pre-weighed foam sheets is placed into the frame. A weighted device is placed onto the foam sheet. The foam sheets are removed from the frames and re-weighed. The weight of emulsion absorbed by each sheet is determined by subtraction and converted to EAR using the known sheet area. Differences in EAR values measured along the length of paving can be used to assess longitudinal variability.

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4. APPARATUS

4.1 *Test Methods A, B, and C*:

4.1.1 *Scale* – sensitive to +/- 0.05 g

4.1.2 *Weighing Box* – to protect scale from wind when used at the project site

4.2 *Test Method A*:

4.2.1 *Elliptical Containers* – containers measuring approximately 3.5 in along the short axis and 9 in along the long axis of the ellipse with 8 in height with approximately one gallon capacity.

4.2.2 *Rubber Bands* – used to hold the plastic bags in place around the elliptical containers.

4.2.3 *Stopwatch* – capable of recording to the nearest 0.1s.

4.2.4 *Plastic Bags* – capable of fitting inside elliptical containers but of a sufficiently larger dimension to allow folding over the edge of the container once placed inside.

4.3 *Test Methods B and C:*

4.3.1 *Tack Lifter* – consisting of a weighted device including a base and handle, weighing 35 lb. The device has a square base that measures 5 in by 5 in. A 2 ft. long handle is attached through the center of the weights.

4.3.2 *Sheet* – consisting of a 5 in by 5 in super-absorbent, polyurethane foam with density of 1.8 lb/ft^3, firmness of 0.6 psi. Sheets can be purchased from McMaster Carr.

4.3.3 *Frame* – consisting of a steel with a rubber, pliable gasket along its bottom edges. The gasket conforms to the surface texture, sealing the area of interest from intrusion of additional emulsion. The inner dimensions of the gasket are 5.25 in by 5.25 in. The out dimensions of the gasket are 5.75 in by 5.75 in.

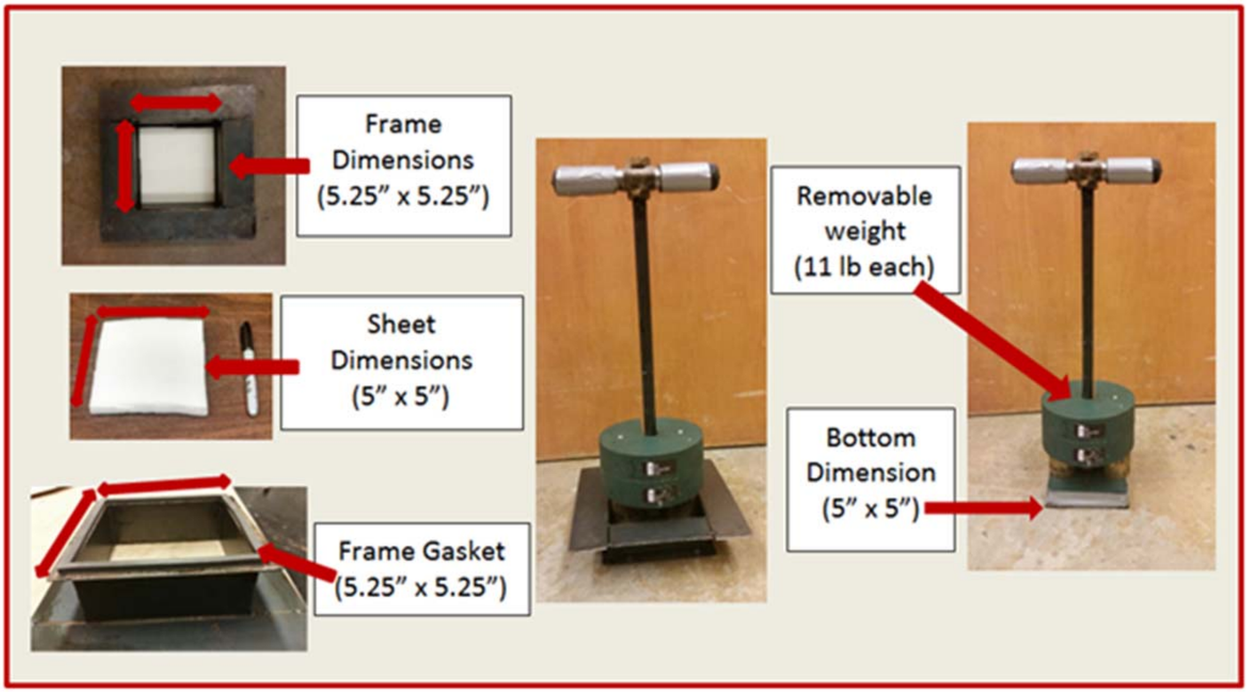

Figure 1—Tack Lifter Components

4.4 *Test Method A*:

4.4.1 Flat pan – comprised of steel, with an outer dimension of 8 in by 8 in and a maximum thickness of 0.25 in.

4.5 *Test Method C*:

4.5.1 *Elevated Plate* – comprised of a steel pan with legs and lip. The inner dimensions of the plates are 7 in by 7 in. The height of each of the four legs, located at the plate’s corners, is 0.5 in. The lip has a 3/8 in height along the plate’s perimeter.

4.5.2 *Peel* – to remove the elevated plate from the paving surface while keeping the plate level. It is comprised of a flat rectangular sheet of steel that is 6 in wide and 8.5 in long with a 16 in handle. The peel also has a lip at the tip to “catch” the plate when removing it so it would not slide off the front of the peel. The lip has 1 in height.

4.5.3 *Leveling Table* – to place the elevated plate on after removal from the paving surface.

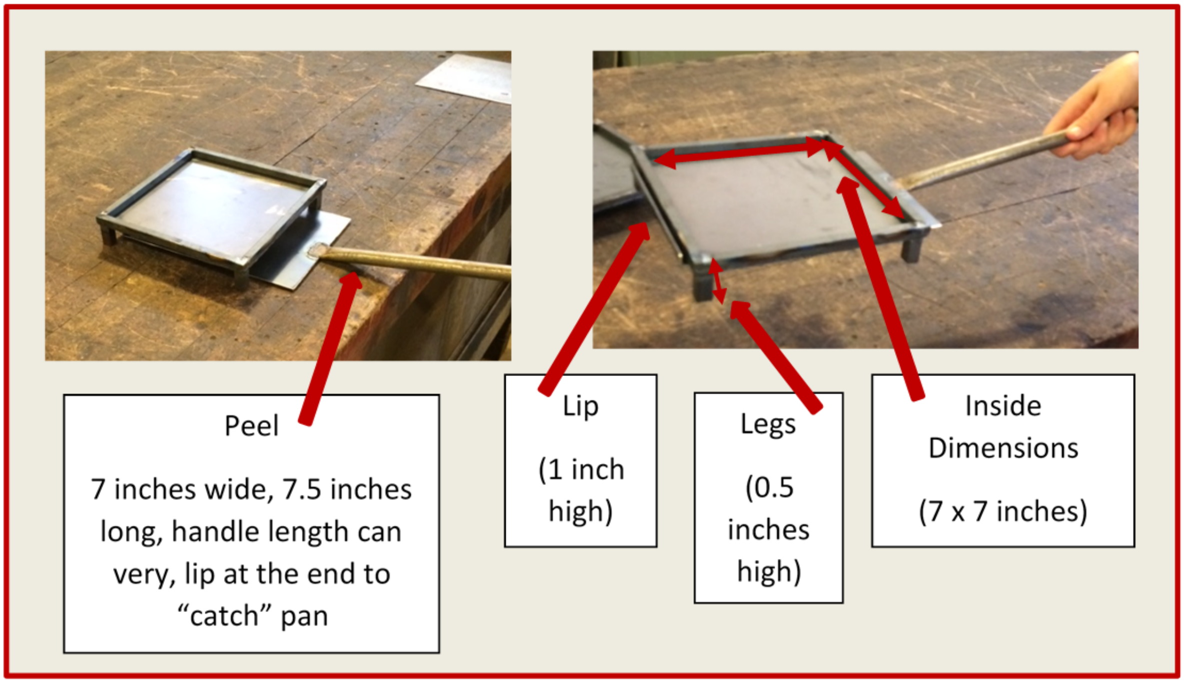

Figure 2—Elevated Plate Components

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5 PROCEDURE

5.1 *Test Method A (Assessment of Transverse EAR Variability)*:

5.1.1 Follow ASTM D 2995 Test Method B. If emulsion output from any nozzle deviates greater than 10% from the mean, then the nozzle should be adjusted and testing should be repeated.

