ABSTRACT

RAWLS, MARY LAWRENCE. In-Situ Determination of Emulsion Application Rates for Tack Coats and Surface Treatments. (Under the direction of Dr. Cassie Castorena.)

Emulsions are used as tack coats to bond asphalt concrete layers and as a bonding agent for aggregates in chip seals. Emulsion application rate (EAR) is critical to the performance of both tack coats and chip seals. Previous research demonstrated that field EARs can be highly variable, which is not captured using current measures for quality control (QC). Comprehensive QC of emulsion application rates 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 is 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 spot check EAR. Tests 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 during experimentation. Elevated plates are placed on the roadway’s lane center prior to arrival of the emulsion 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 by this research. 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, and (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, and (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.
DEDICATION

I dedicate this thesis to my faith, my family, and friends. Without them, I could not have completed the past seven years of school. To my parents, Lawrence and Julie, you have been a constant in my life and I appreciate all your support and love. To my friends and family, this is for you and all the prayers, encouragement, and entertainment you have provided me as I have reached for just one more year of school. Finally, but most importantly, I dedicate this to my Lord and Savior. Those long nights, seemingly impossible assignments, successes, and failures…I could not have kept going without faith and hope.
BIOGRAPHY

Mary Lawrence Rawls is from Oak City, North Carolina where she was raised and attended grade school. She is the daughter of Lawrence and Julie Rawls of Oak City. She has two siblings: a twin sister, Sarah and an older sister Elizabeth. Mary attended Hobgood Academy from Kindergarten through high school graduation. She attended Meredith College and North Carolina State University for her undergraduate career. She participated in the dual degree program at Meredith College in which participants receive a degree from both schools in five years. The degree from North Carolina State University is an engineering degree, and her degree from Meredith College is a Bachelor of Arts in Mathematics with a minor in Religion. She received a Bachelor of Science in Civil Engineering with a concentration in Transportation from North Carolina State University. Both degrees were conferred in the Spring of 2014. While in her undergraduate career, Mary participated in the Honors Program at Meredith College and completed and undergraduate thesis at North Carolina State University as part of the requirement for the Meredith College’s Honors Program. Her undergraduate thesis was under the direction of Dr. Cassie Castorena. This is how Mary became interested in the Transportation Materials side of Civil Engineering and what ultimately helped her decide to pursue a graduate degree at North Carolina State University. Her interests include both transportation materials and transportation systems, and she has taken classes in both areas. She is active in the Institute of Transportation Engineers and the Graduate Student Association since starting her graduate career. One of her proudest accomplishments was presenting a paper at the Transportation Research Board’s Annual Conference in January 2016 and having her paper selected for publication.
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# TABLE OF CONTENTS

List of Tables .................................................................................................................. ix
List of Figures .................................................................................................................. x

1. Introduction .................................................................................................................. 1
   1.1 Research Needs and Significance ......................................................................... 1
   1.2 Research Objectives ............................................................................................ 2
   1.3 Thesis Organization ............................................................................................. 2

2. Literature Review ......................................................................................................... 2
   2.1 Introduction ........................................................................................................... 2
   2.2 Benefits of Asphalt Emulsion ............................................................................... 3
   2.3 Importance of Emulsion Application Rates to Tack Coat Performance ............ 3
   2.4 Importance of Emulsion Application Rates in Surface Treatments ................. 4
   2.5 Factors Affecting Applied Emulsion Application Rates ..................................... 7
      2.5.1 Transverse Variability ................................................................................... 8
      2.5.2 Longitudinal Variability ............................................................................... 8
   2.6 Factors Affecting “Effective” Emulsion Application Rates ................................ 8
      2.6.1 Asphalt Concrete ......................................................................................... 9
      2.6.2 Chip Seal ....................................................................................................... 9
   2.7 Current Practices for Quality Control of Emulsion Application Rates .............. 9
      2.7.1 Current Practice of the North Carolina Department of Transportation ........ 9
      2.7.2 National Review of Current Practices for Quality Control of Applied EARs .. 10
      2.7.3 Current Practices for Adjustments and Measurements to Account for Emulsion Absorption by Pavements ................................................................. 12
   2.8 Surface Texture ..................................................................................................... 16
      2.8.1 ASTM E 965: The Sand Patch Method ......................................................... 16
      2.8.2 Laser Profilometer ....................................................................................... 17
   2.9 Summary of Literature Review ............................................................................. 18

