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Field Tack Coat Evaluator (ATACKer™)

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16. Abstract

Asphalt tack coats are applied during pavement construction to ensure bond between pavement layers, thus providing a more durable pavement. A prototype tack coat evaluation device (TCED) was developed to evaluate the tensile and torque-shear strength of tack coat materials. Three emulsions (SS-1, CSS-1, and CRS-2) and one asphalt binder (PG 67-22), commonly used as tack coats, were evaluated using the TCED at various application temperatures, application rates, dilutions, and set times. A laboratory bond interface strength device (LBISD) was developed to assess interface shear strength of laboratory prepared specimens. Mass loss testing was performed to evaluate moisture evaporation and visual breaking properties of emulsions.
Study results indicate application rate, tack coat, and emulsion set time significantly affect TCED strength. Application rate also affected evaporation rate of emulsions.

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CHAPTER 1 INTRODUCTION

1.1 BACKGROUND

Tack coat is an application of asphalt emulsion or asphalt binder used to improve bonding between pavement layers. The tack coat may be applied to existing clean asphalt or concrete surfaces prior to asphalt overlay and between layers of asphalt during new construction. Adequate bond between layers ensures multiple layers perform as a composite structure. As a result, stresses from applied loads are distributed throughout, subsequently reducing overall pavement damage.

Typically, tack coats are emulsions, which consist of asphalt binder particles dispersed in water with chemical emulsifying agents. Emulsifying agents assist in maintaining asphalt particle suspension in water, thus reducing asphalt consistency from a semi-solid to a thin liquid. This allows emulsions to be more easily distributed at lower temperatures than for asphalt binders. Once applied, moisture in the emulsion evaporates through a process called “breaking”, leaving behind a thin layer of residual asphalt binder on the existing surface. Occasionally, asphalt binder is used as tack coat, but requires more heating for application.

Tack coat’s ability to bond layers can be affected by many factors including tack coat type, application rate, application temperature, emulsion set time, and emulsion dilution. While specifications exist for these variables, few quality control methods exist to evaluate tack coat bond strength and the interface shear strength of pavement layers.

1.2 OBJECTIVES

Research study objectives are as follows:

1. Develop a tack coat evaluation device (TCED) and perform laboratory testing on various tack coat applications.
2. Develop a laboratory bond interface strength device (LBISD) for evaluation of interface bond strength.
3. Investigate moisture evaporation rate in emulsions.

4. Evaluate tensile and torque-shear strength of emulsions at various levels of breaking.

1.3 SCOPE

A TCED was developed to evaluate different types of tack coat and factors affecting tack coat applications. Tensile and torque-shear tests were conducted for three application rates, three application temperatures, three emulsion set times, and two emulsion dilution rates. These tests were conducted on three emulsions and one performance grade (PG) asphalt binder.

LBISD testing was performed on laboratory-prepared specimens at three application rates and two levels of base mix gradations. Maximum shear strength and slope of the load-displacement curve were obtained from tests.

The rate at which moisture evaporates from emulsions was observed by mass loss testing on three emulsions at three application rates. Finally, TCED testing was conducted on one emulsion at four levels of breaking to evaluate the effect of visual break time on tensile and torque-shear strength.

CHAPTER 2 LITERATURE REVIEW

2.1 BACKGROUND AND PROBLEM STATEMENT

Tack coat is either asphalt binder or emulsified asphalt binder applied over an existing surface being paved to improve the bond between pavement structure layers. Sufficient layer bonding results in the pavement structure acting as one composite layer, significantly reducing pavement stresses [1], therefore resulting in increased pavement life [2]. Poor layer bonding can result in pavement distresses such as slippage cracking or shoving [3] as shown in Figures 2.1 and 2.2.

Figure 2.1 Slippage Cracking (View 1) [4]

Figure 2.2 Slippage Cracking (View 2) [4]

Calculating flexible pavement responses using the Waterways Experiment Station layered elastic analysis (WESLEA) program clearly shows increased stress levels for unbonded pavements [5]. An analysis was conducted with the software for a 5.08 cm (2 in) hot mix asphalt (HMA) overlay, placed on a 15.24 cm (6 in) HMA layer, supported by a granular base. It was assumed that the elastic moduli of HMA and granular base are 3.45 GPa (500,000 psi) and 276 MPa (40,000 psi), respectively. Poisson's ratio was 0.35 and 0.4 for the HMA and granular base, respectively, with the lower HMA layer assumed to be fully bonded to the granular base. Full bonding between HMA layers would allow uniform composite layer behavior, resulting in a reduction in pavement stresses, as shown in Figure 2.3. Note that for the unbonded pavement, the two HMA layers respond to loading individually, resulting in greater interface stress. Also note a large amount of negative stress exists in the bottom of the upper layer in the unbonded pavement, in comparison to the fully bonded pavement.

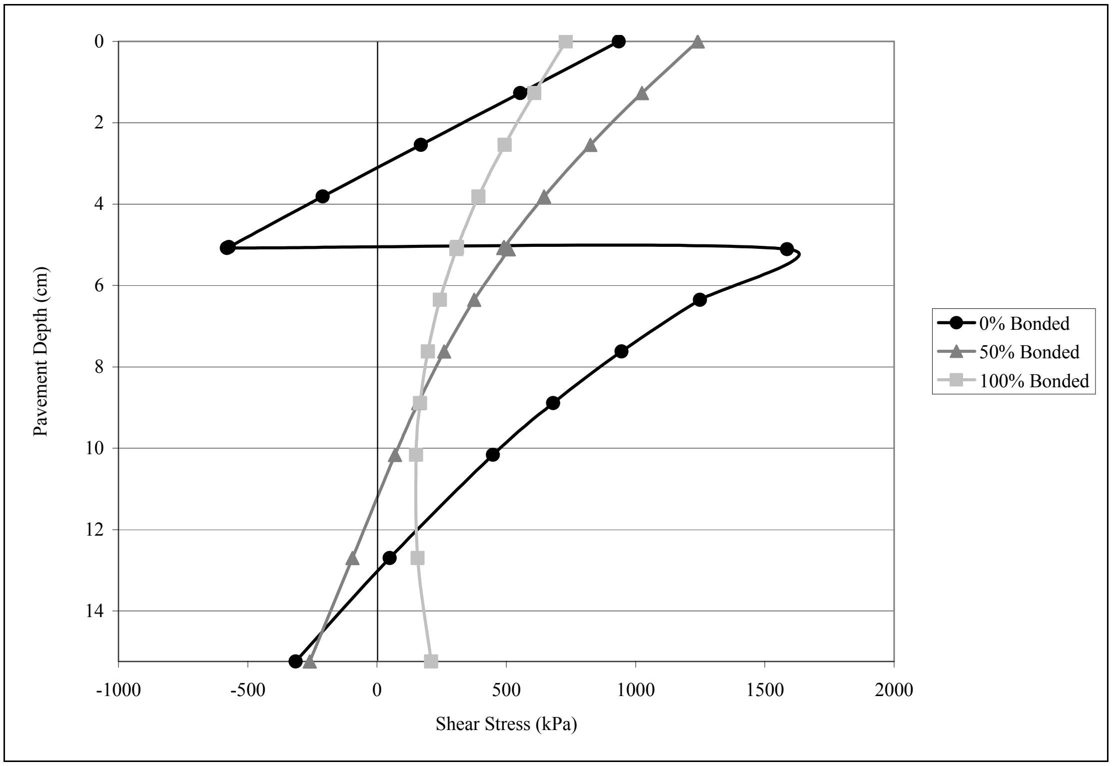

Figure 2.3 Distribution of Shear Stress in Pavements at Various Degrees of Interface Bonding

There are two types of tack coat which are used in pavement construction. The most commonly used tack coat is emulsified asphalt, which is a mixture of asphalt binder, water, and emulsifying agent. Emulsifying agents cause asphalt particles to be suspended in water and allow emulsions to act as liquids. The second type of tack coat that can be used, asphalt binder, is rarely used in the field in comparison to emulsions.

Numerous variables control whether a tack coat application will provide sufficient bond between layers. When using asphalt emulsions, the application must break before it can become an adhesive material. Breaking is the process in which water in the emulsion evaporates [6]. If all moisture has evaporated, the emulsion is considered dry. Inadequate emulsion curing can be the difference between effective and non-effective tack applications, and cure times range from 20 minutes for a broken emulsion to several hours for a dry emulsion [7]. Also, if dust adheres to tack coat before the next layer is placed, it can negatively affect on bond strength between layers [8]. Water on the application surface can have a similar bond-reducing effect. Furthermore, it is possible to have tack coat applications that are too heavy or too light. Applying tack too lightly can result in a lack of bond while excessively heavy applications may introduce a slip plane at the interface [9]. Therefore, an optimum tack coat application rate exists that provides the best possible bond between layers [10].

During multiple pavement layer or pavement overlay construction, factors affecting interface bond strength are often considered trivial in comparison to construction time. Additionally, many contractors dilute emulsions, which affects the residual tack coat application rate.

Today, there is no standardized method to assess tack coat application. The American Society of Testing and Materials (ASTM) has published two standardized tests that could be used for this purpose, but are not exactly what is required for tack coat evaluation. The first test, known as the "Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire" [11], records the force required to pull a locked wheel across a wetted pavement surface. Based on vehicle speed and tire loads, a skid number is assigned to describe pavement skid resistance. This test is limited to wetted pavement surfaces and is not likely to be a good evaluation test for tack coats since test tires would likely remove tack coat from the pavement surface. Another ASTM standard test known as the "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers", obtains the tensile force required to remove two bonded flat surfaces [12]. The test can be performed using either a pass/fail system or recording tensile force. No values are specified regarding the required normal force or pre-compression time before conducting the test. According to the standard, these criteria should be set by the testing apparatus manufacturer. This test could be adapted for assessing tack coat strength, but a standard apparatus and procedure would have to be developed and the test evaluated.

2.2 PREVIOUS STUDIES INVESTIGATING INTERFACE PROPERTIES

Numerous studies have been performed investigating adhesive properties of layer interfaces by developing a test method or instrument for analysis of interface bond strength. Most research evaluated interface bond strength by means of a direct shear device, or what is sometimes described as a "guillotine-style" device [2, 7, 8, 9, 10, 13, 14], such as shown in Figures 2.4 and 2.5. Some researchers evaluated non-destructive testing such as the falling weight deflectometer test [14]. Direct shear tests apply equal and opposite loads parallel to the layer interface plane causing layers to separate. This loading simulates horizontal pavement loads, and has been performed with and without normal loading. Additional methods have been developed that apply loads to interface specimens in other directions, such as direct tension, shear through torsion, and wedge-splitting [7, 17].

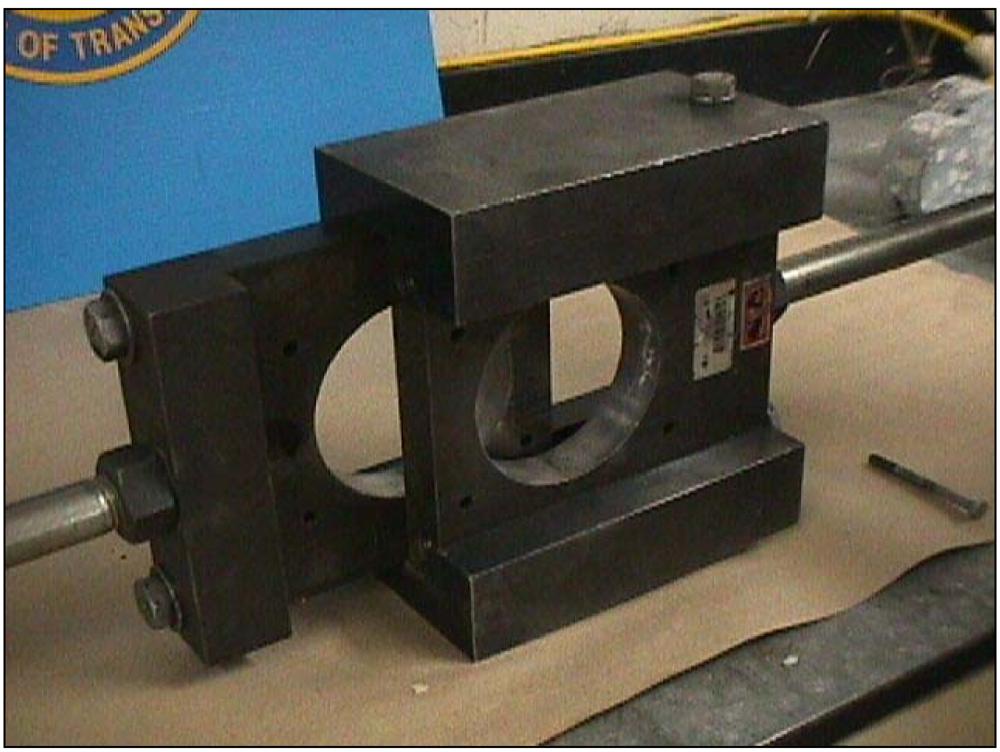

Figure 2.4 Shearing Apparatus for Evaluating Interface Bond Strength of Bituminous Tack Coats [14]

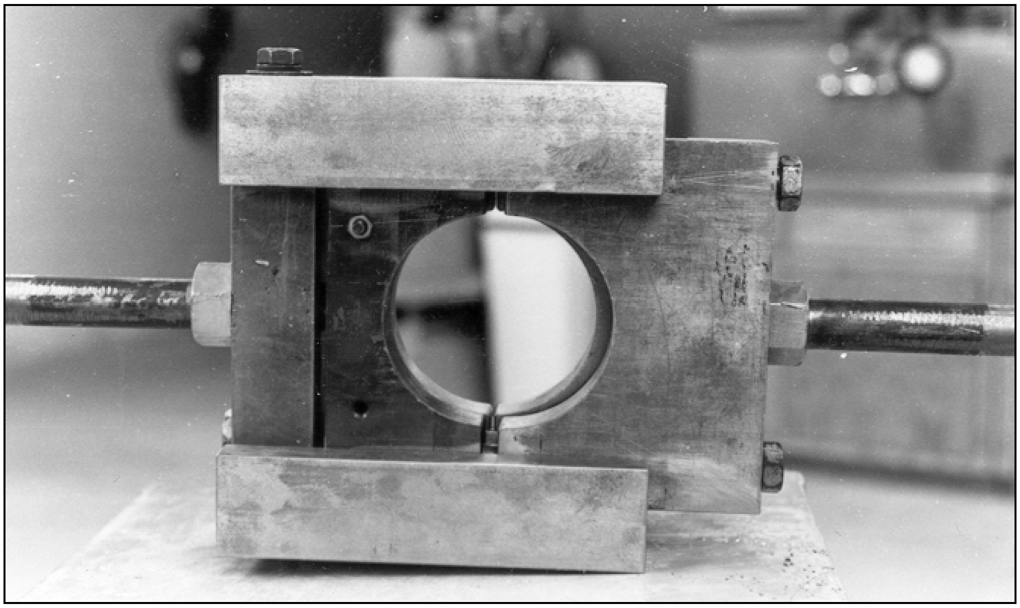

Figure 2.5 Test Apparatus for Determining the Shear Strength of Bonded Concrete [16]

Uzan et al. [10] investigated bond strength of laboratory-prepared interface specimens bonded with a Pen 60-70 asphalt binder at application rates of 0.0 (0.0), 0.49 (0.11), 0.97 (0.22), 1.46 (0.32), and 1.94 (0.43) L/m^2 (gal/yd^2). Rectangular specimens, 15 cm x 10 cm x 5 cm (5.90 in x 3.94 in x 1.97 in), were compacted to a target density of 2280 kg/m^3 (142 lb/ft^3) with a static pressure of 200 kg/cm^2 (2845 lb/in^2). Next, tack coat was applied to the specimen, and 3 cm (1.18 in) of mix compacted on top. A direct shear device was developed for this specimen size, and used a constant displacement rate of 2.5 mm/min (0.098 in/min). Specimens were tested at two temperatures, 25^{o}C (77^{o}F) and 55^{o}C (131^{o}F). The shear test evaluated interface bonds with normal loading pressure of 0.05 (0.71), 0.5 (7.11), 1.0 (14.22), 2.5 (35.56), and 5.0 (71.11) kg/cm^2 (lb/in^2). Aside from determining optimum application rate, results also indicated interface shear resistance increases with decreasing temperature and with increasing normal load. Results also indicated that shear strength is strain-rate dependent.

Tschegg et al. [17] conducted a different type of interface bond strength evaluation method with a wedge splitting test. Previous interface bond strength evaluation methods in Austria were based on direct tensile strength and exhibited extensive variability, hence the wedge splitting test development. Specimens were prepared with a groove at the interface and were split with a wedge of a specified angle, as shown in Figure 2.6. Vertical and horizontal displacements were measured with vertical loads, which were converted into horizontal loads based on wedge angle. This study evaluated cylindrical specimens at three interface orientations and rectangular specimens at one orientation. For this test method, the author indicated that maximum load could not sufficiently delineate between brittle and ductile interface behavior, and therefore developed a new variable, termed specific fracture energy. Specific fracture energy is equivalent to the area under the load displacement curve divided by specimen cross-sectional area. Test temperatures included -21.0 (-5.8), -10.0 (14.0), -5.0 (23.0), 0.0 (32.0), 5.0 (41.0), and 10.5 (50.9) ^{o}C (^{o}F). Testing examined an Austrian cationic

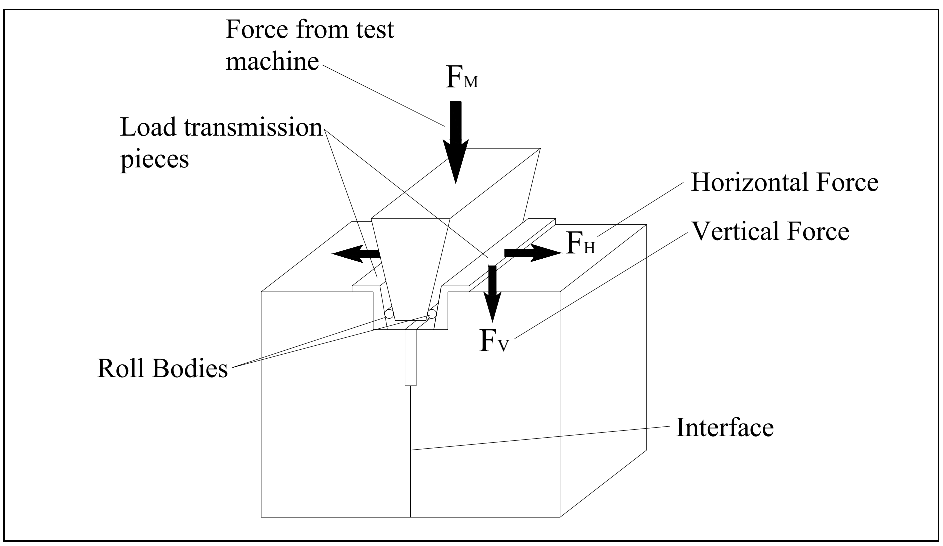

Figure 2.6 Wedge-splitting Test

emulsion (HB 60 K) and a polymer modified emulsion (HB 60 K-PM). Application rate and set time were held constant, but not specified in the study. Results showed maximum specific fracture energy values occurred at -10^{o}C (14.0^{o}F). No other significant results were obtained, but results do establish the wedge-splitting test to adequately distinguish between brittle and ductile interfaces.

Hachiya and Sato [8] investigated interface bonds of airport pavements. Specimens were taken from in-service pavements and subjected to tension and shear tests. Shear tests were performed on rectangular specimens, 100 mm x 100 mm x 50 mm (3.94 in x 1.97 in x 1.97 in), and on cylindrical specimens, 100 mm diameter x 100 mm height (3.94 in x 3.94 in). Tension tests were only performed on rectangular specimens 100 mm x 50 mm x 50 mm (3.94 in x 1.97 in x 1.97 in). All test specimens were either bonded with PK-4, a Japanese cationic emulsion, or PKR-T, a Japanese rubberized emulsion, at application rates of 0.2 (0.044), 0.4 (0.088), and 0.6 (0.132) L/m^2 (gal/yd^2). Curing effects of emulsions were investigated for cure times of 1 and 24 hours. Mass loss of emulsions due to moisture evaporation was observed for different environments. Effect of dirt contamination on tack coat surfaces was also evaluated. According to this report, emulsions must be cured until all moisture has evaporated for the tack coat to provide adequate interface bond. Results indicate properly cured cationic tack coats can still provide sufficient interface bond, even if dirt has adhered to the interface surface. No tack coat provided effective bond at the interface in situations with insufficient curing and dirt contamination. Also, an optimum tack coat rate of 0.2 L/m^2 (0.04 gal/yd^2) was determined for the rubberized emulsion.

Mrawira and Damude [9] evaluated interface strength by a direct shear test, but obtained different results than previous researchers. Specimens were assembled from field cores obtained from in-service pavements. Cores were collected in six subsets varying in pavement age, with three subsets being less than four months old and the remaining three subsets being three, six and fifteen years old. All specimens were the same mix type (Canadian type C) with four subsets having the same aggregate source and similar mix designs. Additional specimens were prepared from cores with smooth, saw cut surfaces. Cores were trimmed to a height of 8 cm (3.15 in) so only the surface layer was present and between 0.2 (0.044) to 0.3 (0.066) L/m^2 (gal/yd^2) of SS1 emulsion was applied. Tack temperatures ranged from 33 (91.4) to 68 (154.4) ^{o}C (^{o}F) with set times left to "engineer's discretion" (less than one hour). Once tack had cured, a 16 mm (0.63 in) nominal maximum aggregate size type C overlay was compacted onto the core in two lifts with 75 Marshall blows per lift. Specimens were cured for two weeks at room temperature, then cut into rectangular specimens, 70 x 75 mm (2.76 x 2.95 in), and placed in a water bath at 22^{o}C (75^{o}F) for thirty minutes. Finally, specimens were sheared at a constant displacement rate of 1mm/min in an Instron testing machine. This machine was modified to conduct "guillotine style" shear testing. Results indicated higher ultimate shear strengths without tack coat, failing to support the hypothesis that tack coat improves interface shear strength. Specimens with smooth saw cut surfaces exhibited lower ultimate shear strengths than traffic-worn specimens with and without tack coat.

Romanoschi and Metcalf [2] performed shear tests on 95 mm (3.75 in) cores extracted from the Louisiana pavement research facility. Direct shear tests were performed for interfaces with and without tack coat at 15, 25, and 35^{o}C (59, 77, and 95^{o}F). Each test was subjected to one of four normal loads: 138, 276, 414, and 552 kPa (20, 40, 60, and 80 psi). Data obtained from each test included interface reaction modulus, (K), obtained from the stress-strain curve slope, maximum shear strength, (S_{max}), and coefficient of friction after failure, (μ). Analysis of variance (ANOVA) yielded the following conclusions:

- Temperature affects S_{max} and K with and without tack coat
- Temperature has an effect on μ for specimens without tack coat, but no effect with tack coat.
- Tack coat affects S_{max} and K, but not μ.
- Normal load affects K, independent of temperature level, for combinations without tack coat.
- Normal load and temperature level affect S_{max} for combinations without tack coat.
- Normal load only affects K and S_{max} for combinations without tack coat.