5.2 *Test Method B (Assessment of Emulsion Absorption by the Paving Surface)*:

5.2.1 Select four sheets. Obtain and record the weight of each sheet to the nearest 0.05 g.

5.2.2 Place a flat, steel pan in each wheel path on the roadway in front of the emulsion distributor. (Figure (a))

5.2.3 As soon as the distributor has passed over the pans, apply frames to each of the steel pans. In addition, place frames on the paving surface directly in front of the pans. Press frames firmly to seal intrusion of emulsion from outside of the frame gasket.

5.2.4 Place a foam sheet into each frame. (Figure (b))

5.2.5 Apply the Tack Lifter weighted device to each sheet for 30 seconds. During this 30 second period, emulsion will be absorbed from the paving surface or pan into the sheet. (Figure (c) and (d))

5.2.6 Remove the sheets from the frame immediately after Tack Lifter removal and transfer to a scale placed inside of the weighing box.

5.2.7 Record the weight of each sheet to the nearest 0.05 g. (Figure (e))

5.2.8 Remove the frames and steel pans from the paving surface.

5.2.9 Repeat procedure at locations where significant changes in surface conditions (e.g., roughness, color, etc.) are noted.

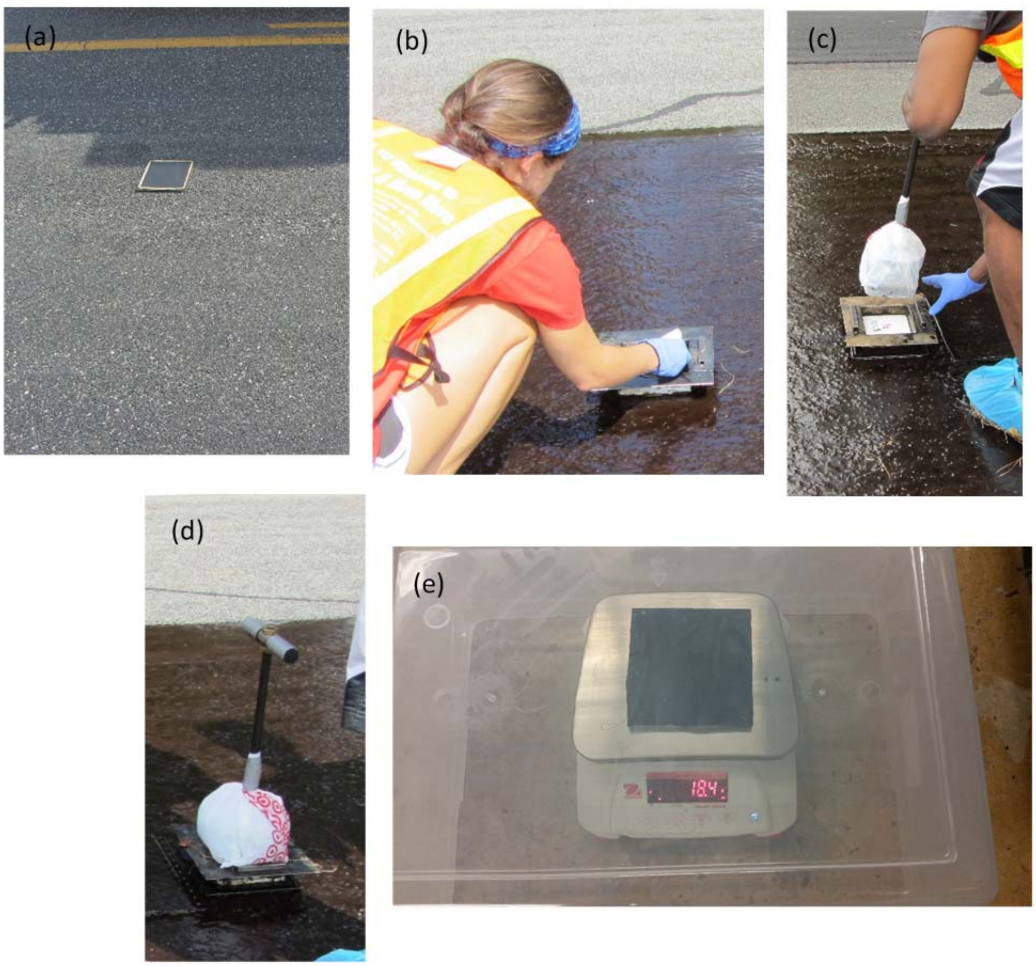

Figure 3 —Tack Lifter testing in the field on the surface including steps (a) placement of flat pan on in the wheel path before construction, (b) placing of frame and sheet in the frame on the surface or pan, (c) placement of Tack Lifter on the sheet (d) Tack Lifter testing and (e) weighing of Tack Lifter sheet

5.3 *Test Method C (Assessment of Longitudinal EAR Variability)*

5.3.1 Select the requisite number of sheets for testing. Testing should be conducted every 0.5 miles and wherever a significant change in curvature or grade is noted. Obtain and record the weight of each sheet to the nearest 0.05 g.