3. Tack Lifter for in-situ Determination of emulsion application rates ....................... 19
   3.1 Tack Lifter Concept and Device .......................................................................... 19
   3.2 Tack Lifter Sheet Selection .................................................................................. 22
3.2.1 Evaluation of Geotextile Sheets ................................................................. 22
3.2.2 Evaluation of Foam Sheets ........................................................................ 24
3.3 Optimization of Tack Lifter Weight................................................................. 27
3.4 Tack Lifter Procedure for Measurement of the Rate by which a Pavement Absorbs Emulsion............................................................................................................ 29
3.5 Tack Lifter Procedure for Measurement of the Applied EAR .................... 31
4. Laboratory Evaluation of the Tack Lifter ......................................................... 33
  4.1 Laboratory Evaluation of Tack Lifter Applied to Steel Pan for Determination of Applied Emulsion Application Rates ......................................................... 33
  4.2 Laboratory Evaluation of Tack Lifter Applied to Paving Surfaces for Determination of Effective Emulsion Application Rates ................................................. 34
    4.2.1 Experimental Plan....................................................................................... 34
    4.2.2 Surface Texture Characterization ............................................................. 35
    4.2.3 Tack Lifter Testing ..................................................................................... 36
    4.2.4 Results ....................................................................................................... 38
      4.2.4.1 Effect of Surface Texture on Tack Lifter Results ............................... 38
      4.2.4.2 Effect of Emulsion Application Rate on Tack Lifter Results .......... 41
      4.2.4.4 Effect of Emulsion Type on Tack Lifter Results .............................. 42
      4.2.4.4 Effect of Temperature on Tack Lifter Results ................................. 43
5. Tack Lifter Field Trials ...................................................................................... 44
  5.1 Comparison between ASTM D2995 Test Method A and Tack Lifter ............ 44
    5.1.1 Summary of Experiments ....................................................................... 44
    5.1.2 Field Trial Conducted on 8/27/14............................................................ 47
    5.1.3 Field Trial Conducted on 9/17/14............................................................ 49
  5.2 Assessment of Emulsion Absorption by Pavements ..................................... 50
    5.2.1 Summary of Field Experiments ................................................................. 50
    5.2.2 Field Trial Conducted on 5/26/15............................................................. 52
    5.2.3 Field Trial Conducted on 6/23/15............................................................. 55
    5.2.4 Field Trial Conducted on 8/10/15............................................................. 59
    5.2.5 Summary and Recommendations for Implementation for Assessment of Pavement Absorption Rate .............................................................. 62
5.3 Assessment of Transverse EAR Variability using the Tack Lifter ........................................65
  5.3.1 Summary of Field Experiments ................................................................. 65
  5.3.2 Field Trial Conducted on 6/23/15 ................................................................. 65
  5.3.3 Field Trial Conducted on 8/10/15 ................................................................. 66
  5.3.3 Summary and Recommendations for Implementation of the Tack Lifter in Transvers Variability Assessment ................................................................. 67
5.4 Assessment of Longitudinal EAR Variability using Tack Lifter Tests Applied to Elevated Plates ........................................................................................................68
  5.4.1 Summary of Field Experiments ................................................................. 68
  5.4.2 Field Trial Conducted on 9/9/15 ................................................................. 69
  5.4.3 Field Trial Conducted on 9/11/15 ................................................................. 71
  5.4.4 Field Trial Conducted on 9/23/15 ................................................................. 72
  5.4.5 Summary and Recommendations for Elevated Plates ........................................73
6. ASTM D 2995 for Quality Control of Transverse Variability in Emulsion Application Rates .........................................................................................................................73
  6.1 Summary of ASTM D 2995 ........................................................................... 73
  6.2 Summary of Experiment to Evaluate ASTM D 2995 Test Method A ................. 74
  6.3 Results of ASTM D 2995 Test Method A ...................................................... 75
  6.4 Summary and Recommendations for Transverse Variability Assessment .......... 76
7. Findings and Conclusions .................................................................................. 77
8. Recommendations ............................................................................................ 79
References ............................................................................................................. 81
Appendix A Quality Control For Emulsion Application Rates .................................. 85
LIST OF TABLES

Table 1 McLeod Method’s Qualitative Existing Pavement Surface Correction Factor (McLeod 1969) ................................................................................................................................. 13
Table 2 NCDOT Tack Coat Application Specifications ................................................................................................................................. 13
Table 3 Summary of existing methods for quality control of EARs .................................................. 18
Table 4 Super-absorbent Polyurethane Foam Sheet Specifications .................................................... 25
Table 5 Laboratory Experimental Plan ................................................................................................. 35
Table 6 Summary of Field Trials completed for ASTM D2995 and Tack Lifter Comparison ........... 45
Table 7 Summary of Field Experiments to Evaluate Emulsion Absorption into Paving Surfaces Using the Tack Lifter .......................................................................................... 51
Table 8 Description of Testing Sites Corresponding to Field Trial Conducted on 5/26/15 ................ 53
Table 9 Description of Testing Sites Corresponding to Field Trial Conducted on 6/23/15 ........ 57
Table 10 Description of Testing Sites Corresponding to Field Trial Conducted on 8/10/15 ........... 60
Table 11 Summary of Field Trials to Assess Longitudinal Variability in Applied EARs ......... 69
LIST OF FIGURES

Figure 1 Tack coat failure modes (Source: Raab and Partl 2004) ........................................ 4
Figure 2 Raveling performance of field observations (Gurer et al. 2012) .............................. 5
Figure 3 50% embedment idea (Adams 2014) .................................................................... 5
Figure 4 Effect of EAR on bleeding (Adams 2014) ................................................................ 6
Figure 5 Effect of EAR on aggregate loss (Adams 2014) ...................................................... 6
Figure 6 Spray bar configuration for emulsion (Mohammad and Button 2005) ...................... 7
Figure 7 Nozzle angle and spacing configuration (Mohammad et al. 2012) ......................... 8
Figure 8 Method 2 depiction of the dipstick procedure (NCDOT Tack Coat Best Practices Field Guide 2012) ................................................................. 10
Figure 9 Method for quality control of EARs (Mohammad et al. 2012) ............................... 11
Figure 10 ASTM D 2995 Method A (West et al. 2005) ...................................................... 11
Figure 11 ASTM D 2995 Method B (Krugler et al. 2009) .................................................. 12
Figure 12 Surface texture correction factor based on the sand patch method (Shuler et al. 2011) ................................................................. 14
Figure 13 Method involving weighing the emulsion sprayer before and after application (Caltrans Division of Maintenance 2010) ................................. 15
Figure 14 Device developed for measuring emulsion absorption proposed by Rasposeiras et al. (2013) ................................................................. 15
Figure 15 Correlation between the CT Meter and sand patch method (Flintsch et al. 2003). 16
Figure 16 Tack Lifter components ...................................................................................... 21
Figure 17 Elevated plate components .................................................................................. 21
Figure 18 Polypropylene sheets tried (a) green sheet and (b) black sheet ............................ 22
Figure 19 Emulsion absorption at different weights: (a) CRS-2 with green sheet (b) CRS-2 with black sheet ................................................................. 23
Figure 20 Deformed sheet after testing: (a) used for 0.06 gal/yd² and (b) used 0.25 gal/yd². 24
Figure 21 Final Tack Lifter sheet ......................................................................................... 25
Figure 22 Tack lifter measured EARs on steel pan ............................................................... 26
Figure 23 Steel pan after Tack Lifter testing ....................................................................... 27
Figure 24 Layout on 9-17-14 .............................................................................................. 28
Figure 25 Weight study results from the field on 9-17-14 ..................................................... 29
Figure 26 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 ....... 30
Figure 27 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 ........................................... 32
Figure 28 (a) Tack lifter measured EARs on pan (b) Photo of pan after Tack Lifter test. ..... 34
Figure 29 Correlation between sand patch and laser results ............................................... 36
Figure 30 (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 ................................................................. 37
Figure 31 Effect of surface texture on Tack Lifter results for 0.25 gal/yd² EAR: (a) comparison between surface texture and Tack Lifter emulsion absorption, (b) comparison between applied
and effective EARs, and for 0.08 gal/yd² EAR: (c) comparison between surface texture and Tack Lifter emulsion absorption, (d) comparison between applied and effective EARs. ........................40
Figure 32 (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.................................................................42
Figure 33 (a) Effect of emulsion type on untrafficked chip seal samples applied at 0.25 gal/yd² and (b) Effect of emulsion type on microsurfacing applied at 0.08 gal/yd²......................43
Figure 34 Chip seal samples at various temperatures showing tack lifter absorption and surface texture .........................................................................................................................44
Figure 35 Experimental layout for 8/27/14 field trial.................................................................46
Figure 36 Experimental layout for 9/17/14 field trial.................................................................46
Figure 37 (a) Surface condition of 8/27/14 field trial and (b) Surface condition of 9/17/14 field trial ........................................................................................................................................47
Figure 38 Comparison between results of ASTM D 2995 and Tack Lifter applied to paving surface (8/27/14) .................................................................48
Figure 39 Paving surface after Tack Lifter application ...............................................................48
Figure 40 Bare spots left by the ASTM D 2995 Test Method A ................................................49
Figure 41 Comparison between results of ASTM D 2995, Tack Lifter applied to pan, and Tack Lifter applied to paving surface (9/17/14) ...........................................................50
Figure 42 Sand patch method being conducted ........................................................................51
Figure 43 Surface condition of 5/26/15 field experiment ..........................................................53
Figure 44 Experimental layout for 5/26/15 field trial ................................................................53
Figure 45 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 55
Figure 46 Surface condition of 6/23/15 field experiment ..........................................................56
Figure 47 Experimental layout for 6/23/15 field trial .................................................................57
Figure 48 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 59
Figure 49 Experimental layout for 8/10/15 field trial ...............................................................60
Figure 50 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 62
Figure 51 Emulsion absorption rate in wheel path for field trials conducted on 6/23/15 and 8/10/15 .........................................................................................................................................64
Figure 52 Assessment of transverse EAR variability in 6/23/15 field trial ..................................66
Figure 53 Assessment of transverse EAR variability in 8/10/15 field trial .................................67
Figure 54 Measured EAR’s for September 9, 2015 in Franklin County ....................................70
Figure 55 Measured EAR’s for September 11, 2015 in Franklin County ....................................71
Figure 56 Measured EAR’s for September 23, 2014 in Person County ......................................72
Figure 57 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 ................................................................................................................75
Figure 58 Results from ASTM D 2995 Test Method A ............................................................76
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 inadequate load transfer between pavement 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 of pavements.