Direct shear test results show temperature affects K and S_{max}, but not μ for interfaces with tack coat. Also, for interfaces with tack coat, magnitude of normal load had no direct effect on interface reaction modulus or peak shear strength. This implies direct shear devices for interface testing do not require normal load.

The International Bitumen Emulsion Federation [7] presented four tests currently being developed to assess interface bond strengths:

- The Swiss method (SN 671 961) involves a 150 mm (5.91 in) core subjected to shear force (Figure 2.7) in which minimum shear force requirements are 15 kN for interfaces between surface and binder courses and 12 kN for interfaces between binder courses and road bases. The intended purpose of the test is to determine appropriate tack coat application rates.

Figure 2.7 Swiss Method Shear Device

- The Austrian Method, discussed briefly in Tschegg's work [17], involves cores being glued to metal plates at both ends and undergoing direct tensile testing, as in Figure 2.8. Tensile strengths must be greater than 1.5 N/mm^2 for modified binders and greater than 1 N/mm^2 for unmodified binders. Penalties are distributed for each 0.1 N/mm^2 below specification.

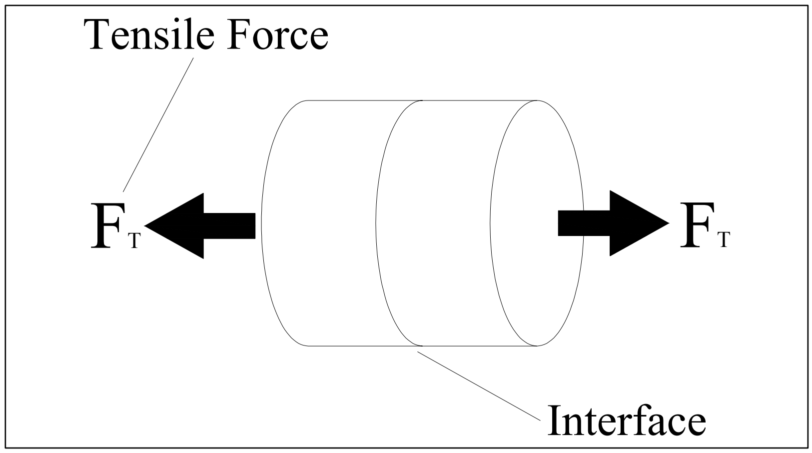

Figure 2.8 Tensile testing

- Great Britain developed a test in which 100 mm diameter cores have metal plates glued to each end as in the Austrian method, with torsional forces introduced to the specimen, as in Figure 2.9. No test specifications have been set at the time of this publication.

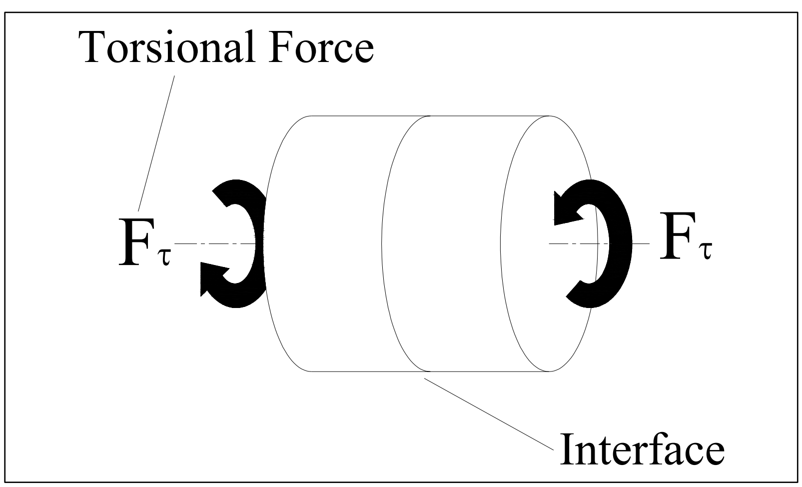

Figure 2.9 Torsional testing

- Test methods are also being developed by The Ministry of Transport in Québec (MTQ). Bond properties at the interface are evaluated based on stripping resistance and non-destructive testing. This test, noted as the “most promising”, has very little available information.

Mohammad et al. [13] conducted simple shear tests on Superpave gyratory compacted specimens. Specimens were initially compacted to 55 mm (2.2 in) height, tack coat applied and cured, and a second lift placed on top and compacted. Tack coats evaluated include two PG asphalt binders (PG 64-22 and PG 76-22M), and four emulsified asphalts (CRS-2P, CSS-1, SS-1, and SS-1h). Five application rates were evaluated, 0.0 (0.0), 0.09 (0.02), 0.23 (0.05), 0.45 (0.1), 0.90 (0.2) L/m^2 (gal/yd^2), along with two test temperatures, 25 and 55^{o}C (77 and 131^{o}F). Unlike previously mentioned simple shear tests, Mohammad loaded interfaces with constant stress rate instead of constant strain rate, which may have influenced the results. Optimum application rates were determined for each tack coat. The author concluded that increasing application rate at lower temperatures would generally result in decreased shear strength. In addition, shear strength was not affected by application rate at higher temperatures.

Hakim [15] used falling weight deflectometer (FWD) testing to conclude low pavements stiffness resulted from a lack of bond at the interface. Layer separation during coring proved weak bonds existed, and laboratory obtained indirect tensile stiffness modulus values were higher than back-calculated stiffness from FWD data. These low stiffness values were likely to have resulted from the lack of bond at the interface. A new method for FWD back-calculation was introduced, which not only estimated pavement stiffness, but also predicted bond condition between layers. Additionally, a mathematical model was developed describing interface bond stiffness in terms of force per volume. Model limits were set at 100 MN/m^3 (6,269 lb/yd^3) for de-bonding and 10,000 MN/m^3 (626,917 lb/yd^3) for approximate full bonding.

The Florida Department of Transportation [14] materials office evaluated the effectiveness of a newly developed interface bond strength shear device. Cores were extracted from multiple highway test sections throughout Florida. Interface bond strength characteristics investigated included water effects and variation of bond strength with time. As anticipated, shear strengths increased with time, but unexpectedly became independent of application rate after a certain time period. Results indicated that shear strength increases with pavement life and water on the tack coat surface reduces strength.

2.3 SURVEYS OF STANDARD TACK COAT CONSTRUCTION PRACTICES

As mentioned previously, tack coats can be applied differently based on many different variables, such as temperature, application rate, set time, and dilution rate. It is necessary to determine common ranges for these variables before conducting tack coat experiments. Surveys have been performed by previous researchers to assess standard practices of tack coat construction [7, 18], and are used as a guide for selection of experimental design variables.

Paul and Sherocman [18] surveyed Department of Transportation materials engineers throughout the United States to determine the state of practice with respect to fog seal and tack coat practices. Survey questions included but were not limited to tack coat type, application rate, common dilution rates, and emulsion set times. Responses were received from 42 states and the District of Columbia. Survey results showed most states use slow-set emulsions such as anionic slow set, SS-1, and cationic slow-set, CSS-1, or the harder base-asphalt versions, SS-1h and CSS-1h. Fewer states specified using rapid-set emulsions such as CRS-1, CRS-2, and RS-1. Two states specified using asphalt binder as a tack coat. Specified residual rates ranged from 0.03 L/m^2 (0.07 gal/yd^2) to 0.52 L/m^2 (0.11 gal/yd^2). Most states specified tack coats to set until visibly broken, with minimum set times ranging from 15 minutes to an hour. The majority of states had no specification for maximum set time. Maximum set times that were available ranged from 4 to 72 hours. Normal dilution rate was one part emulsion to one part water.

Chaignon and Roffe [7], along with the International Bitumen Emulsion Federation, distributed a survey to various countries worldwide covering the following criteria regarding tack coats:

- Tack Coat type
- Application rates
- Set time

- Existing standards and specifications
- Applicable tests and inspection techniques
- Application methods

Survey results showed the most common tack coats to be cationic emulsion, followed by anionic emulsion. Responses from the United States showed that asphalt cement is occasionally used. Residual tack coat rates ranged from 0.12 (0.025) to 0.4 kg/m^3 (0.082 lb/ft^2), and common set times ranged from 20 minutes for a broken binder to several hours for a dry binder.

2.4 OBSERVATIONS FROM LITERATURE REVIEW

The most commonly used method to measure bond strength between pavement layers has been with a direct shear device. Data obtained from these tests include maximum shear strength value, which can be adjusted for specimen size, interface reaction modulus, which is equivalent to stress-strain curve slope, and specific fracture energy, which is equivalent to the area under the stress-strain curve divided by specimen cross-sectional area. Values obtained for shear strength are affected by the following variables:

- Test temperature
- Displacement rate
- Tack application rate
- Tack application temperature
- Tack coat type
- Normal load
- Emulsion cure time
- Tack coat contamination
- Pavement age
- Pavement roughness [9]

Most variables affect interface reaction modulus and specific fracture energy. Studies also show applied normal load only affects maximum shear strength for specimens without tack coat. Also, results from most studies indicate an optimum tack coat rate exists that should provide the strongest shear strength.

CHAPTER 3 RESEARCH TEST PLAN

The research test plan is shown in Figure 3.1. A series of tests were performed to investigate the effect of application rate, set time, tack coat material, and other variables on tack coat tensile and torque-shear strength. A tack coat evaluation device (TCED) was developed to evaluate the adhesive strength of tack coat applications on flat smooth testing surfaces, and a laboratory bond interface strength device (LBISD) was developed to assess interface bond strength between pavement layers by direct shear loading. Additional testing was performed to investigate emulsion breaking rate by observing mass loss and visual break times. Finally, tensile and torque-shear strengths were determined for emulsions at various degrees of breaking.

3.1 TACK COAT EVALUATION DEVICE (TCED)

It was decided that a laboratory device should be developed for evaluating the tensile and torque-shear strength of various tack coat applications. InstroTek® Inc. developed a prototype device which is similar to that which is described in American Society of Testing and Materials (ASTM) specification D4541, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers." [12]. The prototype device, named the ATacker™, shown in Figure 3.2, and determines adhesive strength of tack coat applications by applying normal pressure to a test plate with tack coat applied and recording the tensile force or torque required to break the tack coat bond between the two test plates.

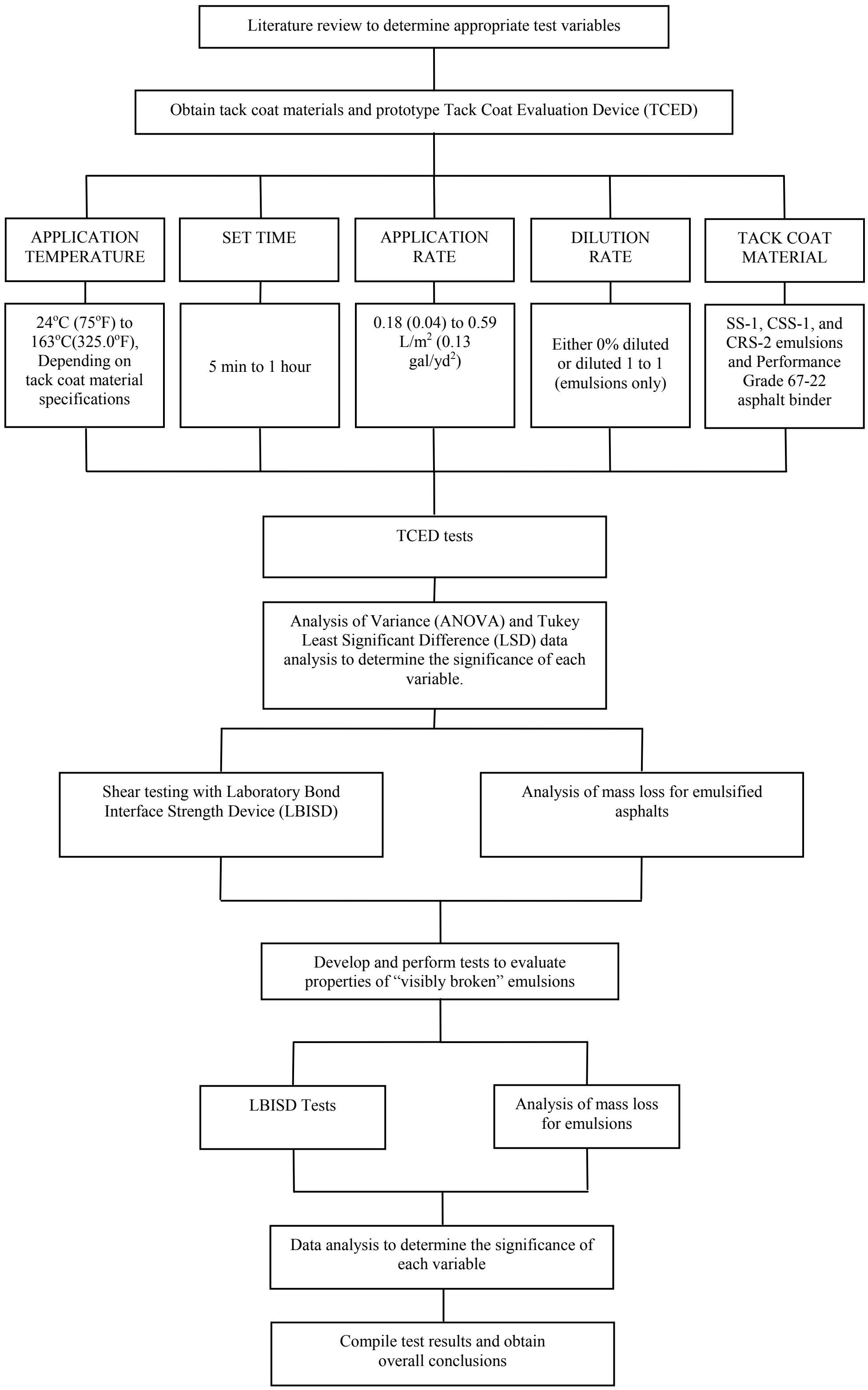

Figure 3.1 Research Test Plan

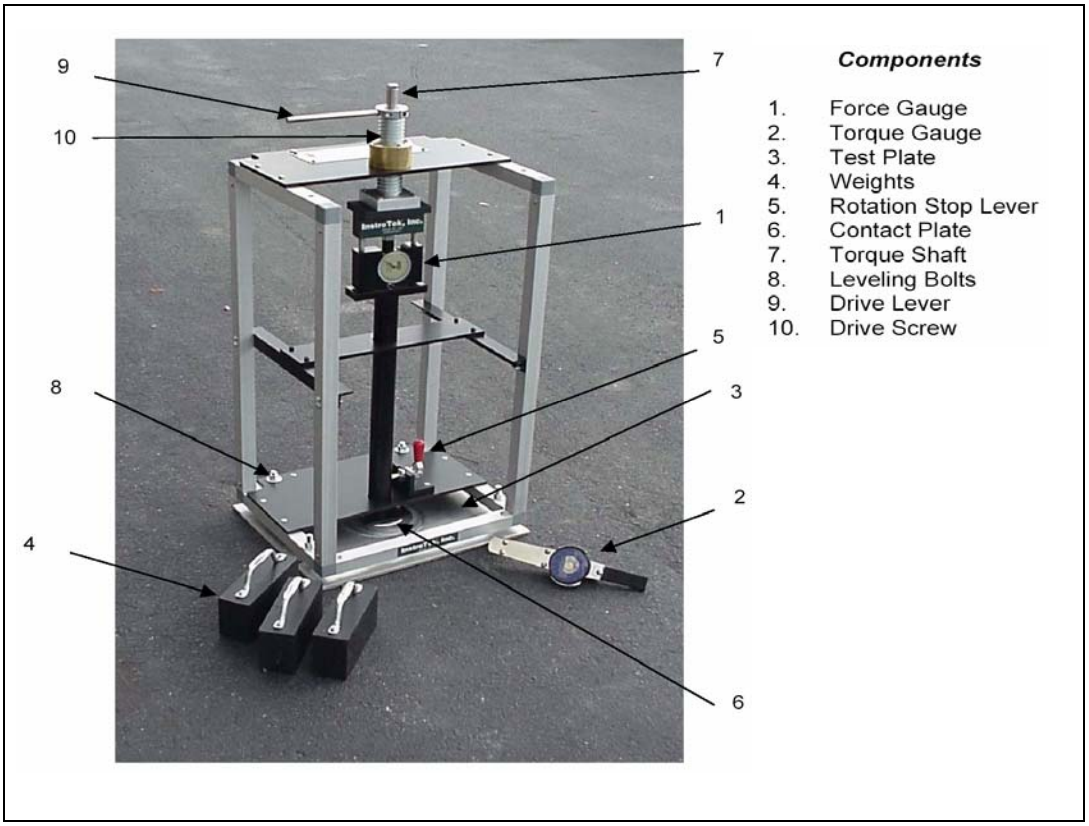

Figure 3.2 Tack Coat Evaluation Device (TCED)

3.1.1 Specimen Preparation

Samples of PG 67-22 asphalt binder, cationic rapid-set (CRS-2) emulsion, and cationic slow-set (CSS-1) emulsion were obtained from the Ergon, Inc. in Vicksburg, Mississippi. Samples of anionic slow-set (SS-1) emulsion were obtained from Blacklidge Emulsions in Gulfport, Mississippi. Emulsions were stored in 18.9 L (5.0 gal) buckets with asphalt binder stored in 3.8 L (1 gal) metal cans. Asphalt binder and emulsions were stored based on manufacturers' storage specifications. After appropriate mixing of the material, 200 mL (6.76 fl oz) glass beakers were filled partially with tack coat and placed in an oven. A high-temperature asphalt thermometer was used to determine sample temperature. Once a sample reached the desired testing temperature, a 10 mL (0.34 fl oz) glass syringe was used to extract the desired tack volume. Required application volumes and specimen diameters were calculated based on contact plate diameters and desired application rates. For example, an application rate of 0.23 L/m^2 (0.05 gal/yd^2) multiplied by the surface area 2026.8 mm^2 (3.14 in^2), required 0.46 mL (0.015 fl oz) of tack coat.

This volume of tack coat was applied with the syringe to the ATacker™ testing surface so the tack coat was evenly distributed over the contact area of the TCED plate, as shown in Figure 3.3.

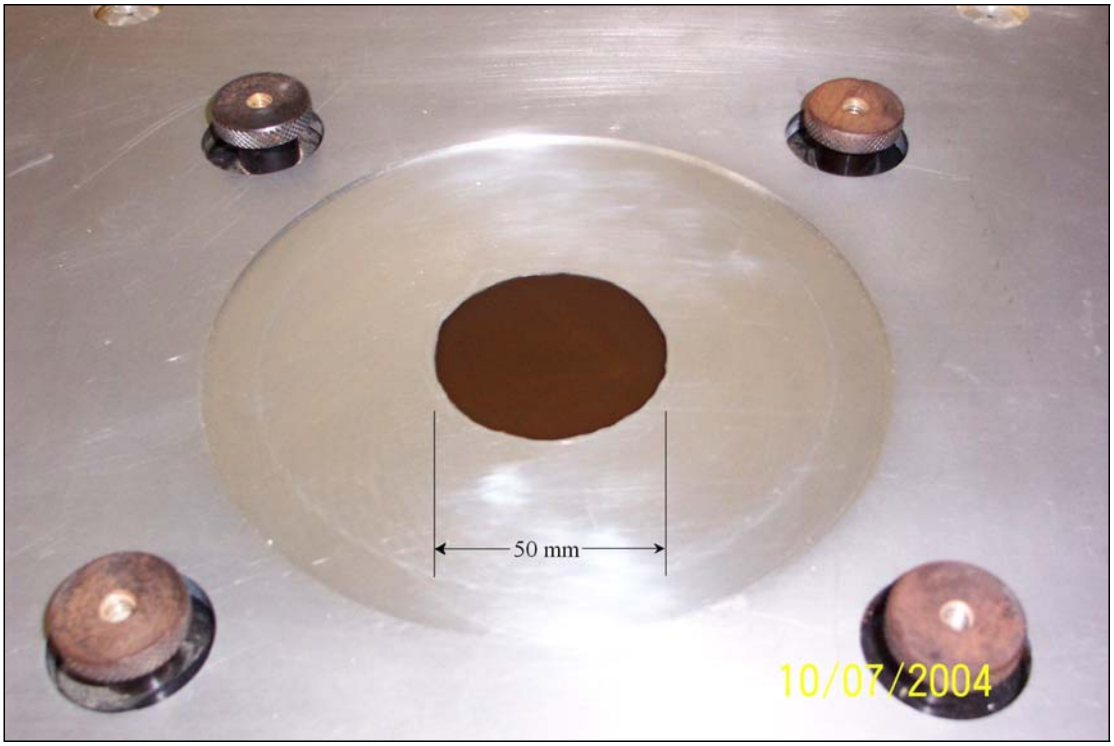

Figure 3.3 TCED test specimen

Once tack coat was applied to the test surface, it was allowed to cure for the selected set time. Set times of 5, 10, and 15 minutes were used for non-diluted emulsion specimens, and times of 15, 30, and 60 minutes were for diluted emulsions. Set time was not evaluated for the PG binder. After the appropriate set time, either tensile or torque-shear strength was determined.

3.1.2 Tack Coat Strength Evaluation

The ATacker™ TCED determines tensile and torque-shear strength by compressing a smooth, circular, aluminum contact plate onto a prepared tack coat specimen with a standard normal force [Figure 3.4(a)] and then recording the force required to remove the contact plate from the testing surface by either tension [Figure 3.4(b)] or torque-shear [Figure 3.4(c)]. Once a tack coat specimen had been cured for the predetermined set time, compression of the specimen was immediately performed by rotating the ATacker™ drive lever (Figure 3.2.9) clockwise until a standard compression load of 178 N (40 lbf) was observed on the force dial gauge (Figure 3.2.1). Different contact plate diameters were selected to test the PG binder, non-diluted emulsions, and diluted emulsions, due to a variation in the tensile and torque-shear strength of the tack coat materials and limitations of the load gauges. Both a 12.7 mm (0.5 in) and a 25.4 mm (1.0 in) plate were used to test PG binders. Non-diluted and diluted emulsions were tested with a 50.8 mm (2.0 in) and a 127.0 mm (5.0 in) diameter plate, respectively. Compression load duration of 60 seconds was used for all test combinations.