5.3.2 Place an elevated plate on the roadway's lane center at each location of testing prior to the arrival of the emulsion distributor.

5.3.3 Place and level the leveling table off of the roadway near the location of the elevated plate placement.

5.3.4 As soon as the distributor has passed over a plate, scoop peel under the plate (Figure (a)) and remove from the roadway (Figure (b)). Place on the leveling table (Figure (c)). Keep the plate as level as possible to prevent flow of emulsion.

5.3.5 Apply a frame to the plate as soon as it is placed on the leveling table. Press the frame firmly to seal intrusion of emulsion from outside of the frame gasket.

5.3.6 Place a foam sheet into the frame.

5.3.7 Apply the Tack Lifter to each sheet for 30 seconds. During this 30 second period, emulsion will be absorbed from the plate into the sheet. (Figure (d))

5.3.8 Remove the sheets from the frame immediately after Tack Lifter removal and transfer to a scale placed inside of the weighing box.

5.3.9 Record the weight of each sheet to the nearest 0.05 g. (Figure (e))

Figure 4—Tack Lifter testing in the field using elevated plates, including steps (a) placement of peel under elevated plate, (b) lifting elevated plate, (c) placement of elevated plate on level table and (d) Tack Lifter testing and (e) weighing of Tack Lifter sheet

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6 CALCULATIONS

6.1 *Test Method A*:

6.1.1 Follow the procedure detailed in ASTM D 2995 Test Method B.

6.2 *Test Method B*:

6.2.1 Subtract the tare weight of each sheet from the weight of each emulsion saturated sheet.

6.2.2 Determine the EAR of emulsion contained on each sheet in gal/yd^2 as follows:

$$EAR, \frac{gal}{yd^2} = \frac{A}{25in^2 \times G_s} \times 0.000264 \frac{gal}{cc} \times 1296 \frac{in^2}{yd^2}$$

Where:

A = net weight of emulsion absorbed by the sheet, g
G_s = specific gravity of asphalt emulsion at spray temperature

6.2.3 EAR values corresponding to sheets applied to pans can be regarded as the total applied EAR. If the measured applied EAR deviates more than +/- 0.03 gal/yd^2 from the target application rate, results should be regarded and invalid. The distributor should be re-calibrated and testing should be repeated.

6.2.4 Determine the rate by which emulsion is absorbed by the pavement in gal/yd^2 by subtracting the EAR values corresponding to the sheets placed on the paving surface from the EAR values corresponding to sheets placed on pans. Average values from the two wheel paths.

6.2.5 The absorbed emulsion rate represents the rate of applied emulsion which will be absorbed by the paving surface. Absorbed emulsion will not be available to bond with material placed on top of the emulsion. The target EAR can hence, be increased by the calculated absorption rate.

6.3 *Test Method C*:

6.3.1 Follow the same procedure as 6.2.1 and 6.2.2.

6.3.2 Comparison between the EARs measured at different locations along the length of paving can be used to assess longitudinal variability in emulsion application.

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7 REPORT

7.1 *Test Method A*:

7.1.1 Follow reporting requirements of ASTM D 2995 Test Method B.

7.2 *Test Method B*:

7.2.1 Location of measurements.

7.2.2 Visual observation of paving surface at locations of EAR measurements (e.g., rough, bled, etc.).

7.2.3 Calculated rate by which the pavement absorbs emulsion (gal/yd^2).

7.3 *Test Method C*:

7.3.1 Locations of EAR measurements.

7.3.2 Measured EAR at each location of testing (gal/yd^2)

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4 PRECISION AND BIAS

8.1 Precision and bias have yet to be established for this procedure.

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5 KEYWORDS

Emulsion application rate, quality control, tack coat, chip seal

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6 REFERENCES

ASTM D2995. "Standard Practice for Estimating Application Rate of Bituminous Distributors," ASTM, 2009.