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 often 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 consists of measuring the change in the volume of emulsion in the distributor 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. 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 Thesis Organization

The thesis is organized into eight chapters and one appendix. Chapter 1 presents the research needs and objectives. Chapter 2 provides 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. Appendix A contains the proposed practice for QC of EARs based on results presented.

2. LITERATURE REVIEW

2.1 Introduction

The literature reviews addresses relevant topics to improving QC of EARs, including the importance of EARs to tack coat and surface treatment performance, factors affecting applied
and effective EARs in the field, current practices for QC of EARs, and current practices for characterization of pavement surface texture. Results of the literature review indicate that relatively few test methods exist for QC of EARs and there are many limitations to the current methods that will be important in the development of a new test method for improve QC.

2.2 Benefits of Asphalt Emulsion

An asphalt emulsion is a mixture of asphalt binder, water, and an emulsifier. The emulsifier is a surfactant that suspends asphalt droplets within the water. The water reduces the viscosity of the asphalt, allowing application of asphalt emulsions at relatively low temperature (25–60°C) compared to asphalt binder. Lower temperatures are safer for workers. Also, by not having to heat the asphalt binder to higher temperatures, less emissions are produced in the environment and less energy is consumed for heating. Once placed in the field, asphalt emulsions “break”, meaning that the water and asphalt separate. Subsequently, water leaves the system through evaporation and absorption and what is left is an asphalt residue. Asphalt emulsions are an economical and sustainable product for the use in pavement preservation techniques.

2.3 Importance of Emulsion Application Rates to Tack Coat Performance

Tack coats are used as bonding layer between pavement layers. Tack coats typically consist of a thin application of asphalt emulsion diluted with water (Mohammad et. al 2012). Proper bonding between adjacent pavement layers is crucial to the performance of the pavement (Mohammad et. al 2012).

Tack coat failure can occur if too little or too much tack is applied to the pavement. If too much tack is applied, shearing can occur at the interface of the two layers. This leads to slippage and delamination (Leng et al. 2008). Also, if too much tack is applied the material can be drawn into the top layer which can affect the mix properties (Proper Tack Coat Applications 2012). Tensile failure will occur if too little tack is applied. Without sufficient bonding between pavement layers, the system does not function as one layer and thus, cannot withstand the traffic loading used in the design. Tensile stresses build up under the tire load that is
concentrated at the bottom of the surface layer (Mohammad et. al 2012). Tensile failure leads to debonding between layers. Figure 1 depicts shear and tensile failure modes. Shear and tensile failure due to inadequate application of tack coats can ultimately cause slippage cracking, top-down cracking, premature fatigue cracking, potholes, and complete delamination (Leng et al. 2008).

![Figure 1 Tack coat failure modes (Source: Raab and Partl 2004)](image)

2.4 Importance of Emulsion Application Rates in Surface Treatments

Surface treatments are used for preventative maintenance of flexible pavements. Surface treatments do not improve the structural capacity of the pavement. However, surface treatments protect the existing pavement from oxygen and water ingress and improve surface quality which can prolong pavement service life. In certain surface treatments, emulsion is applied to the existing surface. These surface treatments include chip seals and fog seals. Fog seals aid in preventing raveling and can restore aged surfaces (Caltrans 2010). Fog seals consist of a thin layer of diluted emulsion applied to existing asphalt concrete or chip seal surfaces. Fog seals help prevent raveling and seal very minor cracks. Fog seals also provide protection against water intrusion into the voids of the pavement. Fog seals help rejuvenate the pavement surface as well by adding more asphalt to the pavement (Caltrans 2010). If too much emulsion is applied in a fog seal application, a slick surface can occur, providing a safety hazard. Emulsion may also track with vehicular loading. If the fog seal application rate is too low, the emulsion will break too fast, which precludes penetration of the emulsion into pavement surface voids (Caltrans 2010).
Chip seals consist of a single layer of aggregate embedded in a layer of emulsion. Chip seals improve skid resistance, seal minor cracks, and extend pavement service life (Shuler et al. 2011). Gurer et al. (2012) found that the performance of chip seals is correlated to the discrepancy between the in-situ EAR and the target EAR. Gurer et al. (2012) found that the closer the applied application rate is to the target, the better the performance of the chip seal. As shown in Figure 2, Gurer et al. (2012) found that three of the five sections studied had field EARs that deviated from the target by approximately 30% and had a lower raveling index, implying poorer performance.