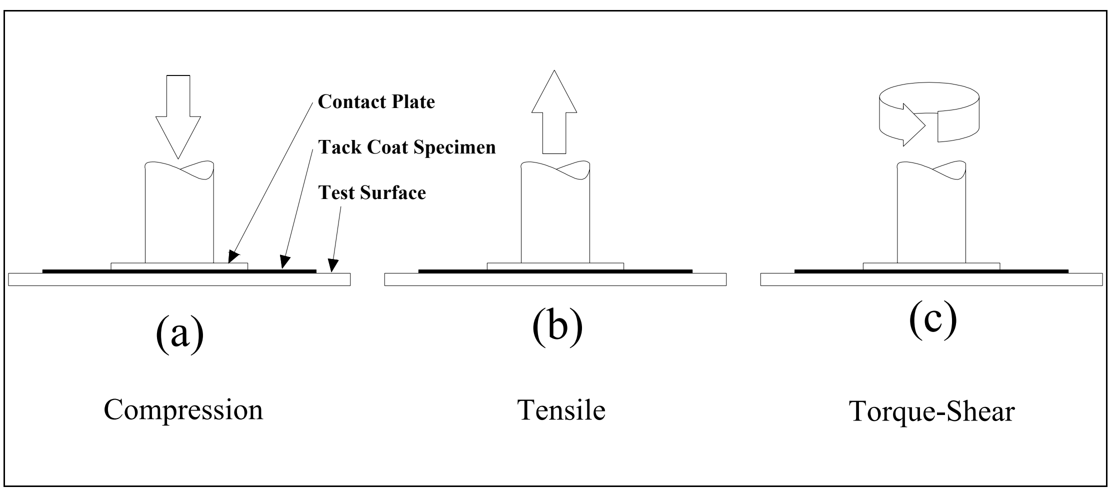

Figure 3.4 TCED Testing

After the 60 second compression load duration, the contact plate was removed and the force required to break the bond was recorded. When testing specimens for tension, the drive lever (Figure 3.2.9) was rotated in a counter-clockwise direction. This applied tension to the specimen, as shown in Figure 3.4(b). The maximum load required to completely remove the contact plate from the test surface was recorded as the tension value. When testing for tension, the drive lever was rotated at a constant rate to ensure comparable data.

When testing specimens for torque-shear, the rotation stop lever (Figure 3.2.5) was turned to the down position to allow shaft rotation (Figure 3.2.7). A torque wrench (Figure 3.2.2) was attached to the shaft, turned clockwise, and the maximum torque value recorded. When testing for torque-shear, the torque wrench was rotated at a constant rate as for tension testing.

3.2 LABORATORY BOND INTERFACE STRENGTH DEVICE (LBISD)

A second device, shown in Figure 3.5, was developed to determine interface shear strength of cylindrical laboratory specimens. This device determines interface shear strength by direct shear, and is similar to the direct shear devices described in Chapter II.

Figure 3.5 Laboratory Bond Interface Strength Device (LBISD)

3.2.1 Specimen Preparation

Laboratory specimens were prepared to determine effects of tack coat material type, application rate, and mix course gradation on interface bond strength. Test variables included coarse and fine base mixes, four tack coats, and three levels of application rate.

Cylindrical hot mix asphalt (HMA) specimens, 150 mm (5.9 in) tall by 152 mm (6.0 in) diameter, were compacted in the gyratory compactor (SGC) and then sawed into two equal 75 mm (2.9 in) specimens. Next, a 200 mL (6.76 fl oz) tack coat sample was obtained. The tack coat sample and three cotton-tip applicators were then placed on a digital balance [accuracy 0.001 g (0.000035 oz)], and the balance was tared. Required tack coat mass was determined based on a 152 mm (6.0 in) diameter surface and the desired application rate. For example, an application rate of 0.23 L/m^2 (0.05 gal/yd^2) multiplied by the surface area 2026.8 mm^2 (3.14 in^2) required 0.46 mL (0.015 fl oz) of tack coat. Cotton-tip applicators were used to apply tack coat from the 200 mL (6.76 fl oz) sample to the uncut surface of the HMA specimen until the desired mass was removed from the balance. Applicators were tared and included in the weighing of the remaining tack sample to account for adhered tack material. Once HMA specimens had been tacked, they were cured for 24 hours in a 24^{o}C (75^{o}F), dust-free environment.

The height of cut HMA specimens was measured before compaction of the top layer to ensure interface location for subsequent shear testing. A digital caliper with accuracy of 0.01 mm (0.0004 in) was used to measure cut specimens at third points.

Prepared specimens were placed in a SGC mold and a 50 mm (2 in) HMA was compacted over the tacked surface. This was conducted to simulate an HMA overlay of an in-place HMA pavement. The overlay mix was a 9.5 mm (3/8 in) nominal maximum aggregate size gravel mix with a PG 67-22 binder. Design asphalt content was 7.2% asphalt. All specimens were compacted to 96 gyrations and then cured at 23^{o}C (75^{o}F) for 24 hours before testing. Previously determined specimen heights were used to mark the interface location, as shown in Figure 3.6.

Figure 3.6 Locating the Interface of Shear Specimens

3.2.2 Shear Testing

After curing, specimens were placed in the shear device with the specimen interface carefully aligned with the LBISD interface gap, as shown in Figure 3.7. The specimen and the shear device were placed into a Marshall loading device for testing, as shown in Figure 3.5. A strain displacement gauge was used to determine specimen displacement during loading. Both the displacement gauge and the load cell were connected to a data logger. The Microsoft Windows data program, Hyperterminal [19], was used to collect load and displacement information from the data logger for all shear tests.

The Marshall device operated at a constant displacement rate of 5.08 cm/min (2.0 in/min). During testing, specimens were loaded parallel to the interface plane, with no normal load. The data logger recorded measurements for displacement and load every 0.1 seconds. After a 467 N (105 lb) decrease in maximum load, the data logging process was stopped. At this point, the specimen interface was considered fully sheared and the test complete. A fully sheared specimen is shown in Figure 3.8.

Figure 3.7 Correct Alignment of Specimens.

Figure 3.8 Fully Sheared Interface Specimen.

3.3 ANALYSIS OF MASS LOSS FOR EMULSIONS

Asphalt emulsions used as tack coats provide best bond at the layer interface if the overlying layer is applied after the emulsion is broken. Breaking is when the moisture in the emulsion evaporates, leaving only asphalt binder. Typically, unbroken emulsions possess approximately 33 to 35 percent moisture. A broken emulsion does not necessary have zero moisture, but does lack moisture at the exposed surface and exhibits adhesive behavior. A "dry emulsion" is an emulsion in which 100 percent of the moisture has evaporated. Time required for the evaporation process is highly dependent on environmental conditions and can range from 20 minutes for a broken emulsion to several hours for a dry emulsion.

An investigation was performed on emulsions to determine moisture evaporation rate in terms of mass loss. Tests were performed on three emulsions at three application rates.

3.3.1 Specimen Preparation

A digital balance with accuracy of 0.0001 g (0.0000035 oz) was used for emulsion mass loss testing. A data cable was connected between the balance and a PC, which used Hyperterminal [19] to collect data.

Aluminum tares, 50.8 mm (2.0 in) diameter, were placed on the balance and the balance zeroed. This was conducted to ensure only the emulsion would be weighed and an accurate measurement of residual application rate could be made. Next, a 200 mL (6.76 fl oz) tack coat sample was obtained, and a 5.0 mL (0.17 fl oz) glass syringe used to extract the desired tack coat amount for testing. This tack coat amount was calculated based on the 50.8 mm (2.0 in) diameter surface of the aluminum tare and the desired application rate. Tack coat was spread evenly across the tare surface to ensure uniform evaporation of the specimen.

3.3.2 Mass Loss Testing

Once tack coat was applied to the tare surface, the specimen was immediately placed on the balance and the test started. Test specimen mass was recorded every 15 seconds for 16 hours, at which time the test was complete.

3.4 ANALYSIS OF EMULSION BREAKING BY MASS LOSS TESTING

Many transportation agencies specify asphalt emulsions to be properly cured when “visibly broken” [18]. This term describes emulsions in which the exposed application surface has dried and tack coat visibly appears to be broken. Emulsion may still possess a slight amount of moisture at this point. Therefore, additional testing was performed to observe emulsion behavior in terms of visual breaking.

The procedures for emulsion breaking analysis were the same as the first series of mass loss testing, with a few additions. When specimens were placed on the balance, a timer was also started. Once the test specimen had visibly broken, the time was recorded and the test continued just as described earlier.

3.5 ANALYSIS OF EMULSION BREAKING BY TCED TESTING

A series of additional tensile and torque-shear strength tests were performed with the TCED to evaluate the strength of emulsions at various levels of visual breaking. Specimens were prepared for analyzing visual emulsion breaking with the TCED in the same manner as the previously mentioned TCED testing, using 50.8 mm (2.0 in) diameter contact plates and specimens. Instead of allowing specimens to cure for predetermined times, tensile and torque-shear strength tests were performed when specimens reached certain levels of visual breaking. The following degrees of visual breaking were tested, keeping in mind that circular specimens of emulsion application break from the outside edge inward:

1) t_o, time at which break begins. This point was defined as when the specimen had broken 1mm (0.04 in) around its edge.
2) $t_{1/2}$, time at 50 percent breaking. This point was defined as when the specimen had broken 7.4mm (0.29 in) from its edge. This point in breaking from the edge provided a test specimen in which 50 percent of the 50.8 mm (2.0 in) diameter specimen surface area had broken.
3) t_{full}, time of full break. Defined as when the entire surface area of the specimen had broken.
4) $t_{full + 10}$, time of full break plus 10 minutes.

Test variables included one type of emulsion and three application rates. Each test combination was performed in duplicate. Once test specimens had been cured to the appropriate level of breaking, the time was recorded, and either tensile or torque-shear strength determined with the TCED.

CHAPTER 4 TEST RESULTS AND ANALYSIS

4.1 TACK COAT EVALUATION DEVICE (TCED)

As mentioned in Chapter III, the TCED was developed for evaluating tensile and torque-shear strength of tack coat applications. Three main types of tack coat were evaluated with the TCED: non-diluted emulsions, diluted emulsions, and PG binders. Testing evaluated the following variables:

- Tack coat type
- Application temperature
- Application rate
- Emulsion set time

Tensile and torque-shear tests were performed in replicate for each test combination. Due to variation in contact plate diameters and set times between diluted and non-diluted emulsion tests, four separate statistical analyses were performed on TCED data. Each set of data was subjected to a statistical analysis of variance (ANOVA) test and a Tukey's analysis by means of SAS version 8 software [20]. Also, interaction plots were constructed with MINITAB version 14 software [21] to display variable effects on tensile and torque-shear strength.

4.1.1 Non-diluted emulsions

Three types of non-diluted emulsion were evaluated: anionic slow-set (SS-1), cationic slow-set (CSS-1), and cationic rapid-set (CRS-2). Emulsion certification sheets are provided in Appendix A. A 50 mm (2 in) diameter contact plate was used with set times of 5, 10, and 15 minutes. Tests were performed at application rates of 0.23 (0.05), 0.41 (0.09), and 0.59 (0.13) L/m^2 (gal/yd^2). SS-1 and CSS-1 emulsions were evaluated at application temperatures of 23.9 (75.0), 43.3 (110.0), and 65.6 (150.0) ^{o}C (^{o}F), while CRS-1 emulsions were evaluated at temperatures of 48.9 (120.0), 62.7 (145.0), and 76.7 (170.0) ^{o}C (^{o}F). Temperature variables were selected based on manufacturers' specifications and were considered as low, medium, and high during statistical analyses.

4.1.1.1 Tensile Strength

TCED tensile strengths obtained in pound-force units were converted to force per contact plate surface area for statistical analyses. Tensile strengths were referred to in terms of kilopascals. ANOVA and Tukey analyses performed with non-diluted emulsion tensile strengths are shown in Tables 4.1 and 4.2. Individual non-diluted emulsion tensile strength data are provided in Appendix B.1.

Table 4.1 ANOVA for Non-diluted Emulsion Tensile Strength (kPa)

Source of Variability	Degrees of Freedom	Mean Square	F-Value	P-Value	Significant*
Tack	2	8247.9	63.88	<0.0001	YES
Temperature	2	2035.2	15.76	<0.0001	YES
Rate	2	6116.8	47.38	<0.0001	YES
Set	2	14095.3	109.17	<0.0001	YES
Tack*Temperature	4	2105.4	16.31	<0.0001	YES
Tack*Rate	4	321	2.49	0.0499	YES
Tack*Set	4	198.1	1.53	0.2000	NO
Temperature*Rate	4	481.2	3.73	0.0078	YES
Temperature*Set	4	81.5	0.63	0.6414	NO
Rate*Set	4	259	2.01	0.1015	NO
Tack*Temperature*Rate	8	546.8	4.23	0.0003	YES
Tack*Temperature*Set	8	264.1	2.05	0.0511	NO
Temperature*Rate*Set	8	373.2	2.89	0.0070	YES
Tack*Temperature*Rate*Set	24	202.3	1.57	0.0707	NO

*P-values greater than 0.05 are not significant (means are not different)

Table 4.2 Tukey Analysis of Non-diluted Emulsion Tensile Strength

Variable	Level	Mean (kPa)	N	Tukey Grouping*
Tack Coat Material	CRS-2	96.863	54	A
	CSS-1	96.435	54	A
	SS-1	75.246	54	B
Application Temperature	Low	94.935	54	A
	Medium	82.848	54	B
	High	90.761	54	A
Application Rate (L/m^2)	0.23	100.059	54	A
	0.41	89.709	54	B
	0.59	78.776	54	C
Set Time (min)	15	104.106	54	A
	10	92.287	54	B
	5	72.152	54	C

*Means with the same letter are not significantly different

The ANOVA analysis in Table 4.1 illustrates main level and interaction significance of study variables. Variables or variable interactions possessing a P-value less than 0.05 significantly affect tensile strength, based on a 95% level of confidence. Table 4.1 shows each individual variable was significant, along with three two-way interactions and two three-way interactions. Multiple interactions can be difficult to analyze, therefore, an interaction plot, shown in Figure 4.1, was developed using MINITAB Version 14 software [21].

Table 4.2 provides mean tensile strength of each test variable and provides each variable a Tukey grouping. Mean values with the same grouping letter are not significantly different. CRS-2 and CSS-1 cationic emulsions exhibited statistically higher tensile strengths than the SS-1 emulsion. Mean tensile strengths increase in SS-1, CSS-1, and CRS-2 specimens, respectively. Previous studies [8, 10, 13] concluded application rate affects interface bond strength. Mean tensile strengths increased with decreasing application rate, indicating higher application rates may decrease tensile strength. Tensile strength also significantly increased with set time, indicating with time moisture evaporates from emulsions, increasing viscosity and tensile strength.

An interaction plot is a matrix of individual sub-plots of mean values for a given set of multi-variable data, with one output variable. In this case, the output variable is non-diluted TCED tensile strength (kPa). The vertical scale is the same for all sub-plots within the entire interaction plot. The horizontal scale is consistent within columns of sub-plots, and the legend of plots is consistent within sub-plot rows. To observe data trends within a full interaction plot matrix, look for trends in the succession of plots within rows or look for trends in plot slope and shape within columns. For example, if all of the plots in a given column have positive slope, it can be said that the output variable consistently increases as the horizontal scale for that column increases. The same data trend can be observed in the row for the same input variable by observing the vertical order of plots. To more clearly observe multiple interactions, look for sub-plots which appear to be significantly different from trends that are visible in the same column or row. The provided interaction plot reiterates what was interpreted from ANOVA and Tukey analyses. For example, by observing the top row of the plot, plot lines for SS-1 remain below both CSS-1 and CRS-2, regardless of other input variables. This same response is indicated by the Tukey grouping of tack coat type. A similar data response can be observed in the bottom two rows of the interaction plot, where the order of set time and application rate remains constant despite other input variables. A clear multiple interaction can be detected between tack coat and temperature level by observing the general trend of plots in the temperature level column, and then noticing the sensitivity of the plots when combined with tack coat. It is apparent from Figure 4.1 this multiple interaction is a result of CRS-2 temperature sensitivity.

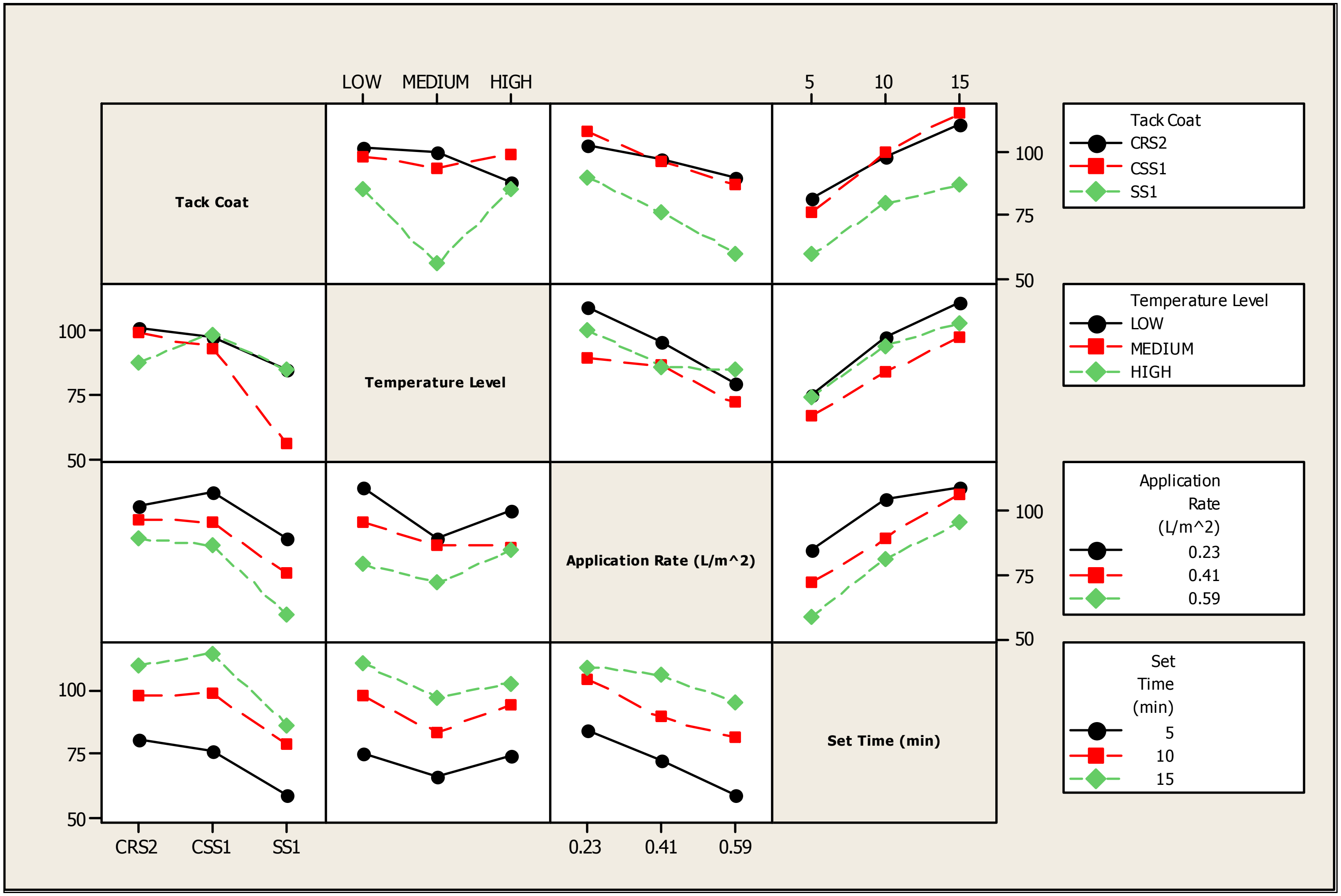

Figure 4.1 Interaction Plot for Non-diluted Emulsion Tensile Strength (kPa)

4.1.1.2 Torque-Shear Strength

Torque values during the torque-shear testing were in units of Newton-meters. Maximum shear stress is calculated by the following formula:

Shear stress (kPa) = T*ρ / J, where Equation (4.1)

J = Polar moment of inertia = $\pi R^4/2$ [m^4]

T = Torque [N*m]

ρ = distance from turning axis = R = radius of the contact plate [m]

Calculated shear stress occurs at the contact plate outer edge. This value will be referred to as torque-shear strength. ANOVA and Tukey statistical analyses were performed on test data and are provided in Tables 4.3 and 4.4. Individual non-diluted emulsion torque-shear strength data are provided in Appendix B.2.

Table 4.3 ANOVA for Non-diluted Emulsion Torque-Shear Strength (kPa)

Source of Variability	Degrees of Freedom	Mean Square	F-Value	P-Value	Significant*
Tack	2	775138.5	703.84	<0.0001	YES
Temperature	2	10346.2	9.39	0.0002	YES
Rate	2	23872.7	21.68	<0.0001	YES
Set	2	61087.2	55.47	<0.0001	YES
Tack*Temperature	4	4763.9	4.33	0.0032	YES
Tack*Rate	4	5452.9	4.95	0.0013	YES
Tack*Set	4	18620.5	16.91	<0.0001	YES
Temperature*Rate	4	404.0	0.37	0.8316	NO
Temperature*Set	4	1410.1	1.28	0.2845	NO
Rate*Set	4	2184.0	1.98	0.1049	NO
Tack*Temperature*Rate	8	2231.0	2.03	0.0534	NO
Tack*Temperature*Set	8	1593.0	1.45	0.1902	NO
Temperature*Rate*Set	8	744.5	0.68	0.7112	NO
Tack*Temperature*Rate*Set	24	1005.0	0.91	0.5851	NO

*P-values greater than 0.05 are not significant (means are not different)

Table 4.4 Tukey Analysis of Non-diluted Emulsion Torque-Shear Strength

Variable	Level	Mean (kPa)	N	Tukey Grouping*
Tack Coat Material	CRS-2	278.416	54	A
	CSS-1	71.224	54	B
	SS-1	70.577	54	B
Application Temperature	Low	155.612	54	A
	Medium	135.540	54	B
	High	129.065	54	B
Application Rate (L/m^2)	0.23	160.577	54	A
	0.41	141.079	54	B
	0.59	118.561	54	C
Set Time (min)	15	168.347	54	A
	10	148.993	54	B
	5	102.877	54	C

*Means with the same letter are not significantly different

ANOVA results shown in Table 4.3 illustrate each variable has a significant effect on emulsion torque-shear strength. Three two-way interactions were also observed, which can be more easily observed in the interaction plot in Figure 4.2.
Table 4.4 provides mean torque-shear strength of each test variable and provides each variable a Tukey grouping. Set time and application rate had a significant effect on torque-shear strength. Even though the CRS-2 was grouped separately from the CSS-1 and SS-1, which contradicts the Tukey groupings from the non-diluted tensile strengths, mean strengths still successively increased from SS-1 to CRS-2. Therefore, the theory that strength increases from SS-1 to CRS-2 is still valid. Also, medium and high application temperatures resulted in lower strengths than low temperatures, which is slightly different from the tensile strength results.

The three two-way interactions, all including tack coat, can more clearly be observed in Figure 4.2 by observing the second, third, and fourth columns from the left and noticing the general trend for each column is the same except when combined with tack coat. It is clear the significantly higher strength of CRS-2 creates these interactions. Also, Tukey grouping of application rate and set time can be observed by noticing the constant order of succession for both variables. For example, in the bottom row, torque-shear strengths increase with increasing set time regardless of other variables.