APPENDIX C: TACK LIFTER SHEET SELECTION AND WEIGHT OPTIMIZATION

C.1 Tack Lifter Sheet Selection

C.1.1 Evaluation of Geotextile Sheets

Initially, geotextile sheets were evaluated for use in Tack Lifter testing based on the pads specified in ASTM D 2995 and the work of Raposeiras et al. (2013). Two geotextile sheets with high absorption capacity were tried. Both were made from polypropylene and manufactured by McMaster–Carr and are pictured in Figure C.. Here, the sheet types will be referred to simply as "black" and "green" sheet types. For initial Tack Lifter tests, a single emulsion (CRS-2) was used and a typical chip seal emulsion application rate (EAR) (0.25 gal/yd^2) and tack coat EAR (0.06 gal/yd^2) were used. For initial trials, emulsion was applied to a smooth, impermeable steel pan. All tests were conducted in environmental chamber at 30°C.

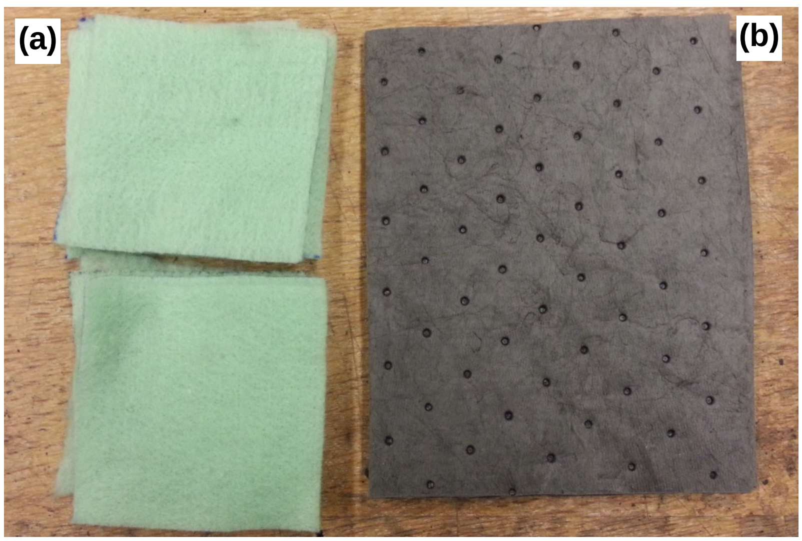

Figure C.1 Polypropylene sheets tried (a) green sheet and (b) black sheet

The results from the study on the "black sheet" and the "green sheet" are shown in Figure C.. Different weights, emulsions, and EARs were tested for the two sheets. Figure C. (a) shows the "green sheet" results for two different EARs (0.06 and 0.25 gal/yd^2) using a CRS-2 emulsion. Figure C. (b) is the results from the "black sheet." It is clear that the green sheet absorbs a greater percentage of the emulsion applied to the pan, regardless of the Tack Lifter weight. Hence, the green sheet was selected as the more promising of the two geotextile sheets. However, it is clear the sheet cannot absorb 100% of emulsion applied to a flat, impermeable surface which was deemed undesirable.

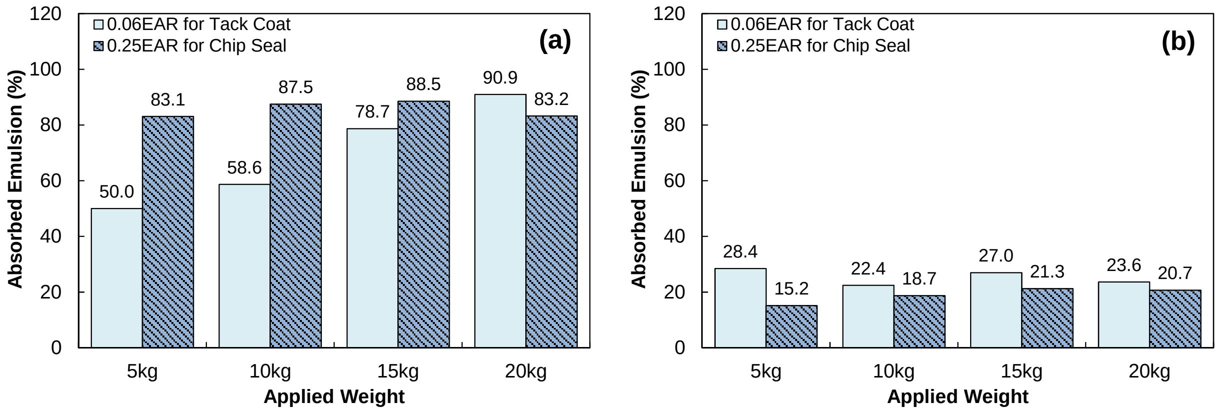

Figure C.2 Emulsion absorption at different weights: (a) CRS- (c) ith green sheet (b) CRS-2 with black sheet, and (c) CRS-2L and CRS-1H with green sheet

Furthermore, in some emulsion soaked through the sorbent sheet which led to the adhesion to the Tack Lifter weighted device. This led to deformation of the sheets upon removal from the Tack Lifter, which may impact the quality of measurements. Figure C. shows an example of deformed sheets.