![Figure 2 Raveling performance of field observations (Gurer et al. 2012)](image)

Chip seal design methods prescribe a target EAR to achieve optimal performance. For example, Adams (2014) developed a performance based chip seal mix design method that dictates that the EAR be selected such that 50% aggregate embedment is attained. Figure 3 demonstrates the concept of the 50% embedment of the chips in the layer of emulsion. 50% embedment ensures that the aggregate chips will not become dislodged during loading and will also will not be saturated or cause bleeding.

![Figure 3 50% embedment idea (Adams 2014)](image)
In chip seals, failure can occur if the applied EAR is too high or too low. Too little emulsion will lead to raveling which can cause windshield damage and ride-ability issues. Too much emulsion leads to bleeding and a loss of friction. The importance of EAR on chip seal performance is demonstrated by the laboratory results presented in Figure 4 and Figure 5 (Adams 2014). The optimal EAR for the aggregate utilized is 0.2 gal/yd² (on the basis of achieving 50% embedment). Results demonstrate bleeding issues if the EAR is increased above 0.2 gal/yd² and raveling problems if the EAR is less than 0.2 gal/yd². Thus, these results demonstrate that it is imperative to performance that field EARs be adequately controlled.

Figure 4 Effect of EAR on bleeding (Adams 2014)

Figure 5 Effect of EAR on aggregate loss (Adams 2014)
2.5 Factors Affecting Applied Emulsion Application Rates

The applied emulsion application rate, typically expressed in units of gallons per square yard, represents the total amount of emulsion applied per unit area of pavement. Multiple factors can influence variability in applied EARs. Emulsion is typically applied using an “emulsion distributor”. Emulsion distributors consist of a truck carrying a tank of emulsion which is applied at the rear of the truck using a spray bar. The distributor plays a vital role in quality control of applied EARs. There are several distributor factors that affect the applied EAR: spray bar height, nozzle pattern, nozzle size, distributor pressure, and temperature of the tank (Mohammad et al. 2012). Another critical factor that affects the applied EAR is the speed of the distributor. The spray bar height, shown in Figure 6, determines the distance between the nozzles and the application surface. The nozzles of the distributor should be equally spaced to provide uniform coverage and oriented at the same angle as seen in Figure 7. A common spacing of nozzles and nozzle angle are chosen such that there is overlap in the spray pattern of each nozzle. This ensures a uniform and full coverage. The nozzle size is chosen to provide, again, uniform and full coverage of the surface. The distributor pressure controls how fast or slow the emulsion is sprayed out of the nozzle. The temperature of the tank should be controlled to ensure breakage of the emulsion at the desired rate and to maintain a uniform viscosity. Finally, the speed of the distributor should be monitored to provide even coverage of the paving surface. These factors can contribute to both transverse and longitudinal variability in applied EARs. All of these factors should be routinely checked and calibrated to minimize variability in applied EARs.

![Figure 6 Spray bar configuration for emulsion (Mohammad and Button 2005)](image-url)
2.5 Transverse Variability

Transverse variability in the applied EAR can result if the individual nozzle angles vary. Also, if one nozzle becomes clogged due to broken emulsion or too small of an opening, variability can occur (Mohammad et al. 2012).

2.5.2 Longitudinal Variability

Longitudinal variability in applied EARs can result from fluctuations in distributor pressure and / or speed. Higher distributor pressures will lead to higher application rates, and faster distributor speeds will result in lower applied EAR (Mohammad et al. 2012).

2.6 Factors Affecting “Effective” Emulsion Application Rates

In addition to the applied EAR, it is important to consider the “effective” EAR. The effective EAR refers to the amount of emulsion available for bonding to material placed on top of the applied emulsion. Pavements inherently contain voids and / or bare aggregate surfaces which will absorb a portion of the applied emulsion. Absorbed emulsion is not available to bond to an adjacent layer placed on top of the emulsion. Generally, it is hypothesized that rougher surfaces will lead to greater opportunities for emulsion absorption. However, it is also important to recognize that different surface types lead to different mechanisms of emulsion absorption.
2.6.1 Asphalt Concrete

Existing asphalt concrete surfaces contain pores which can absorb emulsion. In addition, dry, oxidized asphalt concrete surfaces offer additional opportunity for absorption.

2.6.2 Chip Seal

Chip seals may contain bare aggregate surface, which can absorb emulsion. In addition, emulsion can be absorbed into voids between aggregate particles within a chip seal. With applications of emulsion on top of existing chip seals, various distresses within the chip seal can affect the surface texture and absorption potential. For example, bleeding leads to a smooth, saturated surface which offers little opportunity for absorption of emulsion.

2.7 Current Practices for Quality Control of Emulsion Application Rates

2.7.1 Current Practice of the North Carolina Department of Transportation

The North Carolina Department of Transportation has a “Best Practices Field Guide” for QC of tack coats. This document outlines two methods for QC of applied EARs: (1) a flow meter and (2) a calibrated dipstick. In Method 1, the flow meter on the distributor is checked prior to construction and after construction to determine the amount of emulsion (in gallons) placed on the roadway. Method 2 uses a calibrated dipstick that is placed in the tank of the distributor before and after construction to check the emulsion quantity placed in the field. The best practices field guide also outlines calibrations and checks for the temperature gauges, spray bar height, nozzle angles, application rate gauge, and tank gauge. All of these components are important to the successful application of emulsion in tack coats and surface treatments.