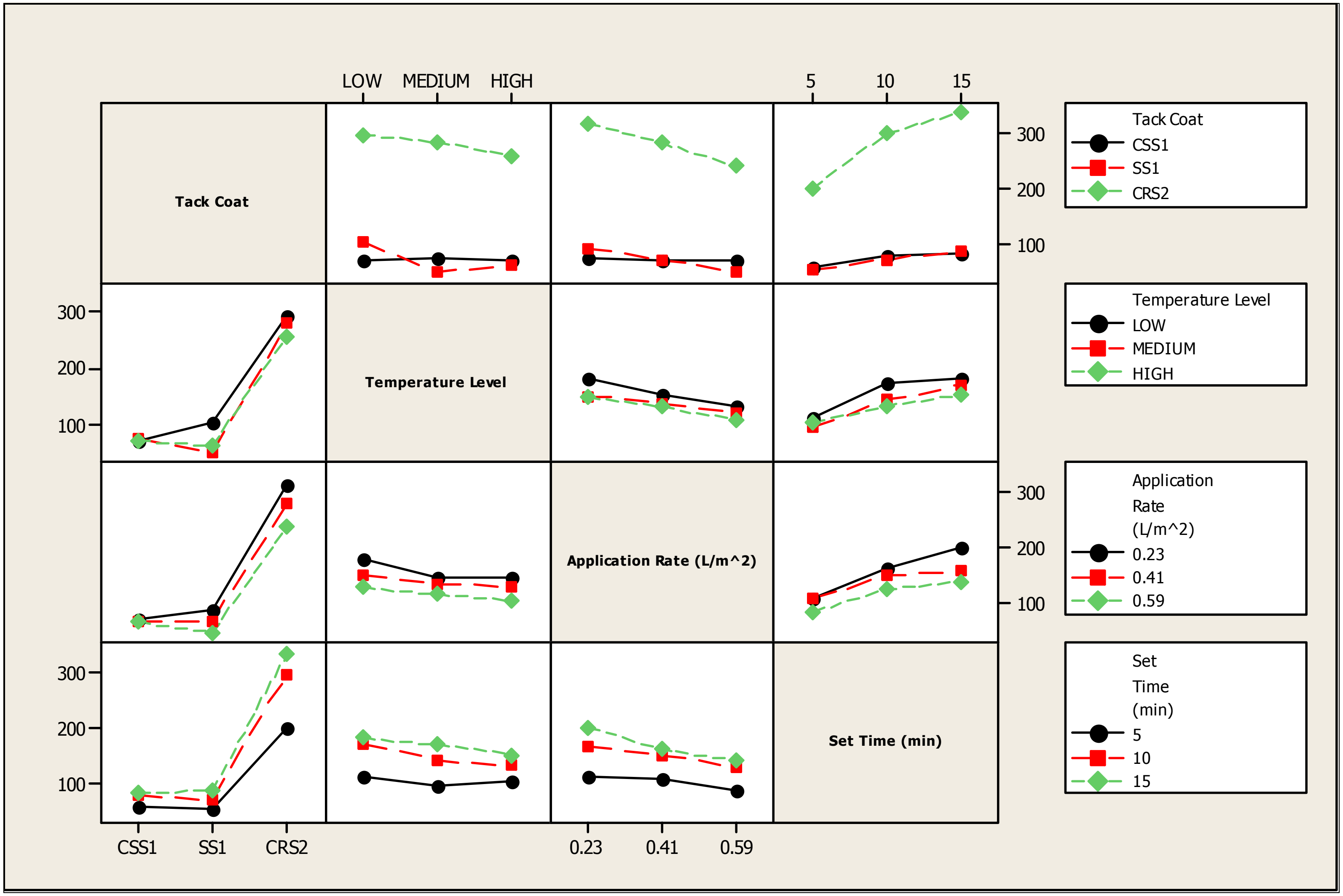

Figure 4.2 Interaction Plot for Non-diluted Emulsion Torque-shear Strength (kPa)

4.1.2 Diluted Emulsions

Testing for diluted emulsions was essentially the same as for non-diluted emulsions, with a few exceptions. All emulsions were diluted by adding one part water to each one part emulsion. This reduced the immediate tensile and torque-shear strength and increased required set time. Therefore, contact plate diameter was increased to 127.0 mm (5.0 in) and set times were increased to 15, 30 and 60 minutes.

4.1.2.1 Tensile Strength

The ANOVA data provided in Table 4.5 indicates temperature has no effect on diluted emulsion tensile strength. Table 4.5 shows set time, tack coat, and application rate significantly affect tensile strength, but no interactions were significant. This fact can also be noticed in the interaction plot provided in Figure 4.3.

The Tukey analysis of diluted tensile strengths, shown in Table 4.6, illustrates how diluted emulsions respond relative to non-diluted. Due to increased set times, specimens cooled more, resulting in application temperature having a lesser effect on tensile strength. Once again, CRS-2 exhibited higher tensile strength than either SS-1 or CSS-1. Since emulsion tensile strength increases with time and moisture loss, rapid set emulsions are capable of achieving higher tensile strengths than slow-set emulsions for the same set time. As expected, each level of set time was statistically significant, as evident by their Tukey grouping with increased set times resulting in increased tensile strength. Also, from Tables 4.2 and 4.6, notice that diluted emulsion tensile strength is much lower than for non-diluted emulsions, even though set times and contact plate diameters were increased for dilutions. This is due to reduced residual binder content of the diluted emulsions. Complete test data for diluted tensile strength data are provided in Appendix B.3.

Table 4.5 ANOVA for Diluted Emulsion Tensile Strength (kPa)

Source of Variability	Degrees of Freedom	Mean Square	F-Value	P-Value	Significant*
Tack	2	328.2	18.03	<0.0001	YES
Temperature	2	29.1	1.60	0.2080	NO
Rate	2	139.2	7.65	0.0009	YES
Set	2	651.3	35.77	<0.0001	YES
Tack*Temperature	4	5.4	0.29	0.8811	NO
Tack*Rate	4	26.4	1.45	0.2248	NO
Tack*Set	4	19.0	1.04	0.3899	NO
Temperature*Rate	4	26.4	1.45	0.2260	NO
Temperature*Set	4	5.8	0.32	0.8664	NO
Rate*Set	4	25.3	1.39	0.2444	NO
Tack*Temperature*Rate	8	16.9	0.93	0.4981	NO
Tack*Temperature*Set	8	6.7	0.37	0.9337	NO
Temperature*Rate*Set	8	4.1	0.23	0.9849	NO
Tack*Temperature*Rate*Set	24	27.2	1.50	0.0932	NO

*P-values greater than 0.05 are not significant (means are not different)

Table 4.6 Tukey Analysis of Diluted Emulsion Tensile Strength

Variable	Level	Mean (kPa)	N	Tukey Grouping*
Tack Coat Material	CRS-2	11.3111	54	A
	CSS-1	8.0037	54	B
	SS-1	6.4907	54	B
Application Temperature	Medium	9.0940	54	A
	High	8.9537	54	A
	Low	7.7574	54	A
Application Rate (L/m^2)	0.23	9.9333	54	A
	0.41	9.0540	54	A
	0.59	6.8185	54	B
Set Time (min)	60	12.2704	54	A
	30	8.1704	54	B
	15	5.3648	54	C

*Means with the same letter are not significantly different

Response inconsistency as a result of temperature level is more clearly observed in row 2 of Figure 4.3. The significant difference of CRS-2, noted in Table 4.6, is also visible in the top row of Figure 4.3. Mean values for CRS-2 remain above CSS-1 and SS-1 in all columns. Likewise for 0.59 L/m^2 (0.13 gal/yd^2), which significantly different from other application rates, is the lowest plot in row 3 regardless of input variables. Also, note the separation of set time plots in row 4 illustrate the Tukey groupings provided in Table 4.6.

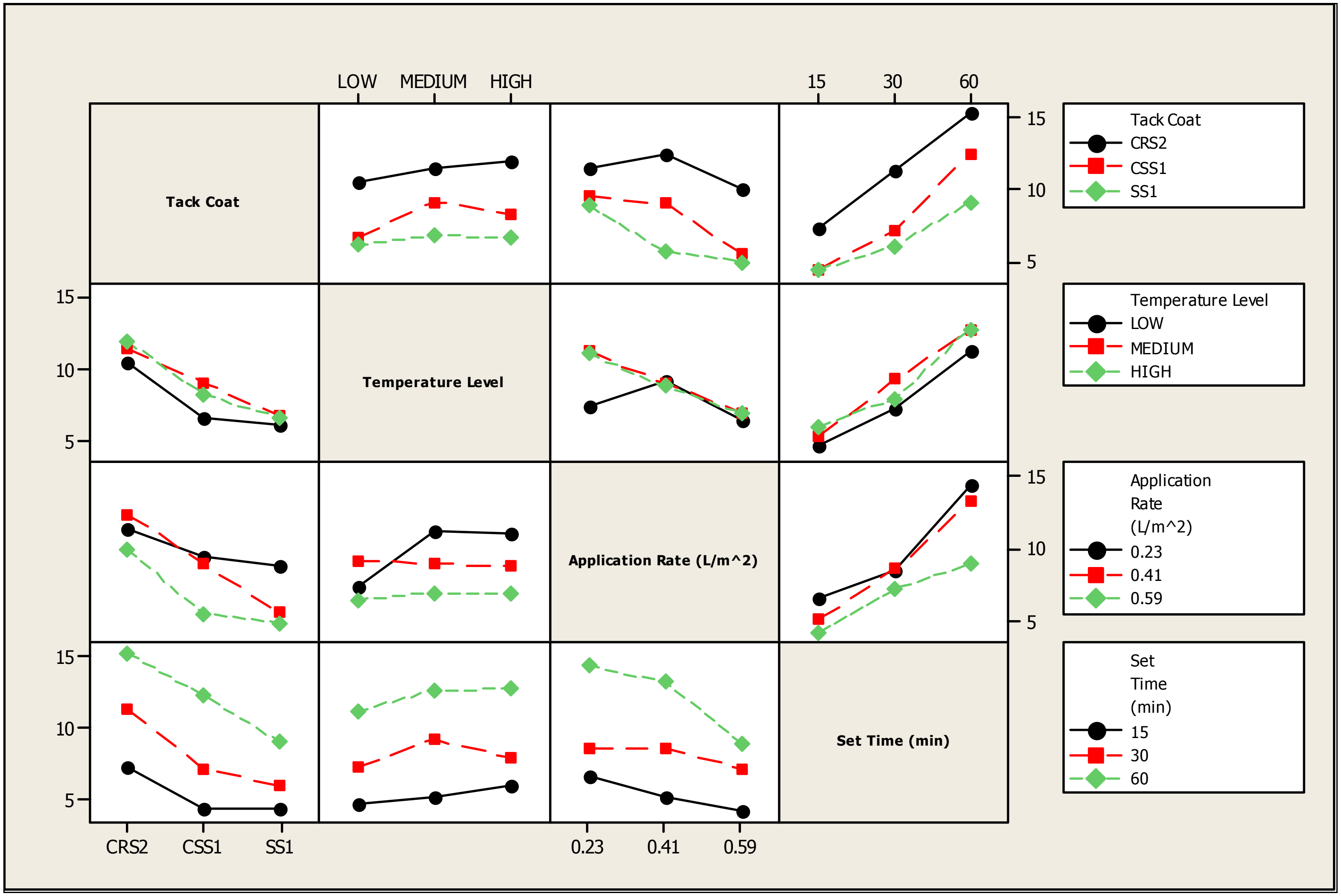

Figure 4.3 Interaction Plot for Diluted Emulsion Tensile Strength (kPa)

4.1.2.2 Torque-shear Strength

Complete diluted torque-shear strength data are provided in Appendix B.4. It is evident that each input variable significantly affects torque-shear strength, as shown in Table 4.7. Three interactions were also significant, which can be observed in the interaction plot in Figure 4.4. According to Table 4.8, temperature slightly affected torque-shear strength for diluted emulsions. As with other results, application temperature does not consistently affect torque-shear strength. Once again, SS-1, CSS-1, and CRS-2 tack coat materials exhibited increasing torque-shear strengths, respectively, due to emulsifying agent particle charge and set speed. Table 4.8 also shows the recurring fact that torque-shear strength increases with decreasing application rate and increasing set time.

Tukey groupings in Table 4.8 can be observed from the mean values plotted in Figure 4.4. Also, an interaction between tack coat and application rate is evident by noticing the location of SS-1 emulsion combined with 0.23 L/m^2 (0.05 gal/yd^2) application rate in the far left column of Figure 4.4.

Table 4.7 ANOVA for Diluted Emulsion Torque-shear Strength (kPa)

Source of Variability	Degrees of Freedom	Mean Square	F-Value	P-Value	Significant*
Tack	2	1756.8	101.77	<0.0001	YES
Temperature	2	116.3	6.74	0.0020	YES
Rate	2	686.9	39.79	<0.0001	YES
Set	2	1814.8	105.13	<0.0001	YES
Tack*Temperature	4	37.6	2.18	0.0788	NO
Tack*Rate	4	68.7	3.98	0.0053	YES
Tack*Set	4	41.2	2.39	0.0577	NO
Temperature*Rate	4	28.3	1.64	0.1726	NO
Temperature*Set	4	3.9	0.23	0.9231	NO
Rate*Set	4	7.0	0.41	0.8045	NO
Tack*Temperature*Rate	8	17.7	1.03	0.4229	NO
Tack*Temperature*Set	8	70.7	4.10	0.0004	YES
Temperature*Rate*Set	8	12.7	0.74	0.6597	NO
Tack*Temperature*Rate*Set	24	59.3	3.44	<0.0001	YES

*P-values greater than 0.05 are not significant (means are not different)

Table 4.8 Tukey Analysis of Diluted Emulsion Torque-shear Strength

Variable	Level	Mean (kPa)	N	Tukey Grouping*
Tack Coat Material	CRS-2	19.2414	54	A
	CSS-1	10.5808	54	B
	SS-1	8.4811	54	B
Application Temperature	High	14.0892	54	A
	Medium	13.0260	54	A
	Low	11.1885	54	A
Application Rate (L/m^2)	0.23	16.6308	54	A
	0.41	12.0730	54	A
	0.59	9.6000	54	B
Set Time (min)	60	18.9791	54	A
	30	11.8239	54	B
	15	7.5004	54	C

*Means with the same letter are not significantly different

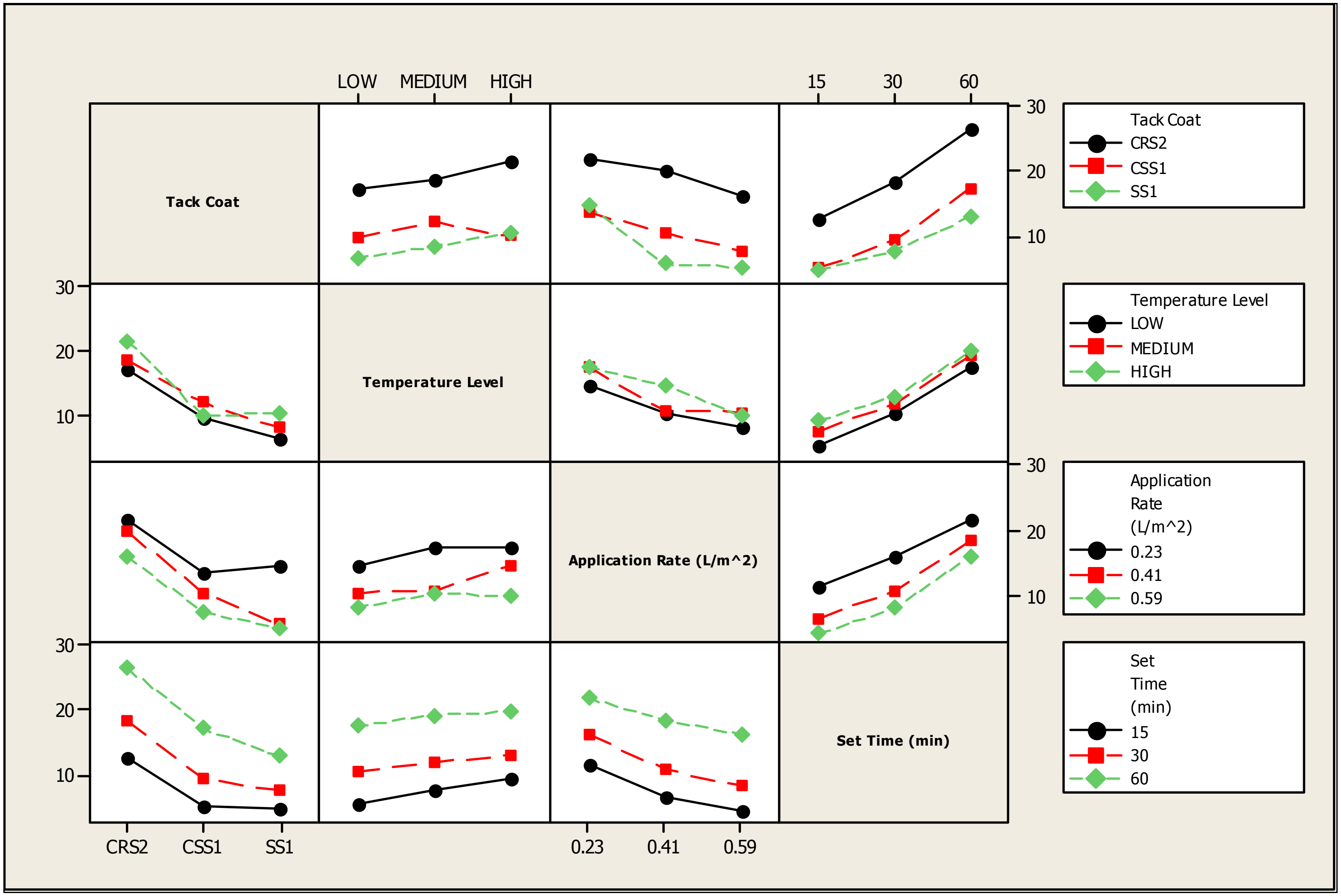

Figure 4.4 Interaction Plot for Diluted Emulsion Torque-shear Strength (kPa)

4.1.3 Performance Grade Binders

Samples of PG 67-22 asphalt binder were evaluated at application rates of 0.18 (0.04) 0.32 (0.07) 0.46 L/m^2 (0.10 gal/yd^2) at application temperatures of 148.9^{o}C (300.0^{o}F). Due to PG binder increased viscosity, contact plate diameters were decreased to 12.7 mm (0.5 in) for tensile testing and to 12.7 (0.5) and 25.4 mm (1.0 in) for torque-shear testing. PG binders do not require a set time for moisture evaporation as do emulsions, and therefore was not evaluated.

4.1.3.1 Tensile Strength

Due to a reduced number of test variables, a Tukey grouping analysis was not conducted. Response data for PG binder tensile testing are shown in Table 4.9 and Figure 4.5. The ANOVA calculated P-value from regression was 0.0029, indicating a significant relationship between application rate and tensile strength, based on a 95 percent confidence level (α=0.05). Notice from Figure 4.5 that tensile strength decreases with increasing application rate, similar to emulsion results. Complete PG 67-22 tensile strength data are provided in Appendix B.5.

Table 4.9 TCED Tensile Strength Data for Performance Grade Binders

Spindle Diameter (mm)	Temperature (^{o}C)	Application Rate (L/m$^{2)}$	Tensile Pressure (kPa)	Average Tensile Pressure (kPa)
12.7	149	0.18	1844.4	1835.7
12.7	149	0.18	1826.9	
12.7	149	0.32	1725.0	1740.8
12.7	149	0.32	1756.6	
12.7	149	0.46	1703.9	1677.6
12.7	149	0.46	1651.2	

Table 4.10 TCED Torque-Shear Strength Data for Performance Grade Binders

Spindle Diameter (mm)	Temperature (°C)	Application Rate (L/m²)	Torque-shear Strength (kPa)	Average Torque-shear Strength (kPa)
12.7	149	0.18	8950.8	11188.5
12.7	149	0.18	13426.2	
12.7	149	0.32	9199.4	11810.1
12.7	149	0.32	14420.7	
12.7	149	0.46	18647.5	17528.6
12.7	149	0.46	16409.8	
25.4	149	0.18	808.1	870.2
25.4	149	0.18	932.4	
25.4	149	0.32	963.5	947.9
25.4	149	0.32	932.4	
25.4	149	0.46	1025.6	1010.1
25.4	149	0.46	994.5	

4.1.3.2 Torque-Shear Strength

Torque-shear strength data are provided in Table 4.10 and Figure 4.6. The ANOVA (α=0.05) calculated P-values for contact plate diameters of 12.7 (0.5) and 25.4 mm (1.0 in) are 0.0981 and 0.0405, respectively. This implies a significant relationship exists for the 25.4 mm (1.0 in) diameter contact plate data, but not for the 12.7 mm (0.5 in) contact plate data. Also, observing Figure 4.6, strength from the 12.7 mm (0.5 in) contact plate appears to increase with increasing application rate, contradicting previous results. Strength data for the 25.4 mm (1.0 in) contact plate appeared to respond to application rate at a reduced slope, which is a result of calculation based on contact plate diameter. However, the 25.4 mm data indicates increasing application rate improves strength. PG binder torque-shear strength is the only TCED data that follows this trend. It is possible that performance grade binders behave differently from emulsions due to a lack of moisture, in which they should perform like dry emulsions. Complete PG 67-22 torque-shear strength data are provided in Appendix B.6.