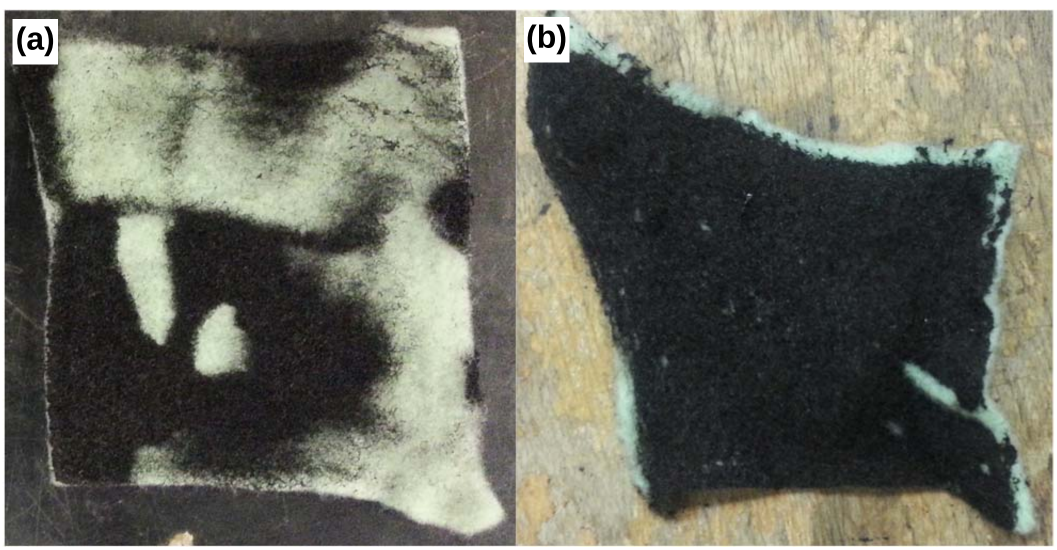

Figure C.3 Deformed sheet after testing: (a) used for 0.06 gal/yd^2 and (b) used 0.25 gal/yd^2

To overcome the issue of emulsion soak through and attempt to absorb 100% of emulsion applied to a steel pan, Tack Lifter testing was tried using multiple layers of green sheets. However, while this was found to lead to higher rates of emulsion absorption and solve the soak through issues, high variability in the quality of the sheets was observed. Two shipments of the same green sheets led to significantly different results. The sheets from the two shipments were visibly different. One was more porous than the other. The manufacturer was contacted to determine if the observed product variability was typical. The manufacturer stated that nothing could be done to improve consistency. Therefore, it was determined that a different sheet was necessary for Tack Lifter testing.

C.1.2 Evaluation of Foam Sheets

Due to the problems encountered with geotextile sheets, efforts shifted to the evaluation of foam sorbent sheets. A search was conducted to identify a suitable foam sheet, using the following criteria:

- Open cell (helps ensure product uniformity compared to woven sheets)
- Ability to absorb both oil and water
- Soft (low firmness) to allow conformation to the macro-texture of a pavement
- Ability to withstand temperatures exceeding 60ºC (typical emulsion application temperature)
- Absorbency

Based on the aforementioned criteria, a polyurethane “super-absorbent” foam from McMaster Carr was selected for Tack Lifter testing. A photograph of the selected sheet is provided in **Figure C.**. A summary of the sheet specifications is provided in Table C.4. The foam was specified to allow absorption of both water and oil, making is suitable for asphalt emulsion. The foam sheet has low firmness which allows for forming into the macro pores of paving surfaces under the weight of the Tack Lifter, unlike the previously tried sheets. The sheet is also specified to be applicable to the temperatures typically encountered in the field. In addition, the foam sheet has an absorbency of 2.43 gal/yd^2, which greatly exceeds the maximum EAR used in field applications (~0.35 gal/yd^2).