The drawback of these practices is that they do not allow for capture of variability in the applied EAR along the length of paving. That is, no in-situ measures of EAR are conducted. In addition, current practices of NCDOT do not consider emulsion absorption by the existing pavement.
2.7.2 National Review of Current Practices for Quality Control of Applied EARs

Mohammad et al. (2012) conducted a national survey to identify methods used for QC of applied EARs. Seventy-two respondents responded to five different options of QC measures. The results of Mohammad et al.’s (2012) survey are shown in Figure 9. Fifty percent of the respondents stated that the volume difference of the emulsion tank before and after paving was the method preferred for quality control. Twenty-seven percent of respondents stated that the weight difference in the tank before and after paving is utilized. It should be noted that only 2% of the participants in the study stated that ASTM D 2995: Standard Practice for Estimating Application Rate of Bituminous Distributors was utilized in practice. This method is recommended to be used by the Federal Highway Administration and is the only national standard test method for QC of EARs. Roughly 20% respondents indicate EARs are “not checked”. Some respondents indicated “other” methods than those listed are used for QC.
ASTM D 2995 is the only standard test procedure specified in the literature for QC of applied EARs. The standard identifies two methods, A and B. Method A consists of spot checks in which the emulsion distributor sprays emulsion on a standard size geotextile pad that has been placed on the roadway. These geotextiles are weighed before and after emulsion application. The weight of emulsion applied to the tarp is used to determine the applied EAR. This method is depicted in Figure 10. Pads can be aligned either longitudinally or transversely. Method B is used to assess transverse EAR variability only. In Method B, containers are placed under each nozzle and the distributor releases emulsion for a set amount of time. The variability in the volume of emulsion deposited into different containers is used to assess transverse variability. It should be noted that ASTM D 2995 recommends distributor calibration prior to paving rather than in-situ measurements of EAR during construction.
West et al. (2005) utilized ASTM D 2995 to check transverse and longitudinal EAR variability and emphasized the importance of measuring in-situ emulsion application rates. They found that there were differences in the target rate and the actual rate which were attributed to the poor calibration of distributors. West et al. (2005) recommended routine use of ASTM D2995 for QC of EARs. Mohammad et al. (2012), conversely, found that the procedure was a “lengthy process and required multiple calibration runs to ensure accuracy and uniformity of tack coat application.” Muench and Moomaw (2008), however, were skeptical of West’s results of the mismatch in target rates and actual rates was not caused by poor calibration of distributors, but rather by ASTM D 2995 measurement insufficiencies (e.g., dripping of emulsion from pads prior to weighing).

2.7.3 Current Practices for Adjustments and Measurements to Account for Emulsion Absorption by Pavements

Emulsion absorbed by pavements is not available for bonding. Thus, it would advantageous if emulsion absorption could readily be measured and used to adjust the target EAR during construction to achieve the target effective EAR. However, generally no measures are taken to
quantify emulsion absorption into pavements. Despite this, absorption into the pavement is documented in many field guides and chip seal design methods as a factor that should be taken into account when selecting the target EAR for a project. For example, the McLeod method for chip seal design provides provisions for adjustments to the target EAR according to the surface condition as listed in Table 1. Corrections range from \(-0.06 \text{ gal/yd}^2\) to \(+0.06 \text{ gal/yd}^2\) (McLeod 1969).

**Table 1 McLeod Method’s Qualitative Existing Pavement Surface Correction Factor (McLeod 1969)**

<table>
<thead>
<tr>
<th>Existing Pavement Surface Texture</th>
<th>Correction (in gal/yd(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black, flushed asphalt surface</td>
<td>-0.06</td>
</tr>
<tr>
<td>Smooth, nonporous surface</td>
<td>-0.03</td>
</tr>
<tr>
<td>Slightly porous, oxidized surface</td>
<td>0.00</td>
</tr>
<tr>
<td>Slightly pocked, porous, oxidized surface</td>
<td>+0.03</td>
</tr>
<tr>
<td>Badly pocked, porous, oxidized surface</td>
<td>+0.06</td>
</tr>
</tbody>
</table>

The majority of the time, visual inspection of the surface is used to adjust target EARs to account for emulsion absorption. For example, the North Carolina Best Practices for Tack Coats specifies target rates based on the type of surface (Table 2). North Carolina recommends increasing the target EAR by \(0.06 +/- 0.01 \text{ gal/yd}^2\) on oxidized or milled surfaces. However, another guide from the Flexible Pavements of Ohio (Proper Tack Coat Application 2012) recommends increasing the target EAR by 0.08 to 0.09 gal/yd\(^2\) for the same surface condition.

**Table 2 NCDOT Tack Coat Application Specifications**

<table>
<thead>
<tr>
<th>Existing Surface</th>
<th>Target Rate (gal/yd(^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Asphalt</td>
<td>0.04 (+/- 0.01)</td>
</tr>
<tr>
<td>Oxidized or Milled</td>
<td>0.06 (+/- 0.01)</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.08 (+/- 0.01)</td>
</tr>
</tbody>
</table>

In addition to visual inspection, in some instances measurement of existing pavement surface texture is used to adjust the target EAR to account for emulsion absorption. Shuler et. al. (2011) recommended adjustments to the target EAR to account for surface absorption on the basis of surface texture quantified using the sand patch method as shown in Figure 12. It can be seen
that the lower the diameter of the circle of the sand, the greater the recommended correction to the target EAR. Note that a smaller diameter circle corresponds to a higher surface texture.

![Figure 12 Surface texture correction factor based on the sand patch method (Shuler et al. 2011)](image)

The US DOT’s guide for fog seals recommends that the absorption rate of emulsion into the pavement be checked using visual inspection of emulsion absorption prior to construction (Federal Highway Administration 2002). To check the rate of emulsion absorption, it is recommended that 1 L of diluted emulsion be poured uniformly over 1 m² of paving surface. The area should be visually monitored for absorption and if the emulsion is not absorbed into the pavement or absorbs too much emulsion, the amount of emulsion should be decreased or increased and applied to another section of roadway until the absorption rate is determined (Pavement Preservation Checklist 2002). The issue with this approach is that it is subjective to the visual inspection of the operator performing the test. Another method outlined by Caltrans Division of Maintenance involves a similar procedure where emulsion is sprayed onto a known area (1 square yard) and visual observation is used to assess absorption. The major difference in Caltran’s procedure is that emulsion is sprayed rather than poured and the applied EAR is determined by weighing the sprayer before and after application (Figure 13) (Caltrans, 2009).
Researchers from Spain developed a device to measure emulsion absorption by a pavement (Raposeiras et al. 2013). The device is shown in Figure 14. The device includes a non-woven polypropylene geotextile affixed to a steel plate that is pressed onto the pavement surface after emulsion application. The geotextile absorbs non-absorbed emulsion. The study done by Raposeiras et al. (2013) tested the device on several emulsion types, application rates, and surfaces in the laboratory. A correlation was found between the macro-texture of the existing surface and the absorption of the geotextile. The device was not tried in the field and only tack coat EARs were considered.
2.8 Surface Texture

Surface texture is anticipated to significantly affect emulsion absorption by pavements. The pavement macrotexture is considered “the deviations of a pavement surface from a true planar surface with the characteristic dimensions of wavelength and amplitude from 0.5 mm up to those that no longer affect tire-pavement interaction” (ASTM E 965 2006). There are two primary types of methods used to characterize surface texture: sand patch and laser. Studies have been done that find a high correlation between the two methods as seen in Figure 15 (Flintsch et al. 2003). The types of surfaces surveyed were different asphalt concrete wearing surfaces including a 12.5 millimeter open-graded friction course and various Superpave mixtures.