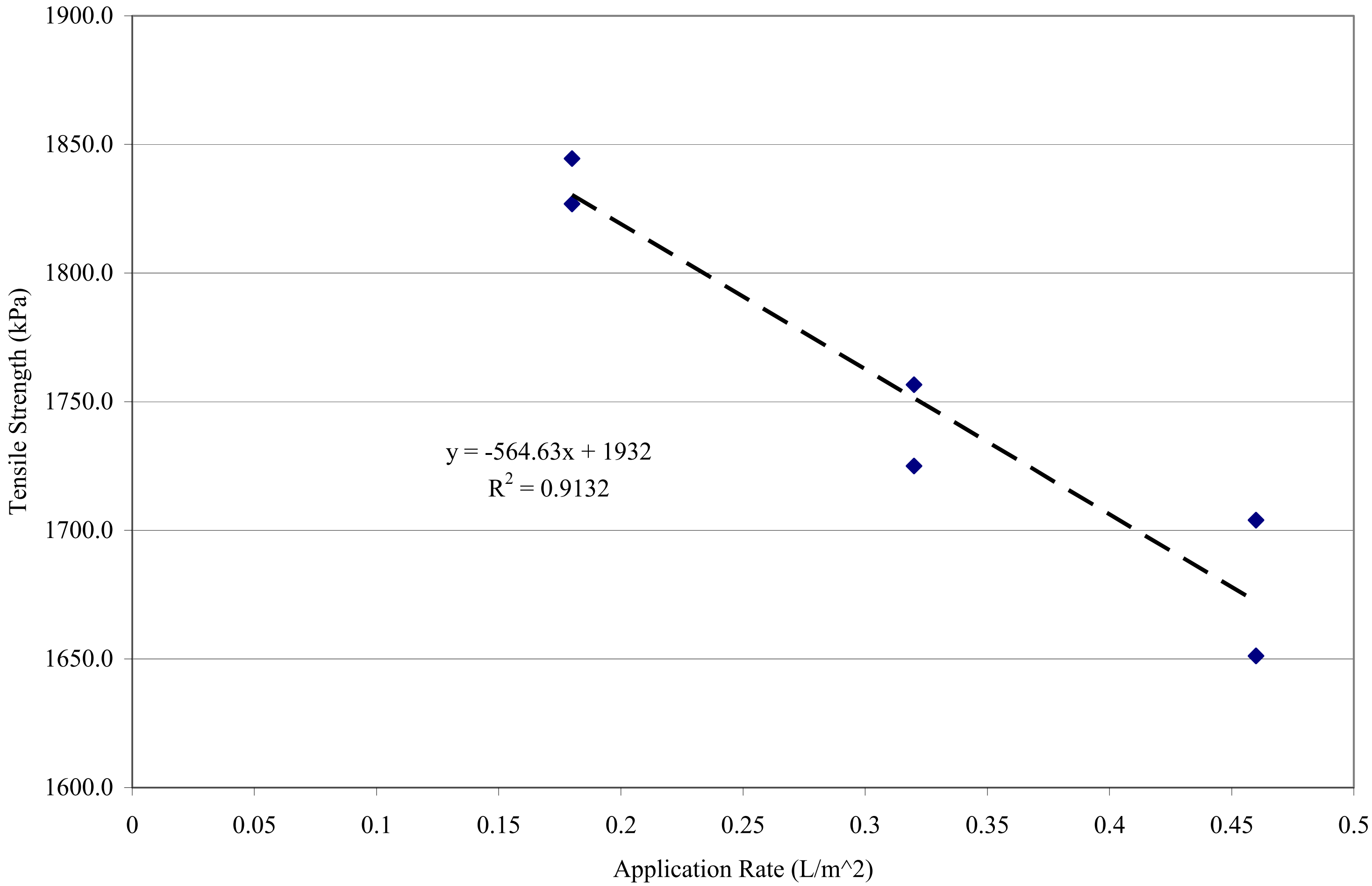

Figure 4.5 TCED Tensile Strength Data for Performance Grade Binders

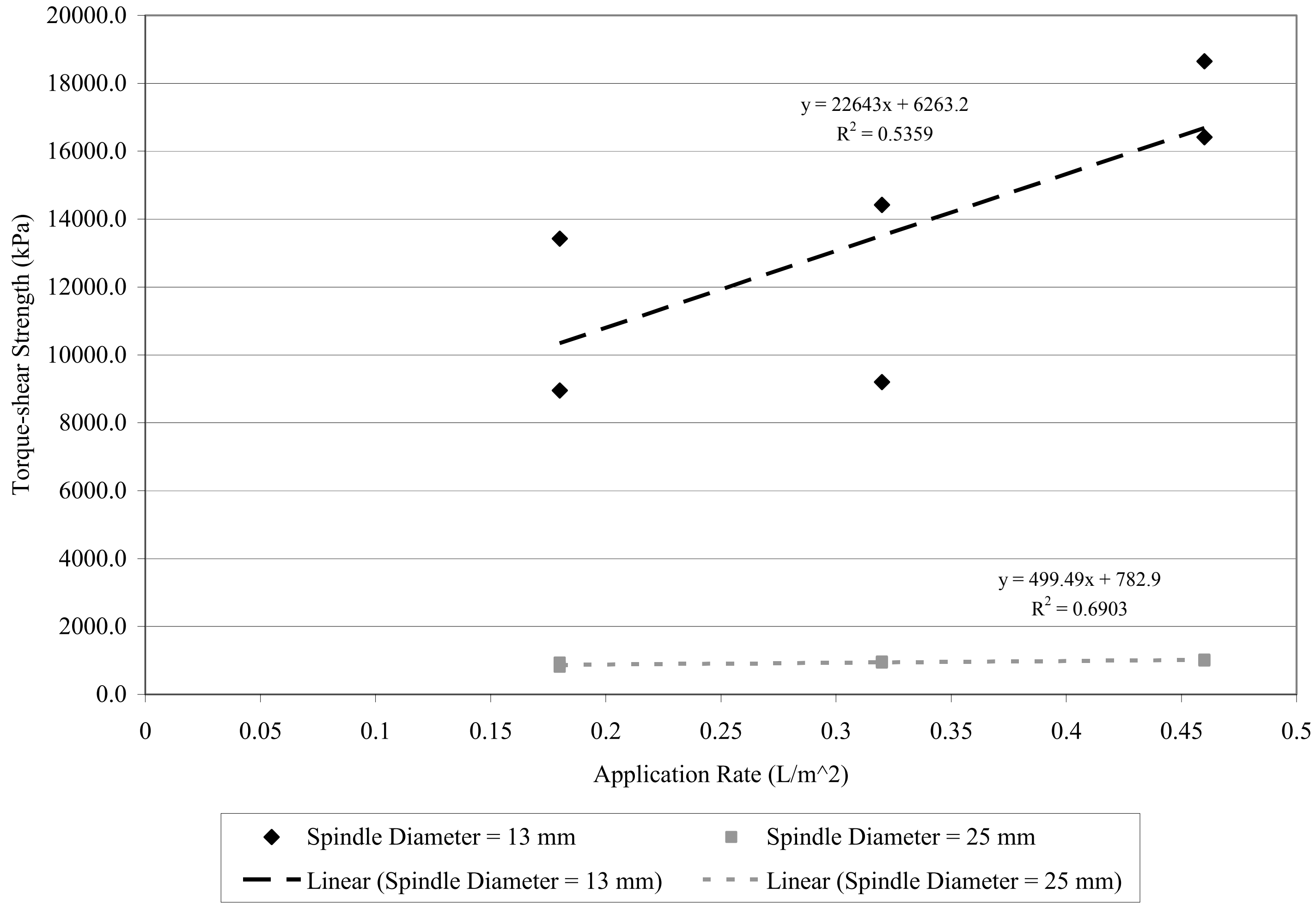

Figure 4.6 TCED Torque-Shear Strength Data for Performance Grade Binders

4.2 LABORATORY BOND INTERFACE STRENGTH DEVICE (LBISD)

The Marshall loading device used for testing with the LBISD provided data for load (lbs) and displacement (in). Loading at constant displacement rate of 50 mm/min (2 in/min), load and displacement data were recorded every 0.1 seconds until maximum load was achieved. A sample plot of load-displacement data is provided in Figure 4.7.

Interface specimens were prepared with four tack coats: SS-1, CSS-1, CRS-2, and PG 67-22 asphalt binder. Emulsions were applied at rates of 0.23(0.05), 0.41(0.09), or 0.59 L/m^2 (0.13gal/yd^2) and asphalt binder was applied at rates of 0.18 (0.04), 0.32 (0.07), 0.46 L/m^2 (0.10 gal/yd^2). Application rates were considered low, medium, and high for analyses. Specimens were also prepared with a coarse or fine base layer.

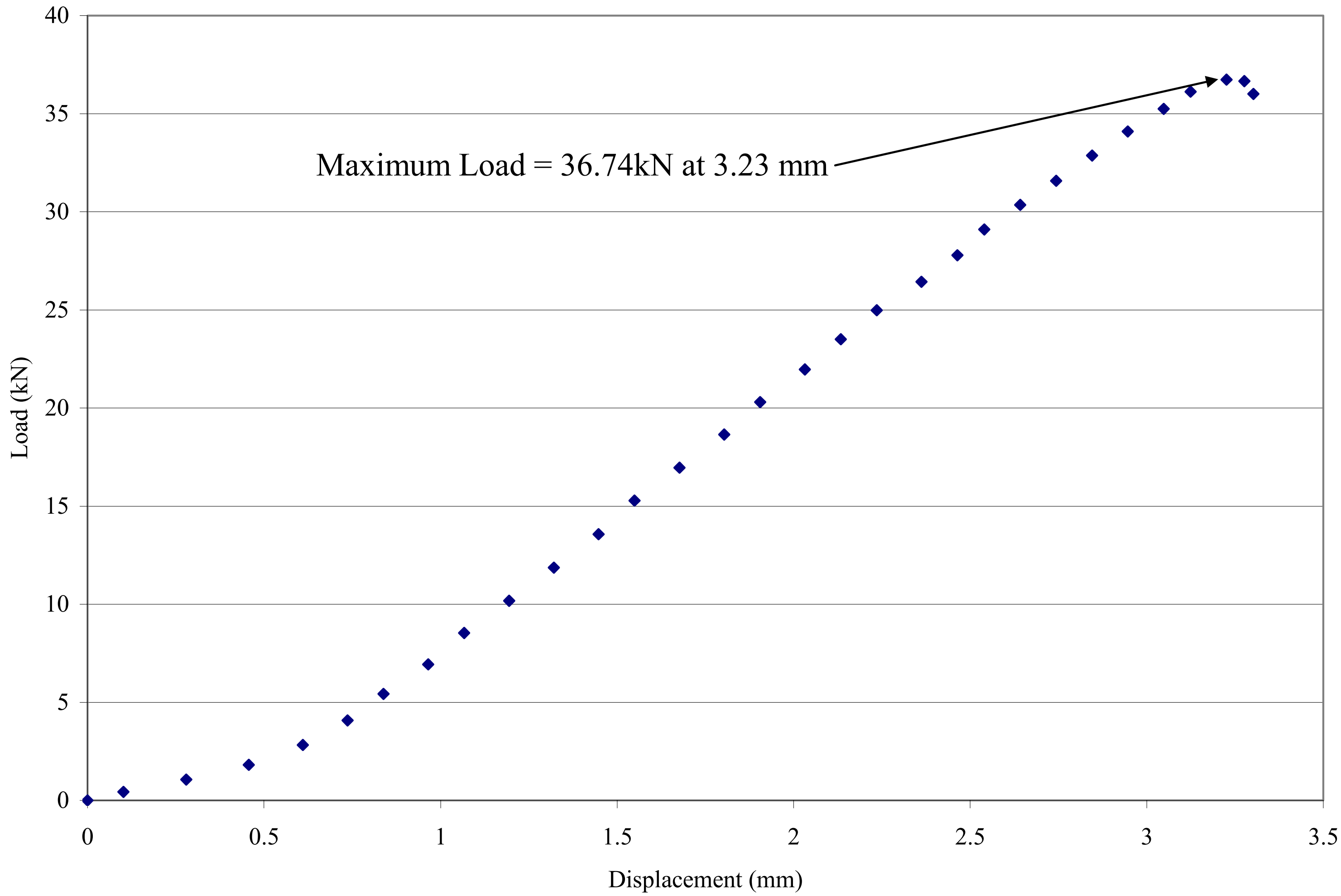

Figure 4.7 Sample Load-Displacement Curve for LBISD Testing

4.2.1 Maximum Shear Strength

Using SAS version 8 software [20], maximum interface shear strength data were analyzed using both ANOVA and Tukey methods, with results provided in Tables 4.11 and 4.12, respectively. As expected, interface specimens bonded with PG binder exhibited higher interface shear strengths than the specimens bonded with emulsion. Shear strengths for emulsion specimens were not significantly different. Neither gradation nor tack application rate significantly affected shear strength. The significance of PG 67-22 is visible in the interaction plot provided in Figure 4.8. Complete LBISD maximum shear strength data are provided in Appendix C.1.

Table 4.11 ANOVA for LBISD Maximum Shear Strength (kN)

Source of Variability	Degrees of Freedom	Mean Square	F-Value	P-Value	Significant*
Tack	3	77.8247	15.54	<0.0001	YES
Gradation	1	11.4446	2.28	0.1437	NO
Rate	2	6.4933	1.30	0.2920	NO
Tack*Gradation	3	62.4773	12.47	<0.0001	YES
Tack*Rate	6	7.7493	1.55	0.2059	NO
Gradation*Rate	2	19.3590	3.86	0.0351	YES
Tack*Gradation*Rate	6	11.1232	2.22	0.0761	NO

*P-values greater than 0.05 are not significant (means are not different)

Table 4.12 Tukey Analysis of LBISD Maximum Shear Strength

Variable	Level	Mean (kN)	N	Tukey Grouping*
Tack Coat Material	PG 67-22	41.6270	12	A
	CRS-2	37.2610	12	B
	SS-1	37.0702	12	B
	CSS-1	35.7849	12	B
Gradation	Fine	38.4241	24	A
	Coarse	37.4475	24	A
Application Rate	L	38.5160	16	A
	M	38.0373	16	A
	H	37.2541	16	A

*Means with the same letter are not significantly different

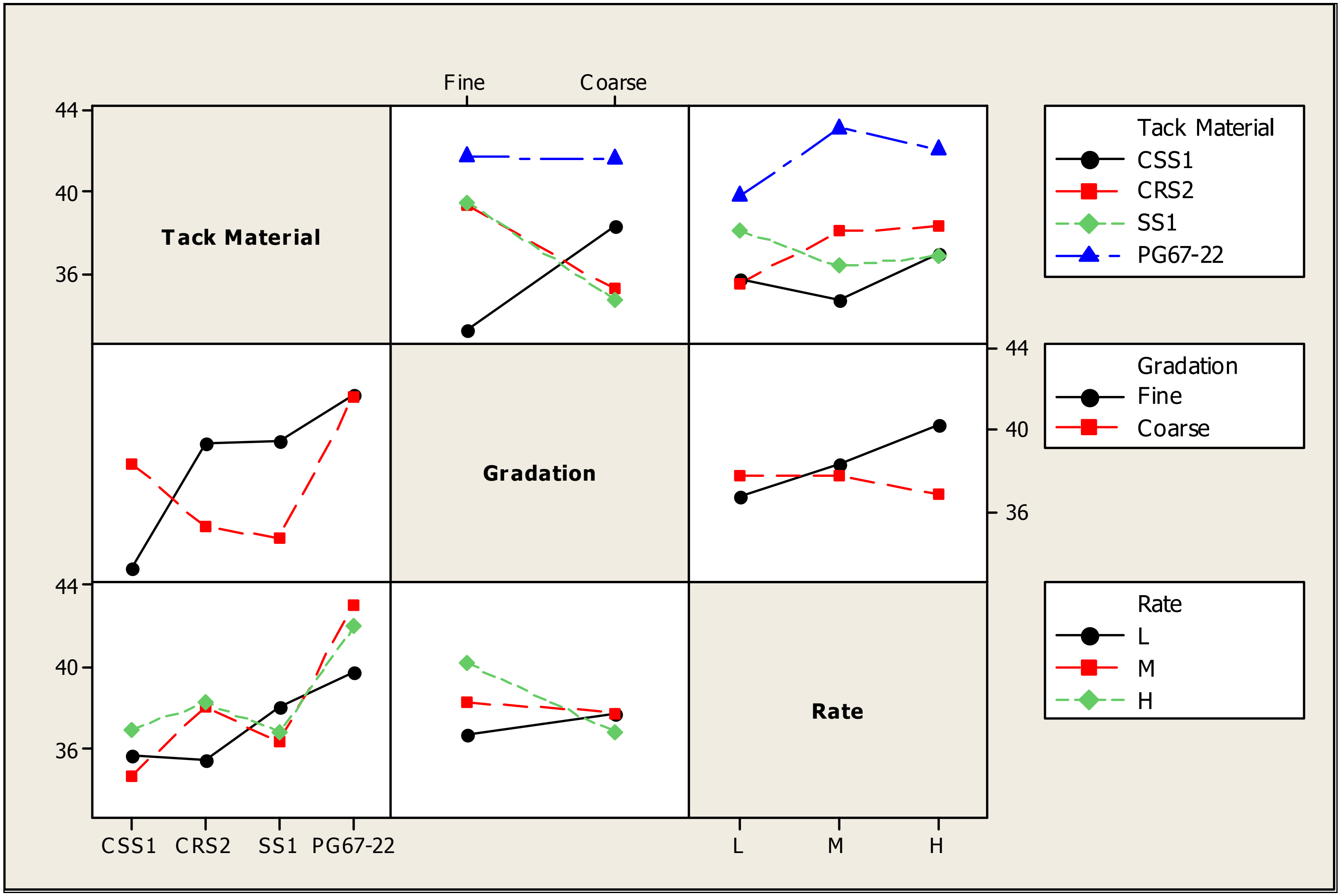

Figure 4.8 Interaction Plot for LBISD Maximum Shear Strength (kN)

4.2.2 Reaction Index

Load and displacement data from LBISD tests were converted into an index value to approximate the slope of the load-displacement diagram from each test. For example, the reaction index for the sample test curve shown in Figure 4.6 would be calculated by dividing the maximum load, 36.74 kN (8259.48 lb), by the specimen displacement at maximum load, 3.23 mm (0.13 in). The resulting value would be an index to approximate curve slope in units of force per distance, or 11.37 kN/mm (63.53 kip/in). This value, similar to the interface reaction modulus discussed by previous researchers [2] and the Marshall stiffness index [3], will be referred to as the reaction index.

Gradation proved to be significant in ANOVA analysis, as shown in Table 4.13. When compared to maximum shear strength results, the gradation and rate interaction is no longer significant for reaction index, but the tack and gradation reaction is still apparent. Data means are plotted in the interaction plot provided in Figure 4.9. Complete LBISD reaction index data is provided in Appendix C.2.

Table 4.13 ANOVA for LBISD Reaction Index (kN/mm)

Source of Variability	Degrees of Freedom	Mean Square	F-Value	P-Value	Significant*
Tack	3	5.5577	7.36	0.0012	YES
Gradation	1	6.3603	8.43	0.0078	YES
Rate	2	1.4527	1.92	0.1678	NO
Tack*Gradation	3	3.8484	5.10	0.0072	YES
Tack*Rate	6	1.4121	1.87	0.1276	NO
Gradation*Rate	2	1.1221	1.49	0.2463	NO
Tack*Gradation*Rate	6	1.2605	1.67	0.1718	NO

*P-values greater than 0.05 are not significant (means are not different)

The Tukey analysis results, shown in Table 4.14, differed slightly from the analysis performed on maximum shear strength. Unlike interface shear strength, reaction index is capable of distinguishing between coarse and fine-graded base course, in which the fine-graded base courses provided higher reaction index values. Also, the reaction index analysis found some similarity between the PG binder and the CRS-2 emulsion.

Table 4.14 Tukey Analysis of LBISD Reaction Index

Variable	Level	Mean (kN/mm)	N	Tukey Grouping*
Tack Coat Material	PG 67-22	10.1492	12	A
	CRS-2	9.3040	12	A,B
	SS-1	8.8317	12	B
	CSS-1	8.6132	12	B
Gradation	Fine	9.5885	24	A
	Coarse	8.8605	24	B
Application Rate	L	9.4394	16	A
	M	9.3540	16	A
	H	8.8801	16	A

*Means with the same letter are not significantly different

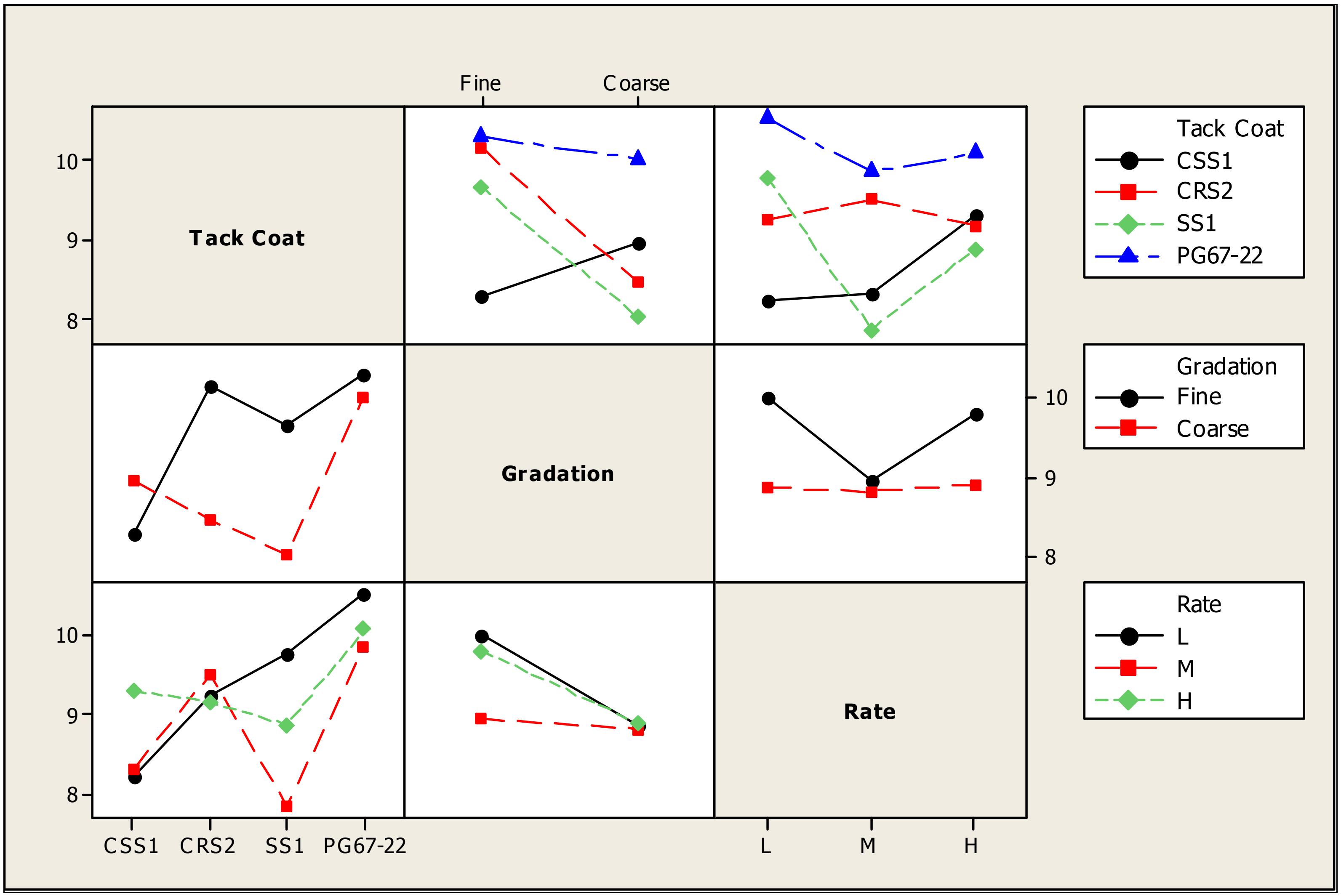

Figure 4.9 Interaction Plot for LBISD Reaction Index (kN/mm)

4.3 ANALYSIS OF MASS LOSS FOR EMULSIONS

Mass loss testing was performed for three emulsions: SS-1, CSS-1, and CRS-2. Specimens were prepared at application rates of 0.23 (0.05), 0.41 (0.09), and 0.59 L/m^2 (0.13 gal/yd^2). Moisture at time *i* was calculated as follows:

$$\% W_i = [(M_i - M_{min}) / M_i]*100 \%, \text{ where} \qquad \text{Equation (4.2)}$$

$\% W_i$ = Percent moisture in the specimen at time *i*

M_i = specimen mass at time i

M_{min} = minimum specimen mass

An approximate interpolation was performed to estimate the evaporation rate exhibited during each test. First, a point was located on the percent moisture plot at which linear evaporation behavior ceased. Next the slope from time zero to that point was considered the evaporation rate (% moisture / hour).