Figure C.4 Final Tack Lifter sheet

Table C.4 Super-absorbent Polyurethane Foam Sheet Specifications

Property	Value
Density	1.8 lb/ft^3
Firmness (25% deflection)	0.6 psi
Temperature range	-23ºC to 82ºC
Thickness	0.5 in
Absorbency	2.43 gal/yd^2

Initial assessment of the super-absorbent polyurethane sheet consisted of Tack Lifter testing on a steel plate surface (i.e., a non-porous surface). Testing included three emulsion types: CRS-2, CRS2-L, and CRS-1H. CRS-2 and CRS-2L. Testing was conducted using an EAR of 0.25 gal/yd^2 to represent a typical chip seal EAR whereas an EAR of 0.06 gal/yd^2 was used for testing the CRS-1H emulsion, representative of a typical tack coat EAR. Testing was conducted at 25°C using a Tack Lifter weight of 15 kg. Initial Tack Lifter trials using geotextile sheets indicated that increasing the Tack Lifter weight to 20 kg did not lead to significantly higher absorption. EARs measured using Tack lifter tests are presented in Figure C.. Results demonstrate very close agreement between the applied and measured EARs, with very little variability between replicates. Note that emulsion was hand applied to the plate so there is potential for non-uniformity in emulsion application over the area of the plate and hence, the results obtained are interpreted to indicate the Tack Lifter absorbed 100% of the applied emulsion. This assumption is supported by the photograph in Figure C.41, which shows a steel plate after emulsion application and subsequent Tack Lifter testing. Thus, the super-absorbent polyurethane foam was selected for use in Tack Lifter testing.

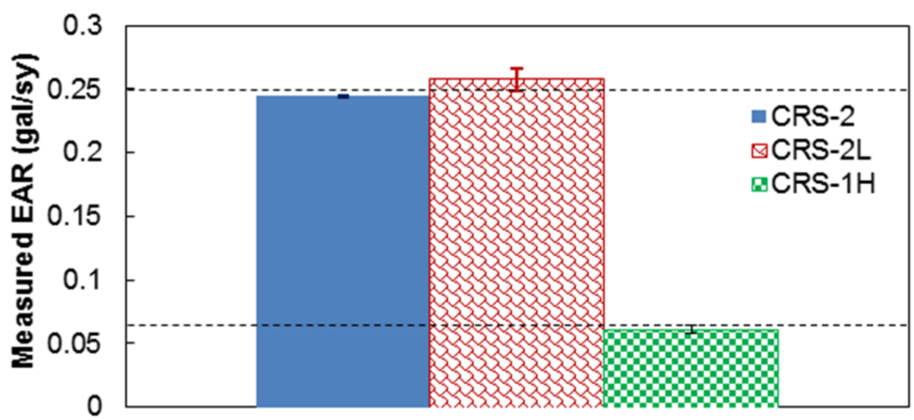

Figure C.5 Tack lifter measured EARs on steel pan

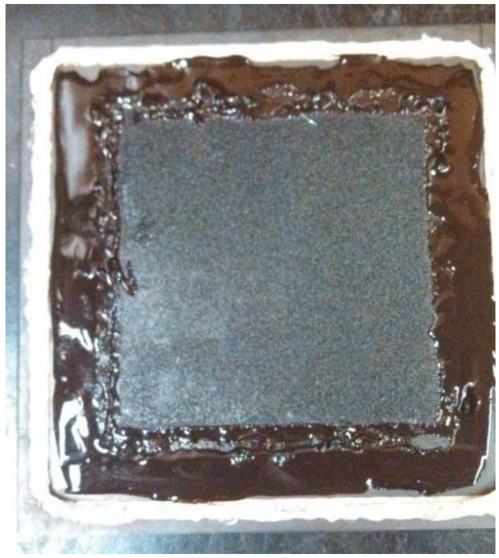

Figure C.41 Steel pan after Tack Lifter testing

C.2 Optimization of Tack Lifter Weight

Initial Tack Lifter tests presented in Figure C. using the super-absorbent polyurethane foam sheet indicate that a Tack Lifter weight of 15 kg allows for 100% of emulsion applied to a smooth, impermeable surface. Thus, a Tack Lifter weight of 15 kg was deemed sufficient for testing. However, reducing the weight of the Tack Lifter would be beneficial in terms of improving ease of use. Thus, a field study was conducted to determine if the Tack Lifter weight could be decreased to 10 kg without compromising results. The field trial was conducted on 9/17/14. Construction consisted of the application of a chip seal with a target EAR of 0.25 gal/yd^2. Testing was conducted at five locations along the length of paving. The experimental layout for each location of testing is presented in Figure C.. At each location of testing, Tack Lifter tests were conducted on a pan placed on the paving surface prior to emulsion application and on two locations adjacent to the pan in the direction of paving. In addition, ASTM D 2995 Test Method A pads were placed adjacent to pans at each test location but results are not relevant to the weight study and are omitted from analysis herein. A 10 kg weight was used for Tack Lifter tests applied to the paving surface in two test locations and 15 kg weight was used for all other tests. No appreciable changes in pavement surface conditions were noted along the length of paving.