2.8.1 ASTM E 965: The Sand Patch Method

The sand patch method, specified in ASTM E 965: Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique, quantifies surface texture using Mean Texture Depth (MTD). This method is commonly accepted and well established. In the sand patch test, a known volume (V) of sand is spread over the paving surface using a flat disk.
to form a circle and measuring the diameter at four different radial locations. The average of all measurements of the diameter (D) is used to calculate Mean Texture Depth (MTD) using Equation 1. The method does not take into account the pavement microtexture.

\[ MTD = \frac{4V}{\pi D^2} \] (1)

The sand patch test method is cheap, efficient, and easy to implement. However, operator variability can lead to poor repeatability (Flintsch et al. 2003). Also, the method can be time consuming (dependent upon the user), be affected by wind, and require sweeping of the pavement.

### 2.8.2 Laser Profilometer

There are many types of lasers on the market, such as the CT meter, as well as in-house lasers such as the laser profilometer developed by a research team at North Carolina State University (Adams and Kim 2014). Laser measurement devices quantify 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 North Carolina State University laser is a stationary profilometer that includes a point laser with adjustable resolution. Surface texture is quantified from laser results using Mean Profile Depth (MPD), which is defined in Equation 2 in accordance to ASTM E1845-09: Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth (ASTM E1845 2009).

\[ MPD = \frac{(Peak \ Level \ 1st) + (Peak \ Level \ 2nd)}{2} - Average \ Level \] (2)

The laser profilometer removes operator variability and provides similar results to the sand patch method. However, it is more time consuming and costly than the sand patch method. Also, traffic control is necessary to obtain the measurement.
2.9 Summary of Literature Review

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 emulsion absorption 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 that includes in-situ measurements of applied and effective EARs.

<table>
<thead>
<tr>
<th>Method</th>
<th>Able to Capture Transverse Variability?</th>
<th>Ability to Capture Longitudinal Variability?</th>
<th>Consider Surface Absorption?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual inspection</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Weight difference</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Caltrans Method for Pavement Absorption</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>US DOT Method for Pavement Absorption</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Volume difference</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Dipstick reading before and after paving</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>ASTM D 2995</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Raposeiras et al. (2013)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
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 during this research to meet this need. A summary of the Tack Lifter is provided herein. Detailed test procedures and device specifics are provided in Appendix A. 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 16 and Figure 17, 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. The weighted device base footprint is 5 in by 5 in. A 5 in by 5 in footprint was chose as it fit inside the wheel path providing a representative area of the most critical distress.

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/ft³, 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.
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 by 7 in footprint with a 3/8” high lip to prevent loss of emulsion and 1/2” 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 16 Tack Lifter components.

Figure 17 Elevated plate components.
3.2 Tack Lifter Sheet Selection

3.2.1 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) (Im and Castorena 2014). Two geotextile sheets with high absorption capacity were tried. Both were made from polypropylene and manufactured by McMaster–Carr (Figure 18). 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.

The results from the study on the “black sheet” and the “green sheet” are shown in Figure 19. Different weights, emulsions, and EARs were tested for the two sheets. Figure 19(a) shows the “green sheet” results for two different EARs (0.06 and 0.25 gal/yd$^2$) using a CRS-2 emulsion. Figure 19(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 19 Emulsion absorption at different weights: (a) CRS-2 with green sheet (b) CRS-2 with black sheet](image)

Furthermore, in some trials emulsion soaked through the absorbent sheet which led to the adhesion to the Tack Lifter weighted device. This caused deformation of the sheets upon removal from the Tack Lifter, which may impact the quality of measurements. Figure 20 shows an example of deformed sheets.
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.

### 3.2.2 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 60°C (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 21. A summary of the sheet specifications is provided in Table 4. The foam was specified to allow absorption of both water and oil, making it 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/yd², which greatly exceeds the maximum EAR used in field applications (~0.35 gal/yd²).

![Figure 21 Final Tack Lifter sheet](image)

**Table 4 Super-absorbent Polyurethane Foam Sheet Specifications**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.8 lb/ft³</td>
</tr>
<tr>
<td>Firmness (25% deflection)</td>
<td>0.6 psi</td>
</tr>
<tr>
<td>Temperature range</td>
<td>-23°C to 82°C</td>
</tr>
<tr>
<td>Thickness</td>
<td>0.5 in</td>
</tr>
<tr>
<td>Absorbency</td>
<td>2.43 gal/yd²</td>
</tr>
</tbody>
</table>
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/yd² to represent a typical chip seal EAR whereas an EAR of 0.06 gal/yd² 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 22. 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 23, 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 22 Tack lifter measured EARs on steel pan](image)
3.3 Optimization of Tack Lifter Weight

Initial Tack Lifter tests presented 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/yd². Testing was conducted at five locations along the length of paving. The experimental layout for each location of testing is presented in Figure 24. 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.
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 25. 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.
3.4 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 26 and summarized herein. The detailed procedure is provided in Appendix A, Test Method B. First, a steel pan is placed on the paving surface prior to the arrival of the emulsion distributor (Figure 26(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 26(b)). Next, pre-weighed sheets are placed in the center of each frame (Figure 26(c)). The weighted device is placed on top of each sheet for 30 seconds to allow for emulsion absorption (Figure 26(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 26(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/\( \text{yd}^2 \)) absorbed by the paving surface.

![Figure 26 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](image)

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 on a test section prior to paving. Pavements undergo the most damage in the wheel paths and hence, achieving
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.