A master plot of percent moisture versus time is provided in Figure 4.10. As application rate increased, moisture evaporated at lower rates. Both ANOVA and Tukey results for evaporation rate, provided in Tables 4.15 and Table 4.16, show only application rate significantly affects evaporation rate. Note that even though Tukey groupings imply no significant difference between emulsions, the mean evaporation rate for CRS-2 is still greater than CSS-1 and SS-1. Complete emulsion mass loss test data are provided in Appendix D.

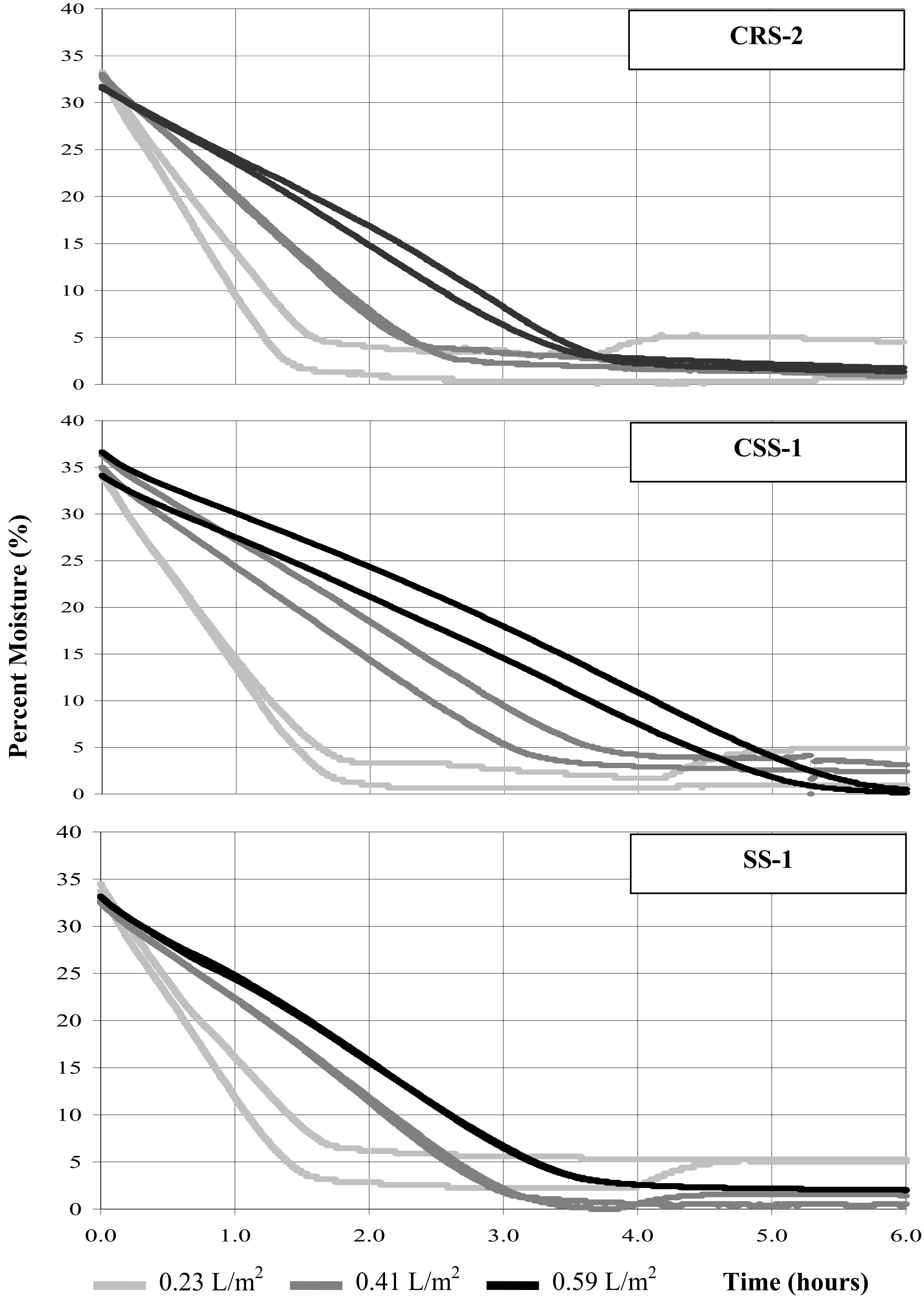

Figure 4.10 Emulsion Mass Loss Data

Table 4.15 ANOVA for Emulsion Evaporation Rates (% Moisture / hour)

Source of Variability	Degrees of Freedom	Mean Square	F-Value	P-Value	Significant*
Tack	2	4.9033	2.16	0.1719	NO
Rate	2	233.1538	102.48	<0.0001	YES
Tack*Rate	4	1.9738	0.87	0.5191	NO

*P-values greater than 0.05 are not significant (means are not different)

Table 4.16 Tukey Analysis for Emulsion Evaporation Rates

Variable	Level	Mean (% Moisture/Hour)	N	Tukey Grouping*
Tack Coat Material	CRS-2	13.3812	6	A
	SS-1	12.7058	6	A
	CSS-1	12.0430	6	A
Application Rate (L/m^2)	0.23	19.8323	6	A
	0.41	10.9227	6	B
	0.59	7.8250	6	C

*Means with the same letter are not significantly different

4.4 ANALYSIS OF EMULSION BREAKING BY MASS LOSS TESTING

Additional mass loss testing was performed on specimens of SS-1 at application rates of 0.14 (0.03), 0.23 (0.05), 0.41 (0.09), and 0.59 L/m^2 (0.13 gal/yd^2). The time at which each specimen was visibly broken was noted for analysis. Using these break times, percent moisture when specimens were first visibly broken was calculated as discussed earlier.

4.4.1 Visual Break Times (VBT)

Mass loss data are summarized provided in Table 4.17, with individual mass loss data provided in Appendix E. VBT's and application rates are plotted in Figure 4.11. As application rates increased, the VBT also increased. An ANOVA analysis (α=0.05) calculates a P-value less than 0.0001, indicating a significant linear relationship between application rate and VBT, based on a 95 percent confidence level.

4.4.2 Percent Moisture at Break

A plot of percent moisture when visibly broken versus application rate is provided in Figure 4.12. As application rate increased, moisture in visibly broken specimens decreased to an apparent asymptotic minimum. Observing Figure 4.10 and Table 4.16, it can be recalled that lower application rates exhibit significantly faster evaporation rates. It is possible that this increased rate of evaporation is true for the exposed surface of the specimen and the unexposed portions of specimens evaporate at approximately equal rates. If so, low application rate specimens would visibly break faster than others while possessing a greater total amount of moisture. It is also possible that application rates greater than 0.7 L/m^2 (0.15 gal/yd^2) may begin to exhibit increasing quantities of moisture when broken, but this study is not focused on rates of that magnitude.

Table 4.17 Mass Loss Data for Analysis of Emulsion Breaking

Application Rate (L/m^2)	Break Time (min)	Percent Moisture When Broken
0.255	87	3.27
0.240	72	4.35
0.230	88	4.87
0.395	105	3.39
0.434	112	3.03
0.408	125	2.52
0.634	172	3.00
0.583	149	3.13
0.590	148	3.59
0.235	85	4.81
0.144	46	8.08
0.136	45	6.88

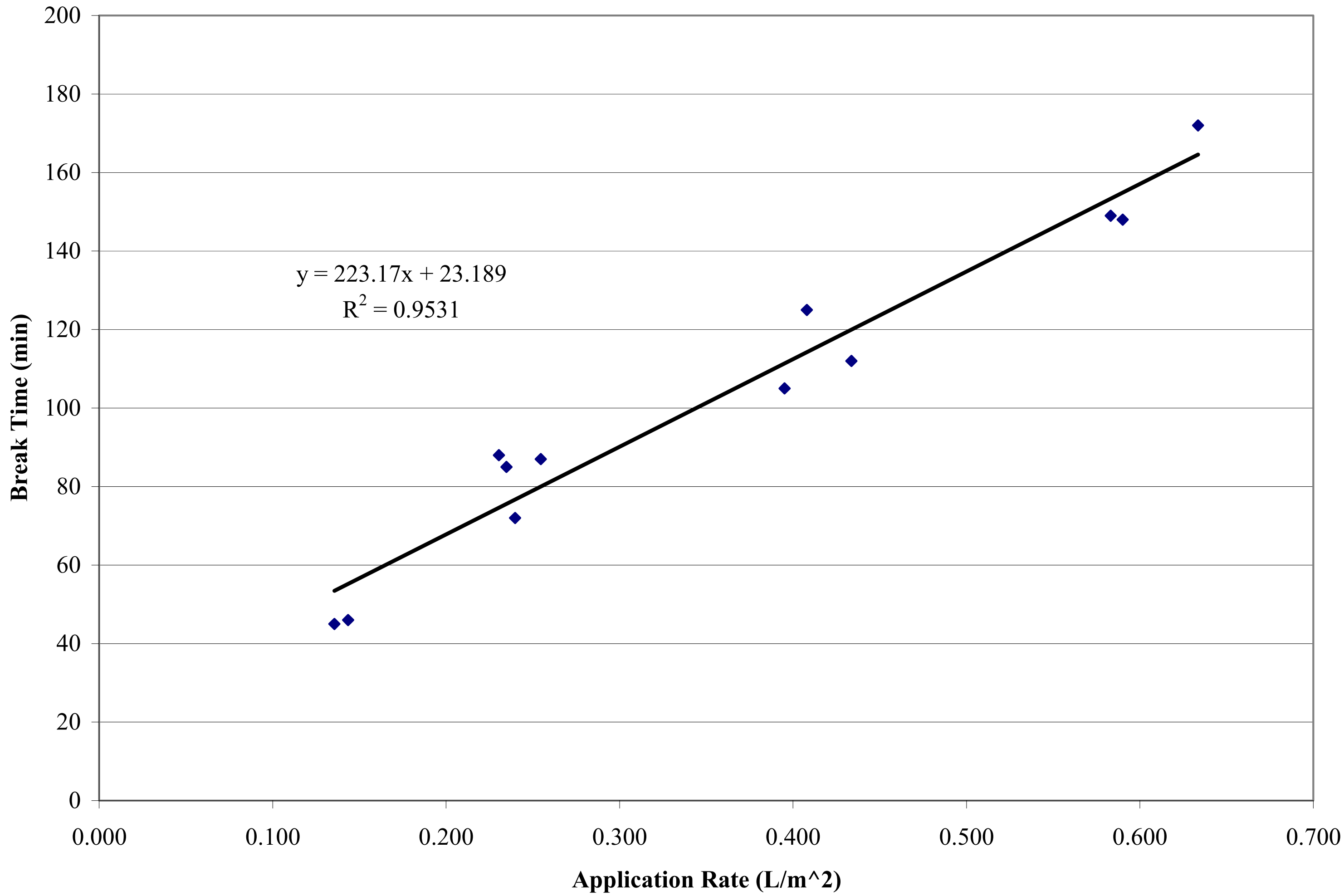

Figure 4.11 Visual Break Time Versus Application Rate

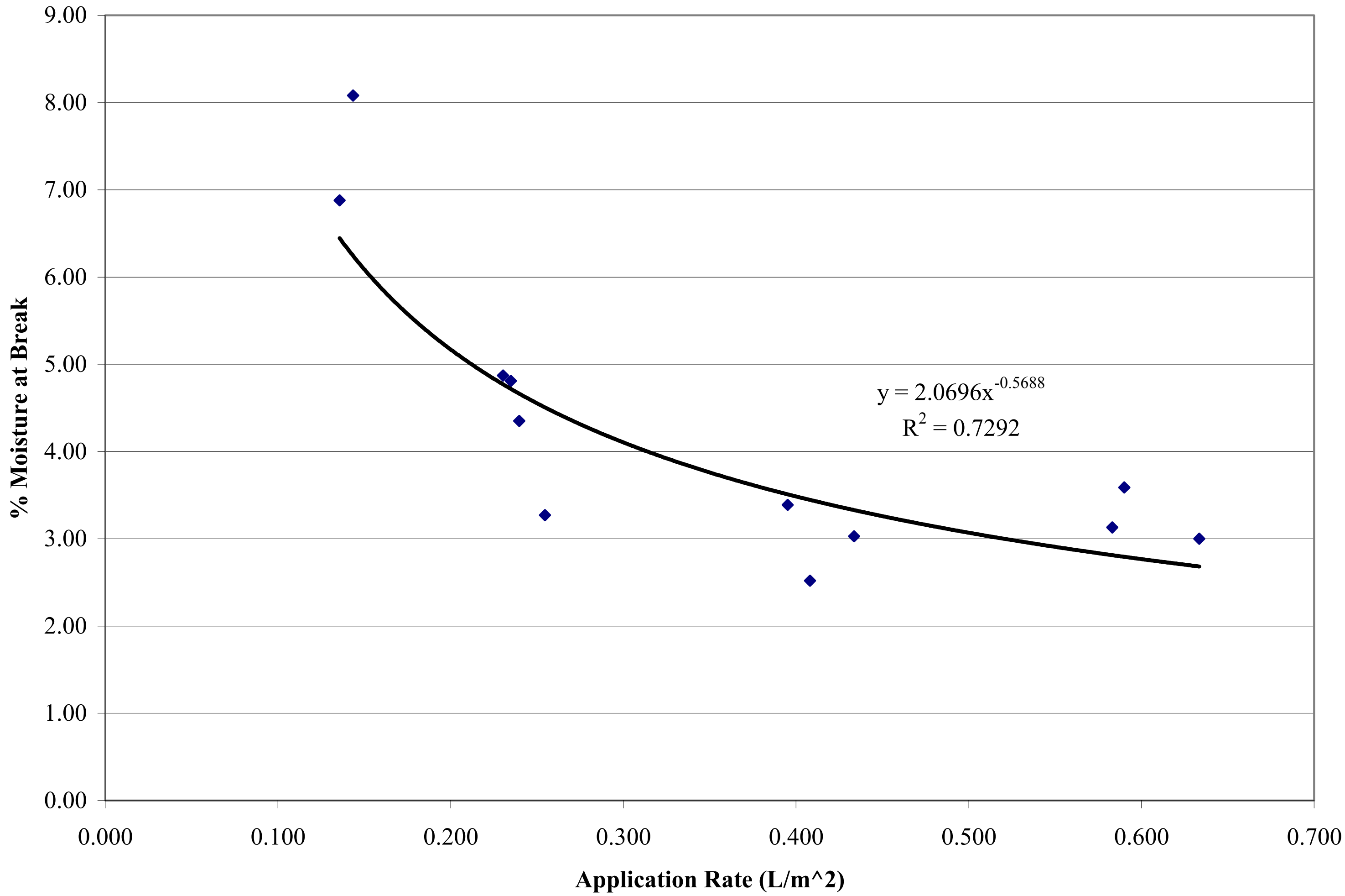

Figure 4.12 Percent Moisture at Break Versus Application Rate

4.5 ANALYSIS OF EMULSION BREAKING BY TCED TESTING

As described in Chapter III, additional TCED tensile and torque-shear strength testing was performed on non-diluted SS-1 specimens at application rates of 0.23 (0.05), 0.41 (0.09), and 0.59 L/m^2 (0.13 gal/yd). Tests were conducted at four break levels, ranging from just when the specimen begins to break (t_0) to ten minutes after the specimen was fully broken ($t_{full + 10}$). The level $t_{1/2}$ describes a specimen with one-half of its exposed area broken. Tensile strength and torque-shear strength tests were conducted on these specimens using a 50.8 mm (2.0 in) contact plate. A visual break time data summary is provided in Table 4.18.

Table 4.18 Mean Visual Break Times (min)

Application Rate (L/m^2)	Break Level			
	t_0	$t_{1/2}$	t_{full}	$t_{full + 10}$
0.23	6.13	23.88	47.00	51.63
0.41	28.75	80.13	100.50	114.50
0.59	51.13	84.50	122.63	163.00

4.5.1 Tensile Strength

Complete tensile and torque-shear strength data for the analysis of emulsion breaking are provided in Appendix F. ANOVA and Tukey results are provided in Tables 4.19 and 4.20, respectively. Both visual break time and application rate significantly affected tensile strength. As expected, tensile strength generally increased with increasing visual break time. Surprisingly, tensile strengths were higher for the t_{full} specimens compared to the $t_{full + 10}$ specimens. Mean tensile strengths also were contrary to the expected for the 0.41(0.09) and 0.59 L/m^2 (0.13 gal/yd^2) application rates. Tensile strengths have typically decreased with increasing application rate when evaluated at set times less than fifteen minutes, but it is expected that for these specimens (set time between ½ and 3 hours), the 0.41 L/m^2 (0.09 gal/yd^2) application rate may provide the best possible tensile strength.

Table 4.19 ANOVA for Analysis of Emulsion Breaking by TCED Tensile Strength Testing (kPa)

Source of Variability	Degrees of Freedom	Mean Square	F-Value	P-Value	Significant*
Rate	2	9682.9543	33.07	<0.0001	YES
Broken	3	10593.9860	36.18	<0.0001	YES
Rate*Broken	6	711.4146	2.43	0.0899	NO

*P-values greater than 0.05 are not significant (means are not different)

Table 4.20 Tukey Analysis for Analysis of Emulsion Breaking by TCED Tensile Strength Testing

Variable	Level	Mean (kPa)	N	Tukey Grouping*
Broken	t_{full}	137.898	6	B
	$t_{full + 10}$	131.313	6	A
	$t_{1/2}$	113.390	6	A
	t_0	46.087	6	A
Rate (L/m^2)	0.41	130.719	8	A
	0.59	123.586	8	A
	0.23	67.211	8	B

*Means with the same letter are not significantly different

4.5.2 Torque-Shear Strength

ANOVA and Tukey analyses results for torque-shear testing, provided in Tables 4.21 and 4.22, also show visual break time and application rate to significantly affect torque-shear strength. As with tensile strength the 0.41 L/m^2 application rate yielded significantly higher strength. As expected, mean torque-shear strengths increased with increasing degrees of visual break time.

Table 4.21 ANOVA for Analysis of Emulsion Breaking by TCED Torque-Shear Strength Testing (kPa)

Source of Variability	Degrees of Freedom	Mean Square	F-Value	P-Value	Significant*
Rate	2	3503.1992	6.34	0.0132	YES
Broken	3	9831.2507	17.79	0.0001	YES
Rate*Broken	6	852.1270	1.54	0.2462	NO

*P-values greater than 0.05 are not significant (means are not different)

Table 4.22 Tukey Analysis for Analysis of Emulsion Breaking by TCED Torque-Shear Strength Testing

Variable	Level	Mean (kPa)	N	Tukey Grouping*
Broken	$t_{full + 10}$	132.09	6	A
	t_{full}	106.84	6	A,B
	$t_{1/2}$	83.53	6	B
	t_0	36.91	6	C
Rate (L/m^2)	0.41	113.63	8	A
	0.59	81.58	8	B
	0.23	74.30	8	B

*Means with the same letter are not significantly different

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

5.1.1 Tack Coat Evaluation Device (TCED)

Four separate sets of testing and analysis were performed on emulsions with the TCED as shown below:

1. Non-diluted tensile strength
2. Non-diluted torque-shear strength
3. Diluted tensile strength
4. Diluted torque-shear strength

Since tensile and torque-shear strength are two different tests, simultaneous analyses were not conducted. Additionally, some testing criteria differed between non-diluted and diluted emulsion tests. Therefore, it was not reasonable to analyze data sets together, so each test set was analyzed separately. However, since each analysis provides a general explanation of the variable effects on tensile and torque-shear strength, overall variable influences will be summarized together. An additional set of tensile and torque-shear tests and analyses were performed on a performance grade binder.

5.1.1.1 Emulsions

Three emulsions (CRS-2, CSS-1, SS-1) evaluated with the TCED exhibited significantly different tensile and torque-shear strengths. CRS-2 consistently exhibited the highest mean strength, with the SS-1 emulsion exhibiting the lowest strengths.

Although some statistical analyses found temperature to significantly affect tensile and torque-shear strength, Tukey results showed considerable variability. This inconsistency points out that temperature does not have a consistent significant effect on strength.

Both application rate and set time proved significant for tensile and torque-shear strength for dilution and non-dilution testing. Tensile and torque-shear strengths significantly increased with decreasing application rate and increasing set time. Most likely, increasing application rate introduces a slip plane onto the test surfaces, thereby reducing tack coat strength. Also, increasing emulsion set time allowed additional moisture to be removed from the specimen, thus increasing viscosity and tensile and torque-shear strength.

5.1.1.2 Performance Grade (PG) Binder

As with emulsions, PG binder tensile strength results significantly decreased with increasing application rate. Torque-shear strength results yielded the opposite trend, with torque-shear strength increasing with increasing application rate. This indicates that PG binders may respond differently to TCED torque-shear testing, and additional testing should be conducted. Two separate torque-shear test sets were conducted, with two contact plate diameters. The smaller contact plate produced substantially higher shear strengths, which means that two contact plate diameters may not be comparable.

5.1.2 Laboratory Bond Interface Strength Device (LBISD)

Tack coat type significantly affected maximum shear strength and reaction index. PG 67-22 produced both the highest maximum shear strength and the highest reaction index. Emulsion type did not significantly influence maximum shear strength or reaction indexes. Mix base course gradation had a significant effect on reaction index, but not maximum shear strength. Finally, tack coat application rate had no significant effect on maximum shear strength or reaction index. It is possible that heated deformation of the base specimen introduced excessive aggregate interlock, negatively affecting results.

5.1.3 Analysis of Mass Loss for Emulsions

Tack coat type did not significantly affect emulsion evaporation rate. Evaporation rates significantly increased with decreasing application rate, as expected.

5.1.4 Analysis of Emulsion Breaking

5.1.4.1 Mass Loss Testing

Visual break time significantly increased with increasing application rate. Specimen moisture was highest for low application rates and appeared to level out at approximately 3 percent moisture for higher application rates. It is expected that since specimens evaporate faster at low application rates, visual breaking is achieved much faster, leaving excess moisture below the exposed surface.

5.1.4.2 TCED Testing

Tensile and torque-shear strengths were highest for specimens at the medium application rate, 0.41 L/m^2. It is expected that the previously mentioned correlation between application rate and tensile ad torque-shear strength changes for longer set times (1/2 to 3 hours, non-diluted), hence the strength reduction for low application rates. Also, tensile strengths were significantly higher immediately after breaking than ten minutes after.

5.2 SUMMARY

Results show the prototype TCED can distinguish between different tack coat applications. Tensile and torque-shear strength tests show that for the four tack coats tested, PG 67-22 yielded the highest strengths and CRS-2 yielded the highest strength of the emulsions. When emulsions are not fully broken, tensile and torque-shear strengths were highest at low application rates. When emulsions are fully broken, application rates of 0.41 L/m^2 (0.09 gal/yd^2) yield the highest tensile and torque-shear strength. The prototype LBISD was capable of distinguishing whether specimens were bonded with emulsions or PG binder and between coarse and fine base mixes. Mass loss testing clearly showed emulsion evaporation rates increase with decreasing application rate. In addition, there is a significant amount of moisture (approximately 3%) in visibly broken specimens.