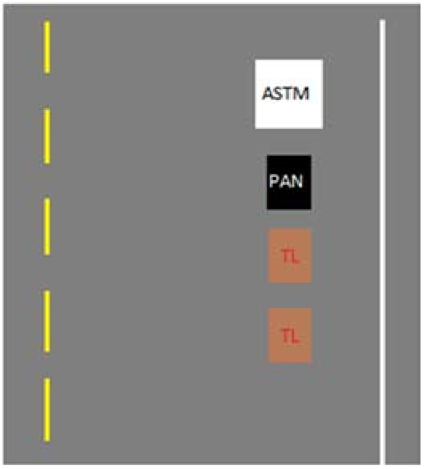

Figure C.7 Layout on 9-17-14

Comparison between results of Tack Lifter tests applied to pans and the paving surface were used to calculate the percentage of applied emulsion absorbed by the Tack Lifter. Tack Lifter tests applied to pans provide a measure of the applied EAR because Tack Lifter tests applied to steel pans absorb 100% of the emulsion applied to the pan. Note that results from different test locations were combined because the paving surface condition did not vary along the length of paving. Results are presented in Figure C.. Results indicate slightly higher emulsion absorption by the Tack Lifter when the 15 kg weight is used as opposed to the 10 kg weight. Variability does not appear to be impacted by the Tack Lifter weight. Based on these results, it was deemed important to use the 15 kg weight for maximum emulsion absorption by the Tack Lifter and thus, accurate measures of applied and effective EARs in the field.

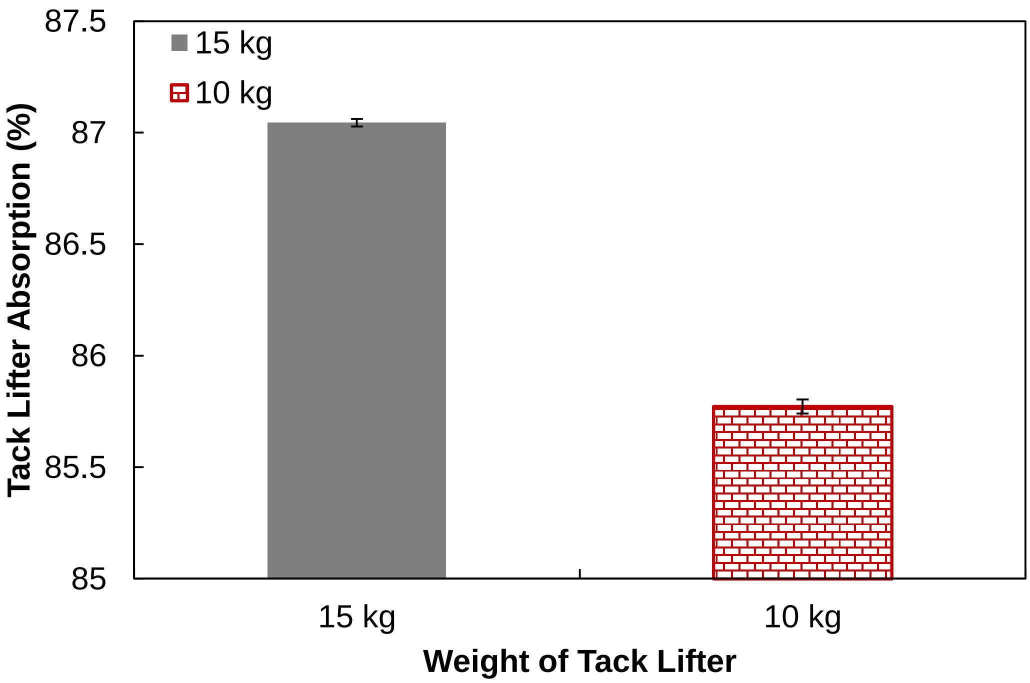

Figure C.8 Weight study results from the field on 9-17-14