3.5 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 A, 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 27. Following emulsion application, the peel is placed under the elevated plate as shown in Figure 27(a). Next, the peel is lifted while keeping the plate as level as possible as shown in Figure 27(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 27(d). The Tack Lifter sheet is subsequently removed and weighed to determine the applied EAR as shown in Figure 27(e).
Figure 27 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/yd² for CRS-2 and CRS-2L emulsions to represent a typical chip seal EAR, whereas an EAR of 0.06 gal/yd² 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 28(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 28(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.
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 5 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 5. 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/yd². 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 5 Laboratory Experimental Plan

<table>
<thead>
<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>
</thead>
<tbody>
<tr>
<td><strong>Target EARs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.08 gal/yd² (CSS-1H)</td>
<td>0.04 gal/yd² (CSS-1H) (25°C)</td>
<td>0.08 gal/yd² (CSS-1H and CQS-1H) (25°C)</td>
<td>0.25 gal/yd² (CRS-2L) (25°C)</td>
<td>0.25 gal/yd² (CRS-2L &amp; CRS-2) (25°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25 gal/yd² (CRS-2L) (25°C)</td>
<td>0.25 gal/yd² (CRS-2L) (25°C)</td>
<td>0.35 gal/yd² (CRS-2L) (25°C)</td>
<td>0.35 gal/yd² (CRS-2L) (25°C)</td>
<td>0.35 gal/yd² (CRS-2L) (25°C)</td>
<td></td>
<td></td>
</tr>
</tbody>
</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). 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. Reported MPD values correspond to the average MPD of each line of scanning.

The compiled correlation between sand patch and laser surface texture results for all surfaces analyzed (HMA, microsurfacings, and chip seals) is presented in Figure 29. 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 patch 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 29 Correlation between sand patch and laser results](image)

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 30(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 30(d) and (e).

Figure 30 (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 31(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 31(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 31(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 31(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 than 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 and 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/yd² are shown in Figure 31(c) and (d). Figure 31(c) shows the comparison between surface texture and the percentage of applied emulsion absorbed by the Tack Lifter. Figure 31(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/yd², is very difficult in the laboratory. Correspondingly, it can be noted that applied EAR results for a target EAR of 0.08 gal/yd² are closer to 0.09 gal/yd² 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 31 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/yd² and 0.08 gal/yd² reflect typical tack coat EARs, whereas 0.25 gal/yd² 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 32(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/yd² 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/yd² and 0.35 gal/yd². A comparison between applied and Tack Lifter effective EARs is shown in Figure 32(b). Results indicate that an applied EAR of 0.35 gal/yd² 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/yd². 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 32 (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/yd² to reflect a typical chip seal EAR. In addition, CSS-1H and CQS-1H emulsions were applied to microsurfacing samples at a target EAR of 0.08 gal/yd² 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 33(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 33(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 33 (a) Effect of emulsion type on untrafficked chip seal samples applied at 0.25 gal/yd\(^2\) and (b) Effect of emulsion type on microsurfacing 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 shown in Figure 34. 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.
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 6 Summary of Field Trials completed for ASTM D2995 and Tack Lifter Comparison

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Existing Surface Condition</th>
<th>Target EAR (gal/yd²)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granville County, NC</td>
<td>8-27-14</td>
<td>Asphalt concrete with moderate block cracking and raveling</td>
<td>0.35</td>
<td>Windy day</td>
</tr>
<tr>
<td>Zebulon, NC</td>
<td>9-17-14</td>
<td>Chip seal (7 years old) with high roughness</td>
<td>0.35</td>
<td>Additional Results in Chapter 3</td>
</tr>
</tbody>
</table>

The experimental layouts for each location of testing are depicted in Figure 35 and Figure 36 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 37.
Figure 35 Experimental layout for 8/27/14 field trial

Figure 36 Experimental layout for 9/17/14 field trial
Figure 37 (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 38. 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/yd². 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 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 38 Comparison between results of ASTM D 2995 and Tack Lifter applied to paving surface (8/27/14)

Figure 39 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 39 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 40 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 40 Bare spots left by the ASTM D 2995 Test Method A](image)

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 41. 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.

![Comparison between results of ASTM D 2995, Tack Lifter applied to pan, and Tack Lifter applied to paving surface (9/17/14)](image)

**Figure 41** 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 emulsification 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 7. 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 42 provides a photo of Sand Patch testing in the field.

![Figure 42 Sand patch method being conducted](image)

**Table 7 Summary of Field Experiments to Evaluate Emulsion Absorption into Paving Surfaces Using the Tack Lifter**

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Existing Surface Condition</th>
<th>Target EAR (gal/yd²)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vance County, NC</td>
<td>5-26-15</td>
<td>Existing chip seal exhibiting raveling and cracking in the wheel paths</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Warren County, NC</td>
<td>6-23-15</td>
<td>Existing asphalt concrete pavement, exhibiting raveling and cracking</td>
<td>0.30</td>
<td>Very hot day</td>
</tr>
<tr>
<td>Franklin County, NC</td>
<td>8-10-15</td>
<td>Existing chip seal, exhibiting cracking and raveling</td>
<td>0.30</td>
<td></td>
</tr>
</tbody>
</table>
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 43. 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 44 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 8 provides a summary of the different longitudinal locations and transverse sites of testing with corresponding visual observations of surface conditions.
Table 8 Description of Testing Sites Corresponding to Field Trial Conducted on 5/26/15

<table>
<thead>
<tr>
<th>Label</th>
<th>Longitudinal Location</th>
<th>Transverse Site</th>
<th>Surface Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>1</td>
<td>Wheel Path</td>
<td>Smooth (Worn but not bled)</td>
</tr>
<tr>
<td>1B</td>
<td>1</td>
<td>Lane Center</td>
<td>Rough with raveling</td>
</tr>
<tr>
<td>1C</td>
<td>1</td>
<td>Lane Edge</td>
<td>Heavily Bled</td>
</tr>
<tr>
<td>2A</td>
<td>2</td>
<td>Wheel Path</td>
<td>Rough with raveling</td>
</tr>
<tr>
<td>2B</td>
<td>2</td>
<td>Lane Center</td>
<td>Bled</td>
</tr>
</tbody>
</table>

Results of the 5/26/15 field trial are shown in Figure 45. Figure 45(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 45 (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 45 (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 45 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/yd² 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 46. 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 47. (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 9 provides a summary of the different longitudinal locations and transverse sites of testing with corresponding visual observations of surface conditions.