5.3 RECOMMENDATIONS

To obtain a better understanding of tack coat material properties and to further develop the previously mentioned test devices and methods, the following recommendations are provided.

- Obtain additional test data for performance grade binders with the TCED.
- Increase TCED force gauge load capacity.
- Standardize TCED loading rate, tensile unloading rate, and shearing rate through automation.
- Perform additional mass loss testing on emulsions at different atmospheric conditions to better understand the evaporation properties of emulsions. .
- Standardize the TCED contact plate size to ensure comparable results.
- Develop a laboratory interface specimen mixing process that more accurately reproduces interfaces found in the field.
- Conduct a field study, performing TCED tests on asphalt and concrete surfaces at various known application rates (ASTM D2995) and for different tack coats. After application of the overlying HMA layer, obtain field cores from similar locations for testing with the LBISD.

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APPENDIX A

EMULSION CERTIFICATION SHEETS

JUL.16'2003 15:29 601-630-8327 ERGON LAB #7225 P.005/005

2611 Haining Rd.
Vicksburg, MS 39180
Phone: 601-630-8343
Fax: 601-630-8347

CRS-2

ERGON ASPHALT & EMULSIONS INC.
MISSISSIPPI DOT CRS-2 CERTIFICATION

Date: 7-16-03

Sample ID: EE- 5974 Tank No. 325 Gallons Represented 32,000

	Results	Specs
Particle Charge Test	Positive	Positive
Viscosity @ 122° C, SSF	322	100-400
Sieve Test (%)	.01%	0.10-
Residue (%)	66.9%	65.0+
Storage Stability, 24 hrs (%)	.2%	1.0-
Oil Distillate (% Volume)	-0-	3.0-
Classification Test	Pass	Pass
Test for Residue by Evaporation:		
Penetration @ 77° F, 100g, 5sec, dmm	145	100-250
Ductility @ 77° F, 5cm/min, (cm)	92	40+
Solubility in TCE (%)	99.8%	97.5+

LABORATORY ANALYST: Charles E. Lewis

Figure A.1 CRS-2 Emulsion Certification Sheet

UN.25'2003 15:44 601-630-8327 ERGON LAB #6079 P.001/003

2611 Haining Rd.
Vicksburg, MS
39180
Phone: 601-630-8343
Fax: 601-630-8347

CSS1

ERGON ASPHALT & EMULSIONS INC.
MISSISSIPPI DOT CSS-1 CERTIFICATION

Date: 6-25-03

Sample ID: EE - 5885 Tank No. 311 Gallons Represented 18,000

	Results	Specs
Particle Charge Test	Positive	Positive
Viscosity @ 77°F, SSF	35	20-100
Sieve Test (%)	.01%	0.10-
Residue (%)	62.5%	57.0+
Cement Mixing (%)	.01%	2.0-
Storage Stability (24 hr.) (%)	.1%	1.0-

Test on Residue by Evaporation:

Penetration @ 77°F, 100g, 5sec, dmm	132	100-250
Ductility @ 77°F, 5 cm/min, (cm)	93	40+
Solubility in TCE (%)	99.9%	97.5+

LABORATORY ANALYST:

Figure A.2 CSS-1 Emulsion Certification Sheet

OCT-20-2004(WED) 08:35 BLACKLIDGE EMULSIONS (FAX)228 864 0437 P.002/002

--- MISSISSIPPI DEPARTMENT OF TRANSPORTATION --
MATERIALS DIVISION

TMD-002cg
Rev 12/83

ASPHALT-ANIONIC EMULSION TEST REPORT SEP 23 2004

Test	Code	Fund	Accnt	Func	Obj	Detail Code	Par	Quantity
1	011			739	846	00 0000 00 264 0 0	1	1.0

MDOT Lab Number: 9824405 Accept Code: 1 Responsibility Code: 00
Mtl: BIT MTL SS-1
Batch - Lot Nbr: TANK 1C Quantity Represented: 13295.0 GAL
Producer: BLACKLIDGE EMULSIONS INC Address: GULFPORT, MS GULFPORT
Manufacturer: BLACKLIDGE EMULSIONS INC Address: GULFPORT, MS GULFPORT
Sampled By: CARL CRAIG Samp Id: P-2045 Date: 08/09/2004
Submitted By: INSPECTION SECTION JERRY E ANDERSON Date: 08/09/2004

Reported To: INSPECTION SECTION JERRY E ANDERSON Date: 08/31/2004
Intended Use: Test Desired: USUAL
Remarks: STOCK SAMPLE

TESTS ON ANIONIC EMULSION
(AASHTO M 140 T59)

P/F		Results	Min	Max
P	Furol Viscosity @ F, Sec	51	20	100
P	Sieve Test, %	0.01		0.10
P	Residue By (Evaporation), %	66	57	
P	Storage Stability Test, 1 Day, %	0.2		1
P	Cement Mixing Test, %	0.0		2.0

TESTS ON RESIDUE

P/F		Results	Min	Max
P	Penetration @77F, 100g, 5 Sec	124	100	200
P	Ductility @77F, 5cm/min, cm	≥ 40	40	
P	Solubility in Trichloroetnane, %	99.8	97.5	

PRIME

Asphalt Content, % ______
Water Content, % ______

This material DOES meet the requirements of Section 702-07(SS-1)
on the basis of the above tests.

Tested By: CHEMICAL LAB-JAMES GRICE

--- SAMPLE ACCEPTED ---

Figure A.3 SS-1 Emulsion Certification Sheet

APPENDIX B.1

NON-DILUTED EMULSION TCED TENSILE STRENGTH RESULTS

Table B.1.1 Non-diluted Emulsion TCED Tensile Strength Results

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m^2)	Set Time (min)	Tensile Strength (kPa)	Average Tensile Strength (kPa)
CSS1-75-5-5-0	2.00	CSS1	24.00	LOW	0.23	5.00	94.42	98.81
	2.00	CSS1	24.00	LOW	0.23	5.00	103.20	
CSS1-75-5-10-0	2.00	CSS1	24.00	LOW	0.23	10.00	104.30	101.01
	2.00	CSS1	24.00	LOW	0.23	10.00	97.71	
CSS1-75-5-15-0	2.00	CSS1	24.00	LOW	0.23	15.00	121.87	115.83
	2.00	CSS1	24.00	LOW	0.23	15.00	109.79	
CSS1-75-9-5-0	2.00	CSS1	24.00	LOW	0.41	5.00	74.66	73.01
	2.00	CSS1	24.00	LOW	0.41	5.00	71.36	
CSS1-75-9-10-0	2.00	CSS1	24.00	LOW	0.41	10.00	103.20	102.10
	2.00	CSS1	24.00	LOW	0.41	10.00	101.01	
CSS1-75-9-15-0	2.00	CSS1	24.00	LOW	0.41	15.00	118.57	112.53
	2.00	CSS1	24.00	LOW	0.41	15.00	106.50	
CSS1-75-13-5-0	2.00	CSS1	24.00	LOW	0.59	5.00	50.50	50.50
	2.00	CSS1	24.00	LOW	0.59	5.00	50.50	
CSS1-75-13-10-0	2.00	CSS1	24.00	LOW	0.59	10.00	105.40	104.30
	2.00	CSS1	24.00	LOW	0.59	10.00	103.20	
CSS1-75-13-15-0	2.00	CSS1	24.00	LOW	0.59	15.00	117.47	122.96
	2.00	CSS1	24.00	LOW	0.59	15.00	128.45	
CSS1-110-5-5-0	2.00	CSS1	43.00	MEDIUM	0.23	5.00	60.38	75.21
	2.00	CSS1	43.00	MEDIUM	0.23	5.00	90.03	
CSS1-110-5-10-0	2.00	CSS1	43.00	MEDIUM	0.23	10.00	116.38	110.34
	2.00	CSS1	43.00	MEDIUM	0.23	10.00	104.30	
CSS1-110-5-15-0	2.00	CSS1	43.00	MEDIUM	0.23	15.00	122.96	124.06
	2.00	CSS1	43.00	MEDIUM	0.23	15.00	125.16	
CSS1-110-9-5-0	2.00	CSS1	43.00	MEDIUM	0.41	5.00	71.36	75.21
	2.00	CSS1	43.00	MEDIUM	0.41	5.00	79.05	
CSS1-110-9-10-0	2.00	CSS1	43.00	MEDIUM	0.41	10.00	102.10	86.18
	2.00	CSS1	43.00	MEDIUM	0.41	10.00	70.27	
CSS1-110-9-15-0	2.00	CSS1	43.00	MEDIUM	0.41	15.00	108.69	114.73
	2.00	CSS1	43.00	MEDIUM	0.41	15.00	120.77	
CSS1-110-13-5-0	2.00	CSS1	43.00	MEDIUM	0.59	5.00	57.97	53.14
	2.00	CSS1	43.00	MEDIUM	0.59	5.00	48.31	
CSS1-110-13-10-0	2.00	CSS1	43.00	MEDIUM	0.59	10.00	82.34	85.09
	2.00	CSS1	43.00	MEDIUM	0.59	10.00	87.83	
CSS1-110-13-15-0	2.00	CSS1	43.00	MEDIUM	0.59	15.00	114.18	118.57
	2.00	CSS1	43.00	MEDIUM	0.59	15.00	122.96	
CSS1-150-5-5-0	2.00	CSS1	66.00	HIGH	0.23	5.00	117.47	107.59
	2.00	CSS1	66.00	HIGH	0.23	5.00	97.71	
CSS1-150-5-10-0	2.00	CSS1	66.00	HIGH	0.23	10.00	120.77	119.67
	2.00	CSS1	66.00	HIGH	0.23	10.00	118.57	
CSS1-150-5-15-0	2.00	CSS1	66.00	HIGH	0.23	15.00	119.67	118.57
	2.00	CSS1	66.00	HIGH	0.23	15.00	117.47	
CSS1-150-9-5-0	2.00	CSS1	66.00	HIGH	0.41	5.00	68.07	77.95
	2.00	CSS1	66.00	HIGH	0.41	5.00	87.83	
CSS1-150-9-10-0	2.00	CSS1	66.00	HIGH	0.41	10.00	103.20	103.20
	2.00	CSS1	66.00	HIGH	0.41	10.00	103.20	
CSS1-150-9-15-0	2.00	CSS1	66.00	HIGH	0.41	15.00	117.47	119.12
	2.00	CSS1	66.00	HIGH	0.41	15.00	120.77	
CSS1-150-13-5-0	2.00	CSS1	66.00	HIGH	0.59	5.00	92.22	73.01
	2.00	CSS1	66.00	HIGH	0.59	5.00	53.80	
CSS1-150-13-10-0	2.00	CSS1	66.00	HIGH	0.59	10.00	75.75	82.34
	2.00	CSS1	66.00	HIGH	0.59	10.00	88.93	
CSS1-150-13-15-0	2.00	CSS1	66.00	HIGH	0.59	15.00	83.44	90.03
	2.00	CSS1	66.00	HIGH	0.59	15.00	96.61	

Table B.1.1 Non-diluted Emulsion TCED Tensile Strength Results (Cont.)

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m^2)	Set Time (min)	Tensile Strength (kPa)	Average Tensile Strength (kPa)
SS1-75-5-5-0	2.00	SS1	24.00	LOW	0.23	5.00	103.20	101.55
	2.00	SS1	24.00	LOW	0.23	5.00	99.91	
SS1-75-5-10-0	2.00	SS1	24.00	LOW	0.23	10.00	106.50	111.44
	2.00	SS1	24.00	LOW	0.23	10.00	116.38	
SS1-75-5-15-0	2.00	SS1	24.00	LOW	0.23	15.00	105.40	114.18
	2.00	SS1	24.00	LOW	0.23	15.00	122.96	
SS1-75-9-5-0	2.00	SS1	24.00	LOW	0.41	5.00	72.46	71.36
	2.00	SS1	24.00	LOW	0.41	5.00	70.27	
SS1-75-9-10-0	2.00	SS1	24.00	LOW	0.41	10.00	92.22	93.32
	2.00	SS1	24.00	LOW	0.41	10.00	94.42	
SS1-75-9-15-0	2.00	SS1	24.00	LOW	0.41	15.00	109.79	106.50
	2.00	SS1	24.00	LOW	0.41	15.00	103.20	
SS1-75-13-5-0	2.00	SS1	24.00	LOW	0.59	5.00	46.11	39.52
	2.00	SS1	24.00	LOW	0.59	5.00	32.94	
SS1-75-13-10-0	2.00	SS1	24.00	LOW	0.59	10.00	62.58	63.13
	2.00	SS1	24.00	LOW	0.59	10.00	63.68	
SS1-75-13-15-0	2.00	SS1	24.00	LOW	0.59	15.00	76.85	64.78
	2.00	SS1	24.00	LOW	0.59	15.00	52.70	
SS1-110-5-5-0	2.00	SS1	43.00	MEDIUM	0.23	5.00	66.97	52.70
	2.00	SS1	43.00	MEDIUM	0.23	5.00	38.43	
SS1-110-5-10-0	2.00	SS1	43.00	MEDIUM	0.23	10.00	62.58	71.91
	2.00	SS1	43.00	MEDIUM	0.23	10.00	81.24	
SS1-110-5-15-0	2.00	SS1	43.00	MEDIUM	0.23	15.00	66.97	71.91
	2.00	SS1	43.00	MEDIUM	0.23	15.00	76.85	
SS1-110-9-5-0	2.00	SS1	43.00	MEDIUM	0.41	5.00	52.70	49.41
	2.00	SS1	43.00	MEDIUM	0.41	5.00	46.11	
SS1-110-9-10-0	2.00	SS1	43.00	MEDIUM	0.41	10.00	62.58	60.93
	2.00	SS1	43.00	MEDIUM	0.41	10.00	59.29	
SS1-110-9-15-0	2.00	SS1	43.00	MEDIUM	0.41	15.00	74.66	77.95
	2.00	SS1	43.00	MEDIUM	0.41	15.00	81.24	
SS1-110-13-5-0	2.00	SS1	43.00	MEDIUM	0.59	5.00	26.35	30.74
	2.00	SS1	43.00	MEDIUM	0.59	5.00	35.13	
SS1-110-13-10-0	2.00	SS1	43.00	MEDIUM	0.59	10.00	36.23	40.07
	2.00	SS1	43.00	MEDIUM	0.59	10.00	43.92	
SS1-110-13-15-0	2.00	SS1	43.00	MEDIUM	0.59	15.00	49.41	45.56
	2.00	SS1	43.00	MEDIUM	0.59	15.00	41.72	
SS1-150-5-5-0	2.00	SS1	66.00	HIGH	0.23	5.00	82.34	76.30
	2.00	SS1	66.00	HIGH	0.23	5.00	70.27	
SS1-150-5-10-0	2.00	SS1	66.00	HIGH	0.23	10.00	105.40	97.16
	2.00	SS1	66.00	HIGH	0.23	10.00	88.93	
SS1-150-5-15-0	2.00	SS1	66.00	HIGH	0.23	15.00	104.30	109.24
	2.00	SS1	66.00	HIGH	0.23	15.00	114.18	
SS1-150-9-5-0	2.00	SS1	66.00	HIGH	0.41	5.00	45.01	49.95
	2.00	SS1	66.00	HIGH	0.41	5.00	54.89	
SS1-150-9-10-0	2.00	SS1	66.00	HIGH	0.41	10.00	73.56	80.15
	2.00	SS1	66.00	HIGH	0.41	10.00	86.73	
SS1-150-9-15-0	2.00	SS1	66.00	HIGH	0.41	15.00	96.61	95.52
	2.00	SS1	66.00	HIGH	0.41	15.00	94.42	
SS1-150-13-5-0	2.00	SS1	66.00	HIGH	0.59	5.00	63.68	62.58
	2.00	SS1	66.00	HIGH	0.59	5.00	61.48	
SS1-150-13-10-0	2.00	SS1	66.00	HIGH	0.59	10.00	105.40	96.61
	2.00	SS1	66.00	HIGH	0.59	10.00	87.83	
SS1-150-13-15-0	2.00	SS1	66.00	HIGH	0.59	15.00	92.22	97.16
	2.00	SS1	66.00	HIGH	0.59	15.00	102.10	

Table B.1.1 Non-diluted Emulsion TCED Tensile Strength Results (Cont.)

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m^2)	Set Time (min)	Tensile Strength (kPa)	Average Tensile Strength (kPa)
CRS2-120-5-5-0	2.00	CRS2	49.00	LOW	0.23	5.00	119.67	93.32
	2.00	CRS2	49.00	LOW	0.23	5.00	66.97	
CRS2-120-5-10-0	2.00	CRS2	49.00	LOW	0.23	10.00	128.45	123.51
	2.00	CRS2	49.00	LOW	0.23	10.00	118.57	
CRS2-120-5-15-0	2.00	CRS2	49.00	LOW	0.23	15.00	118.57	124.61
	2.00	CRS2	49.00	LOW	0.23	15.00	130.65	
CRS2-120-9-5-0	2.00	CRS2	49.00	LOW	0.41	5.00	94.42	96.07
	2.00	CRS2	49.00	LOW	0.41	5.00	97.71	
CRS2-120-9-10-0	2.00	CRS2	49.00	LOW	0.41	10.00	95.52	101.55
	2.00	CRS2	49.00	LOW	0.41	10.00	107.59	
CRS2-120-9-15-0	2.00	CRS2	49.00	LOW	0.41	15.00	127.36	107.59
	2.00	CRS2	49.00	LOW	0.41	15.00	87.83	
CRS2-120-13-5-0	2.00	CRS2	49.00	LOW	0.59	5.00	48.31	54.89
	2.00	CRS2	49.00	LOW	0.59	5.00	61.48	
CRS2-120-13-10-0	2.00	CRS2	49.00	LOW	0.59	10.00	72.46	83.44
	2.00	CRS2	49.00	LOW	0.59	10.00	94.42	
CRS2-120-13-15-0	2.00	CRS2	49.00	LOW	0.59	15.00	142.73	131.20
	2.00	CRS2	49.00	LOW	0.59	15.00	119.67	
CRS2-145-5-5-0	2.00	CRS2	63.00	MEDIUM	0.23	5.00	90.03	92.77
	2.00	CRS2	63.00	MEDIUM	0.23	5.00	95.52	
CRS2-145-5-10-0	2.00	CRS2	63.00	MEDIUM	0.23	10.00	101.01	103.20
	2.00	CRS2	63.00	MEDIUM	0.23	10.00	105.40	
CRS2-145-5-15-0	2.00	CRS2	63.00	MEDIUM	0.23	15.00	98.81	105.95
	2.00	CRS2	63.00	MEDIUM	0.23	15.00	113.08	
CRS2-145-9-5-0	2.00	CRS2	63.00	MEDIUM	0.41	5.00	87.83	87.83
	2.00	CRS2	63.00	MEDIUM	0.41	5.00	87.83	
CRS2-145-9-10-0	2.00	CRS2	63.00	MEDIUM	0.41	10.00	96.61	110.34
	2.00	CRS2	63.00	MEDIUM	0.41	10.00	124.06	
CRS2-145-9-15-0	2.00	CRS2	63.00	MEDIUM	0.41	15.00	121.87	116.93
	2.00	CRS2	63.00	MEDIUM	0.41	15.00	111.98	
CRS2-145-13-5-0	2.00	CRS2	63.00	MEDIUM	0.59	5.00	92.22	81.79
	2.00	CRS2	63.00	MEDIUM	0.59	5.00	71.36	
CRS2-145-13-10-0	2.00	CRS2	63.00	MEDIUM	0.59	10.00	105.40	88.38
	2.00	CRS2	63.00	MEDIUM	0.59	10.00	71.36	
CRS2-145-13-15-0	2.00	CRS2	63.00	MEDIUM	0.59	15.00	119.67	105.95
	2.00	CRS2	63.00	MEDIUM	0.59	15.00	92.22	
CRS2-170-5-5-0	2.00	CRS2	77.00	HIGH	0.23	5.00	65.87	66.97
	2.00	CRS2	77.00	HIGH	0.23	5.00	68.07	
CRS2-170-5-10-0	2.00	CRS2	77.00	HIGH	0.23	10.00	116.38	108.14
	2.00	CRS2	77.00	HIGH	0.23	10.00	99.91	
CRS2-170-5-15-0	2.00	CRS2	77.00	HIGH	0.23	15.00	87.83	105.40
	2.00	CRS2	77.00	HIGH	0.23	15.00	122.96	
CRS2-170-9-5-0	2.00	CRS2	77.00	HIGH	0.41	5.00	76.85	72.46
	2.00	CRS2	77.00	HIGH	0.41	5.00	68.07	
CRS2-170-9-10-0	2.00	CRS2	77.00	HIGH	0.41	10.00	74.66	70.27
	2.00	CRS2	77.00	HIGH	0.41	10.00	65.87	
CRS2-170-9-15-0	2.00	CRS2	77.00	HIGH	0.41	15.00	105.40	109.79
	2.00	CRS2	77.00	HIGH	0.41	15.00	114.18	
CRS2-170-13-5-0	2.00	CRS2	77.00	HIGH	0.59	5.00	87.83	83.44
	2.00	CRS2	77.00	HIGH	0.59	5.00	79.05	
CRS2-170-13-10-0	2.00	CRS2	77.00	HIGH	0.59	10.00	94.42	93.87
	2.00	CRS2	77.00	HIGH	0.59	10.00	93.32	
CRS2-170-13-15-0	2.00	CRS2	77.00	HIGH	0.59	15.00	88.93	83.99
	2.00	CRS2	77.00	HIGH	0.59	15.00	79.05	