Figure 46 Surface condition of 6/23/15 field experiment
Table 9 Description of Testing Sites Corresponding to Field Trial Conducted on 6/23/15

<table>
<thead>
<tr>
<th>Label</th>
<th>Longitudinal Location</th>
<th>Transverse Site</th>
<th>Surface description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>1</td>
<td>Wheel Path</td>
<td>Cracking, some raveling</td>
</tr>
<tr>
<td>2A</td>
<td>2</td>
<td>Wheel Path</td>
<td>Cracking, some raveling</td>
</tr>
<tr>
<td>2B</td>
<td>2</td>
<td>Lane Center</td>
<td>Relatively smooth, low severity cracking/raveling</td>
</tr>
<tr>
<td>3A</td>
<td>3</td>
<td>Lane Wheel Path</td>
<td>Cracking, some raveling</td>
</tr>
<tr>
<td>3B</td>
<td>3</td>
<td>Lane Center</td>
<td>Relatively smooth, low severity cracking/raveling</td>
</tr>
</tbody>
</table>

Results of Tack Lifter tests are displayed in Figure 48. 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 48(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 48(a) demonstrate 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 48(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/yd² 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/yd² 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 48 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/yd² 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 49. 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 10.

![Figure 49 Experimental layout for 8/10/15 field trial](image)

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

<table>
<thead>
<tr>
<th>Label</th>
<th>Longitudinal Location</th>
<th>Transverse Site</th>
<th>Surface Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>1</td>
<td>Wheel Path</td>
<td>Rough</td>
</tr>
<tr>
<td>1B</td>
<td>1</td>
<td>Lane Center</td>
<td>Rough</td>
</tr>
<tr>
<td>2A</td>
<td>2</td>
<td>Wheel Path</td>
<td>Light Bleeding, low severity cracking/raveling</td>
</tr>
<tr>
<td>2B</td>
<td>2</td>
<td>Lane Center</td>
<td>Light Bleeding, minimal distress</td>
</tr>
<tr>
<td>3A</td>
<td>3</td>
<td>Wheel Path</td>
<td>Rough</td>
</tr>
<tr>
<td>3B</td>
<td>3</td>
<td>Lane Center</td>
<td>Rough</td>
</tr>
</tbody>
</table>

Figure 50 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 50(b) for Location 2A indicate unusually high EAR results, which could be the source of unexpected trend in Figure 50(a). Figure 50(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/yd² to 0.36 gal/yd². Tack Lifter tests applied to the paving surface indicates variation in the “effective” EAR ranging from 0.26 gal/yd² to 0.32 gal/yd².
Figure 50 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 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 guide 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. Appendix A, Test Method B gives a recommended, detailed procedure for evaluating the rate by which a pavement absorbs emulsion.

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 51. 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.
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/yd² of emulsion and the applied EAR is 0.04 gal/yd², 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/yd², 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.

Figure 51 Emulsion absorption rate in wheel path for field trials conducted on 6/23/15 and 8/10/15
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, 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 (28 sheets for a 12 foot lane). 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 feasible. 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 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 52. 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.
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 53. 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/yd².
5.3.3 Summary and Recommendations for Implementation of the Tack Lifter in Transvers Variability Assessment

The relatively limited investigations of transverse EAR variability using the Tack Lifter presented show 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 remedies. 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.

![Figure 53 Assessment of transverse EAR variability in 8/10/15 field trial](image)
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 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. However, 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.

An initial approach to quick, in-situ, longitudinal assessment of EAR involved using flat steel pans on the paving surface and immediately removing them after applying emulsion. The pans were transferred to a table off of the roadway for subsequent Tack Lifter testing to minimize construction 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. 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. This can cause non-uniformity on the surface of the pan, skewing results of the Tack Lifter. 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. The peel also aids in keeping the elevated plate level when removing it from the pavement as it can slide under the plate and lift
the elevated plate up. 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 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 11. 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 11 Summary of Field Trials to Assess Longitudinal Variability in Applied EARs

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Target EAR (gal/yd²)</th>
<th>Approximate Length of Paving (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Franklin County, NC</td>
<td>9-9-15</td>
<td>0.30</td>
<td>1.5</td>
</tr>
<tr>
<td>Warren County, NC</td>
<td>9-11-15</td>
<td>0.30</td>
<td>0.6</td>
</tr>
<tr>
<td>Franklin County, NC</td>
<td>9-23-15</td>
<td>0.30</td>
<td>1.6</td>
</tr>
</tbody>
</table>

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 1.5 miles of rural road. CRS-2L emulsion was utilized with a target application rate of 0.30gal/yd². 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 54, 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/yd² and the maximum 0.32 gal/yd². 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 54 Measured EAR’s for September 9, 2015 in Franklin County](image)
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/yd². 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 55. 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/yd². Measured EARs varied from 0.25 gal/yd² to 0.30 gal/yd². Note that EAR variability is deemed relatively high despite the relatively short length of paving.

![Figure 55 Measured EAR’s for September 11, 2015 in Franklin County](image-url)
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 miles of rural road 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 56. 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.

![Figure 56 Measured EAR’s for September 23, 2014 in Person County](image-url)
5.4.5 Summary and Recommendations for 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 placing the 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 A, 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 57. It can be seen in Figure 57 (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.
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 58. 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/yd². 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 4 through 7, and Location 9 indicate relatively little transverse variability, with measured EARs between 0.24 gal/yd² and 0.27 gal/yd². 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 58: Results from ASTM D 2995 Test Method A](image)

**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 A, 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 the procedure is not recommended for practice. 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/yd²). The target, applied EAR should be adjusted to account for emulsion lost to absorption.

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 rapid 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 A 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 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.
REFERENCES


APPENDIX
APPENDIX A QUALITY CONTROL FOR EMULSION APPLICATION RATES

Proposed Practice for

Quality Control of Emulsion Application Rates

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.

2. REFERENCED DOCUMENTS

2.1 ASTM Standards:
   - D 2995-99, Standard Practice for Estimating Application Rate of Bituminous Distributors

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 sheet 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.

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.
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

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:

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

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.

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/\text{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/\text{yd}^2)

4  PRECISION AND BIAS

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

5  KEYWORDS

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

6  REFERENCES