APPENDIX B.2

NON-DILUTED EMULSION TCED TORQUE-SHEAR STRENGTH RESULTS

Table B.2.1 Non-diluted Emulsion TCED Torque-shear Strength Results

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m^2)	Set Time (min)	Torque (N-m)	Average Torque (N-m)	Shear Stress (kPa)	Average Shear Stress (kPa)
CSS1-75-5-5-0	2.00	CSS1	24.00	LOW	0.23	5.00	1.00	1.25	38.85	48.56
	2.00	CSS1	24.00	LOW	0.23	5.00	1.50		58.27	
CSS1-75-5-10-0	2.00	CSS1	24.00	LOW	0.23	10.00	2.00	1.75	77.70	67.99
	2.00	CSS1	24.00	LOW	0.23	10.00	1.50		58.27	
CSS1-75-5-15-0	2.00	CSS1	24.00	LOW	0.23	15.00	1.30	1.45	50.50	56.33
	2.00	CSS1	24.00	LOW	0.23	15.00	1.60		62.16	
CSS1-75-9-5-0	2.00	CSS1	24.00	LOW	0.41	5.00	1.60	1.80	62.16	69.93
	2.00	CSS1	24.00	LOW	0.41	5.00	2.00		77.70	
CSS1-75-9-10-0	2.00	CSS1	24.00	LOW	0.41	10.00	2.00	2.40	77.70	93.24
	2.00	CSS1	24.00	LOW	0.41	10.00	2.80		108.78	
CSS1-75-9-15-0	2.00	CSS1	24.00	LOW	0.41	15.00	1.20	2.10	46.62	81.58
	2.00	CSS1	24.00	LOW	0.41	15.00	3.00		116.55	
CSS1-75-13-5-0	2.00	CSS1	24.00	LOW	0.59	5.00	1.00	1.50	38.85	58.27
	2.00	CSS1	24.00	LOW	0.59	5.00	2.00		77.70	
CSS1-75-13-10-0	2.00	CSS1	24.00	LOW	0.59	10.00	2.00	2.25	77.70	87.41
	2.00	CSS1	24.00	LOW	0.59	10.00	2.50		97.12	
CSS1-75-13-15-0	2.00	CSS1	24.00	LOW	0.59	15.00	2.00	1.90	77.70	73.81
	2.00	CSS1	24.00	LOW	0.59	15.00	1.80		69.93	
CSS1-110-5-5-0	2.00	CSS1	43.00	MEDIUM	0.23	5.00	1.20	1.10	46.62	42.73
	2.00	CSS1	43.00	MEDIUM	0.23	5.00	1.00		38.85	
CSS1-110-5-10-0	2.00	CSS1	43.00	MEDIUM	0.23	10.00	2.40	2.25	93.24	87.41
	2.00	CSS1	43.00	MEDIUM	0.23	10.00	2.10		81.58	
CSS1-110-5-15-0	2.00	CSS1	43.00	MEDIUM	0.23	15.00	3.00	2.50	116.55	97.12
	2.00	CSS1	43.00	MEDIUM	0.23	15.00	2.00		77.70	
CSS1-110-9-5-0	2.00	CSS1	43.00	MEDIUM	0.41	5.00	0.50	1.15	19.42	44.68
	2.00	CSS1	43.00	MEDIUM	0.41	5.00	1.80		69.93	
CSS1-110-9-10-0	2.00	CSS1	43.00	MEDIUM	0.41	10.00	2.00	1.90	77.70	73.81
	2.00	CSS1	43.00	MEDIUM	0.41	10.00	1.80		69.93	
CSS1-110-9-15-0	2.00	CSS1	43.00	MEDIUM	0.41	15.00	2.20	2.60	85.47	101.01
	2.00	CSS1	43.00	MEDIUM	0.41	15.00	3.00		116.55	
CSS1-110-13-5-0	2.00	CSS1	43.00	MEDIUM	0.59	5.00	1.50	1.75	58.27	67.99
	2.00	CSS1	43.00	MEDIUM	0.59	5.00	2.00		77.70	
CSS1-110-13-10-0	2.00	CSS1	43.00	MEDIUM	0.59	10.00	2.40	1.90	93.24	73.81
	2.00	CSS1	43.00	MEDIUM	0.59	10.00	1.40		54.39	
CSS1-110-13-15-0	2.00	CSS1	43.00	MEDIUM	0.59	15.00	2.00	1.95	77.70	75.76
	2.00	CSS1	43.00	MEDIUM	0.59	15.00	1.90		73.81	
CSS1-150-5-5-0	2.00	CSS1	66.00	HIGH	0.23	5.00	1.20	1.60	46.62	62.16
	2.00	CSS1	66.00	HIGH	0.23	5.00	2.00		77.70	
CSS1-150-5-10-0	2.00	CSS1	66.00	HIGH	0.23	10.00	2.20	2.10	85.47	81.58
	2.00	CSS1	66.00	HIGH	0.23	10.00	2.00		77.70	
CSS1-150-5-15-0	2.00	CSS1	66.00	HIGH	0.23	15.00	3.20	3.30	124.32	128.20
	2.00	CSS1	66.00	HIGH	0.23	15.00	3.40		132.09	
CSS1-150-9-5-0	2.00	CSS1	66.00	HIGH	0.41	5.00	1.10	1.05	42.73	40.79
	2.00	CSS1	66.00	HIGH	0.41	5.00	1.00		38.85	
CSS1-150-9-10-0	2.00	CSS1	66.00	HIGH	0.41	10.00	2.20	1.75	85.47	67.99
	2.00	CSS1	66.00	HIGH	0.41	10.00	1.30		50.50	
CSS1-150-9-15-0	2.00	CSS1	66.00	HIGH	0.41	15.00	1.60	1.80	62.16	69.93
	2.00	CSS1	66.00	HIGH	0.41	15.00	2.00		77.70	
CSS1-150-13-5-0	2.00	CSS1	66.00	HIGH	0.59	5.00	2.20	1.60	85.47	62.16
	2.00	CSS1	66.00	HIGH	0.59	5.00	1.00		38.85	
CSS1-150-13-10-0	2.00	CSS1	66.00	HIGH	0.59	10.00	1.50	1.40	58.27	54.39
	2.00	CSS1	66.00	HIGH	0.59	10.00	1.30		50.50	
CSS1-150-13-15-0	2.00	CSS1	66.00	HIGH	0.59	15.00	1.20	1.40	46.62	54.39
	2.00	CSS1	66.00	HIGH	0.59	15.00	1.60		62.16	

Table B.2.1 Non-diluted Emulsion TCED Torque-shear Strength Results (Cont.)

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m^2)	Set Time (min)	Torque (N-m)	Average Torque (N-m)	Shear Stress (kPa)	Average Shear Stress (kPa)
SS1-75-5-5-0	2.00	SS1	24.00	LOW	0.23	5.00	3.10	2.80	120.43	108.78
	2.00	SS1	24.00	LOW	0.23	5.00	2.50		97.12	
SS1-75-5-10-0	2.00	SS1	24.00	LOW	0.23	10.00	3.40	3.50	132.09	135.97
	2.00	SS1	24.00	LOW	0.23	10.00	3.60		139.86	
SS1-75-5-15-0	2.00	SS1	24.00	LOW	0.23	15.00	4.00	4.30	155.40	167.05
	2.00	SS1	24.00	LOW	0.23	15.00	4.60		178.71	
SS1-75-9-5-0	2.00	SS1	24.00	LOW	0.41	5.00	1.40	1.70	54.39	66.04
	2.00	SS1	24.00	LOW	0.41	5.00	2.00		77.70	
SS1-75-9-10-0	2.00	SS1	24.00	LOW	0.41	10.00	1.50	2.85	58.27	110.72
	2.00	SS1	24.00	LOW	0.41	10.00	4.20		163.17	
SS1-75-9-15-0	2.00	SS1	24.00	LOW	0.41	15.00	3.20	3.40	124.32	132.09
	2.00	SS1	24.00	LOW	0.41	15.00	3.60		139.86	
SS1-75-13-5-0	2.00	SS1	24.00	LOW	0.59	5.00	0.80	0.60	31.08	23.31
	2.00	SS1	24.00	LOW	0.59	5.00	0.40		15.54	
SS1-75-13-10-0	2.00	SS1	24.00	LOW	0.59	10.00	2.00	1.75	77.70	67.99
	2.00	SS1	24.00	LOW	0.59	10.00	1.50		58.27	
SS1-75-13-15-0	2.00	SS1	24.00	LOW	0.59	15.00	2.00	2.60	77.70	101.01
	2.00	SS1	24.00	LOW	0.59	15.00	3.20		124.32	
SS1-110-5-5-0	2.00	SS1	43.00	MEDIUM	0.23	5.00	2.00	1.50	77.70	58.27
	2.00	SS1	43.00	MEDIUM	0.23	5.00	1.00		38.85	
SS1-110-5-10-0	2.00	SS1	43.00	MEDIUM	0.23	10.00	1.60	1.50	62.16	58.27
	2.00	SS1	43.00	MEDIUM	0.23	10.00	1.40		54.39	
SS1-110-5-15-0	2.00	SS1	43.00	MEDIUM	0.23	15.00	1.40	1.70	54.39	66.04
	2.00	SS1	43.00	MEDIUM	0.23	15.00	2.00		77.70	
SS1-110-9-5-0	2.00	SS1	43.00	MEDIUM	0.41	5.00	1.20	1.20	46.62	46.62
	2.00	SS1	43.00	MEDIUM	0.41	5.00	1.20		46.62	
SS1-110-9-10-0	2.00	SS1	43.00	MEDIUM	0.41	10.00	1.00	1.50	38.85	58.27
	2.00	SS1	43.00	MEDIUM	0.41	10.00	2.00		77.70	
SS1-110-9-15-0	2.00	SS1	43.00	MEDIUM	0.41	15.00	2.00	1.80	77.70	69.93
	2.00	SS1	43.00	MEDIUM	0.41	15.00	1.60		62.16	
SS1-110-13-5-0	2.00	SS1	43.00	MEDIUM	0.59	5.00	0.60	0.80	23.31	31.08
	2.00	SS1	43.00	MEDIUM	0.59	5.00	1.00		38.85	
SS1-110-13-10-0	2.00	SS1	43.00	MEDIUM	0.59	10.00	0.70	0.65	27.19	25.25
	2.00	SS1	43.00	MEDIUM	0.59	10.00	0.60		23.31	
SS1-110-13-15-0	2.00	SS1	43.00	MEDIUM	0.59	15.00	0.60	0.90	23.31	34.96
	2.00	SS1	43.00	MEDIUM	0.59	15.00	1.20		46.62	
SS1-150-5-5-0	2.00	SS1	66.00	HIGH	0.23	5.00	1.20	1.40	46.62	54.39
	2.00	SS1	66.00	HIGH	0.23	5.00	1.60		62.16	
SS1-150-5-10-0	2.00	SS1	66.00	HIGH	0.23	10.00	2.40	1.90	93.24	73.81
	2.00	SS1	66.00	HIGH	0.23	10.00	1.40		54.39	
SS1-150-5-15-0	2.00	SS1	66.00	HIGH	0.23	15.00	2.80	2.60	108.78	101.01
	2.00	SS1	66.00	HIGH	0.23	15.00	2.40		93.24	
SS1-150-9-5-0	2.00	SS1	66.00	HIGH	0.41	5.00	1.00	1.20	38.85	46.62
	2.00	SS1	66.00	HIGH	0.41	5.00	1.40		54.39	
SS1-150-9-10-0	2.00	SS1	66.00	HIGH	0.41	10.00	1.20	1.40	46.62	54.39
	2.00	SS1	66.00	HIGH	0.41	10.00	1.60		62.16	
SS1-150-9-15-0	2.00	SS1	66.00	HIGH	0.41	15.00	1.20	1.40	46.62	54.39
	2.00	SS1	66.00	HIGH	0.41	15.00	1.60		62.16	
SS1-150-13-5-0	2.00	SS1	66.00	HIGH	0.59	5.00	1.30	1.25	50.50	48.56
	2.00	SS1	66.00	HIGH	0.59	5.00	1.20		46.62	
SS1-150-13-10-0	2.00	SS1	66.00	HIGH	0.59	10.00	1.00	1.40	38.85	54.39
	2.00	SS1	66.00	HIGH	0.59	10.00	1.80		69.93	
SS1-150-13-15-0	2.00	SS1	66.00	HIGH	0.59	15.00	1.20	1.45	46.62	56.33
	2.00	SS1	66.00	HIGH	0.59	15.00	1.70		66.04	

Table B.2.1 Non-diluted Emulsion TCED Torque-shear Strength Results (Cont.)

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m^2)	Set Time (min)	Torque (N-m)	Average Torque (N-m)	Shear Stress (kPa)	Average Shear Stress (kPa)
CRS2-120-5-5-0	2.00	CRS2	49.00	LOW	0.23	5.00	4.00	6.70	155.40	260.29
	2.00	CRS2	49.00	LOW	0.23	5.00	9.40		365.18	
CRS2-120-5-10-0	2.00	CRS2	49.00	LOW	0.23	10.00	7.60	9.30	295.25	361.30
	2.00	CRS2	49.00	LOW	0.23	10.00	11.00		427.34	
CRS2-120-5-15-0	2.00	CRS2	49.00	LOW	0.23	15.00	12.00	11.00	466.19	427.34
	2.00	CRS2	49.00	LOW	0.23	15.00	10.00		388.49	
CRS2-120-9-5-0	2.00	CRS2	49.00	LOW	0.41	5.00	5.00	5.30	194.24	205.90
	2.00	CRS2	49.00	LOW	0.41	5.00	5.60		217.55	
CRS2-120-9-10-0	2.00	CRS2	49.00	LOW	0.41	10.00	7.20	7.90	279.71	306.91
	2.00	CRS2	49.00	LOW	0.41	10.00	8.60		334.10	
CRS2-120-9-15-0	2.00	CRS2	49.00	LOW	0.41	15.00	8.00	8.30	310.79	322.45
	2.00	CRS2	49.00	LOW	0.41	15.00	8.60		334.10	
CRS2-120-13-5-0	2.00	CRS2	49.00	LOW	0.59	5.00	3.50	4.35	135.97	168.99
	2.00	CRS2	49.00	LOW	0.59	5.00	5.20		202.01	
CRS2-120-13-10-0	2.00	CRS2	49.00	LOW	0.59	10.00	7.40	8.10	287.48	314.68
	2.00	CRS2	49.00	LOW	0.59	10.00	8.80		341.87	
CRS2-120-13-15-0	2.00	CRS2	49.00	LOW	0.59	15.00	6.30	7.30	244.75	283.60
	2.00	CRS2	49.00	LOW	0.59	15.00	8.30		322.45	
CRS2-145-5-5-0	2.00	CRS2	63.00	MEDIUM	0.23	5.00	4.00	4.50	155.40	174.82
	2.00	CRS2	63.00	MEDIUM	0.23	5.00	5.00		194.24	
CRS2-145-5-10-0	2.00	CRS2	63.00	MEDIUM	0.23	10.00	8.50	8.35	330.22	324.39
	2.00	CRS2	63.00	MEDIUM	0.23	10.00	8.20		318.56	
CRS2-145-5-15-0	2.00	CRS2	63.00	MEDIUM	0.23	15.00	12.00	11.50	466.19	446.76
	2.00	CRS2	63.00	MEDIUM	0.23	15.00	11.00		427.34	
CRS2-145-9-5-0	2.00	CRS2	63.00	MEDIUM	0.41	5.00	6.00	6.00	233.09	233.09
	2.00	CRS2	63.00	MEDIUM	0.41	5.00	6.00		233.09	
CRS2-145-9-10-0	2.00	CRS2	63.00	MEDIUM	0.41	10.00	8.80	7.70	341.87	299.14
	2.00	CRS2	63.00	MEDIUM	0.41	10.00	6.60		256.40	
CRS2-145-9-15-0	2.00	CRS2	63.00	MEDIUM	0.41	15.00	8.00	8.20	310.79	318.56
	2.00	CRS2	63.00	MEDIUM	0.41	15.00	8.40		326.33	
CRS2-145-13-5-0	2.00	CRS2	63.00	MEDIUM	0.59	5.00	5.20	3.80	202.01	147.63
	2.00	CRS2	63.00	MEDIUM	0.59	5.00	2.40		93.24	
CRS2-145-13-10-0	2.00	CRS2	63.00	MEDIUM	0.59	10.00	7.00	7.30	271.94	283.60
	2.00	CRS2	63.00	MEDIUM	0.59	10.00	7.60		295.25	
CRS2-145-13-15-0	2.00	CRS2	63.00	MEDIUM	0.59	15.00	8.00	8.20	310.79	318.56
	2.00	CRS2	63.00	MEDIUM	0.59	15.00	8.40		326.33	
CRS2-170-5-5-0	2.00	CRS2	77.00	HIGH	0.23	5.00	5.20	5.10	202.01	198.13
	2.00	CRS2	77.00	HIGH	0.23	5.00	5.00		194.24	
CRS2-170-5-10-0	2.00	CRS2	77.00	HIGH	0.23	10.00	7.60	8.10	295.25	314.68
	2.00	CRS2	77.00	HIGH	0.23	10.00	8.60		334.10	
CRS2-170-5-15-0	2.00	CRS2	77.00	HIGH	0.23	15.00	8.20	8.55	318.56	332.16
	2.00	CRS2	77.00	HIGH	0.23	15.00	8.90		345.76	
CRS2-170-9-5-0	2.00	CRS2	77.00	HIGH	0.41	5.00	7.00	6.00	271.94	233.09
	2.00	CRS2	77.00	HIGH	0.41	5.00	5.00		194.24	
CRS2-170-9-10-0	2.00	CRS2	77.00	HIGH	0.41	10.00	8.00	7.90	310.79	306.91
	2.00	CRS2	77.00	HIGH	0.41	10.00	7.80		303.02	
CRS2-170-9-15-0	2.00	CRS2	77.00	HIGH	0.41	15.00	8.50	7.75	330.22	301.08
	2.00	CRS2	77.00	HIGH	0.41	15.00	7.00		271.94	
CRS2-170-13-5-0	2.00	CRS2	77.00	HIGH	0.59	5.00	3.60	4.50	139.86	174.82
	2.00	CRS2	77.00	HIGH	0.59	5.00	5.40		209.78	
CRS2-170-13-10-0	2.00	CRS2	77.00	HIGH	0.59	10.00	3.70	4.75	143.74	184.53
	2.00	CRS2	77.00	HIGH	0.59	10.00	5.80		225.32	
CRS2-170-13-15-0	2.00	CRS2	77.00	HIGH	0.59	15.00	7.50	7.05	291.37	273.89
	2.00	CRS2	77.00	HIGH	0.59	15.00	6.60		256.40	

APPENDIX B.3

DILUTED EMULSION TCED TENSILE STRENGTH RESULTS

Table B.3.1 Diluted Emulsion TCED Tensile Strength Results

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m2)	Set Time (min)	Tensile Strength (kPa)	Average Tensile Strength (kPa)
CSS1-75-5-15-100	5.00	CSS1	24.00	LOW	0.23	15.00	3.34	3.60
	5.00	CSS1	24.00	LOW	0.23	15.00	3.86	
CSS1-75-5-30-100	5.00	CSS1	24.00	LOW	0.23	30.00	4.39	5.09
	5.00	CSS1	24.00	LOW	0.23	30.00	5.80	
CSS1-75-5-60-100	5.00	CSS1	24.00	LOW	0.23	60.00	11.59	10.01
	5.00	CSS1	24.00	LOW	0.23	60.00	8.43	
CSS1-75-9-15-100	5.00	CSS1	24.00	LOW	0.41	15.00	4.57	4.66
	5.00	CSS1	24.00	LOW	0.41	15.00	4.74	
CSS1-75-9-30-100	5.00	CSS1	24.00	LOW	0.41	30.00	6.15	6.50
	5.00	CSS1	24.00	LOW	0.41	30.00	6.85	
CSS1-75-9-60-100	5.00	CSS1	24.00	LOW	0.41	60.00	20.20	18.44
	5.00	CSS1	24.00	LOW	0.41	60.00	16.69	
CSS1-75-13-15-100	5.00	CSS1	24.00	LOW	0.59	15.00	3.34	3.25
	5.00	CSS1	24.00	LOW	0.59	15.00	3.16	
CSS1-75-13-30-100	5.00	CSS1	24.00	LOW	0.59	30.00	3.51	3.78
	5.00	CSS1	24.00	LOW	0.59	30.00	4.04	
CSS1-75-13-60-100	5.00	CSS1	24.00	LOW	0.59	60.00	4.04	4.57
	5.00	CSS1	24.00	LOW	0.59	60.00	5.09	
CSS1-110-5-15-100	5.00	CSS1	43.00	MEDIUM	0.23	15.00	3.51	3.25
	5.00	CSS1	43.00	MEDIUM	0.23	15.00	2.99	
CSS1-110-5-30-100	5.00	CSS1	43.00	MEDIUM	0.23	30.00	14.76	16.69
	5.00	CSS1	43.00	MEDIUM	0.23	30.00	18.62	
CSS1-110-5-60-100	5.00	CSS1	43.00	MEDIUM	0.23	60.00	17.04	17.83
	5.00	CSS1	43.00	MEDIUM	0.23	60.00	18.62	
CSS1-110-9-15-100	5.00	CSS1	43.00	MEDIUM	0.41	15.00	4.57	5.36
	5.00	CSS1	43.00	MEDIUM	0.41	15.00	6.15	
CSS1-110-9-30-100	5.00	CSS1	43.00	MEDIUM	0.41	30.00	7.03	6.50
	5.00	CSS1	43.00	MEDIUM	0.41	30.00	5.97	
CSS1-110-9-60-100	5.00	CSS1	43.00	MEDIUM	0.41	60.00	7.20	14.49
	5.00	CSS1	43.00	MEDIUM	0.41	60.00	21.78	
CSS1-110-13-15-10	5.00	CSS1	43.00	MEDIUM	0.59	15.00	4.39	4.13
	5.00	CSS1	43.00	MEDIUM	0.59	15.00	3.86	
CSS1-110-13-30-10	5.00	CSS1	43.00	MEDIUM	0.59	30.00	6.15	5.88
	5.00	CSS1	43.00	MEDIUM	0.59	30.00	5.62	
CSS1-110-13-60-10	5.00	CSS1	43.00	MEDIUM	0.59	60.00	8.26	7.82
	5.00	CSS1	43.00	MEDIUM	0.59	60.00	7.38	
CSS1-150-5-15-100	5.00	CSS1	66.00	HIGH	0.23	15.00	5.97	6.41
	5.00	CSS1	66.00	HIGH	0.23	15.00	6.85	
CSS1-150-5-30-100	5.00	CSS1	66.00	HIGH	0.23	30.00	8.08	7.29
	5.00	CSS1	66.00	HIGH	0.23	30.00	6.50	
CSS1-150-5-60-100	5.00	CSS1	66.00	HIGH	0.23	60.00	15.63	15.11
	5.00	CSS1	66.00	HIGH	0.23	60.00	14.58	
CSS1-150-9-15-100	5.00	CSS1	66.00	HIGH	0.41	15.00	4.57	5.45
	5.00	CSS1	66.00	HIGH	0.41	15.00	6.32	
CSS1-150-9-30-100	5.00	CSS1	66.00	HIGH	0.41	30.00	5.27	7.29
	5.00	CSS1	66.00	HIGH	0.41	30.00	9.31	
CSS1-150-9-60-100	5.00	CSS1	66.00	HIGH	0.41	60.00	6.68	12.30
	5.00	CSS1	66.00	HIGH	0.41	60.00	17.92	
CSS1-150-13-15-10	5.00	CSS1	66.00	HIGH	0.59	15.00	3.69	3.69
	5.00	CSS1	66.00	HIGH	0.59	15.00	3.69	
CSS1-150-13-30-10	5.00	CSS1	66.00	HIGH	0.59	30.00	6.32	5.62
	5.00	CSS1	66.00	HIGH	0.59	30.00	4.92	
CSS1-150-13-60-10	5.00	CSS1	66.00	HIGH	0.59	60.00	13.17	11.07
	5.00	CSS1	66.00	HIGH	0.59	60.00	8.96	

Table B.3.1 Diluted Emulsion TCED Tensile Strength Results (Cont.)

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m2)	Set Time (min)	Tensile Strength (kPa)	Average Tensile Strength (kPa)
SS1-75-5-15-100	5.00	SS1	24.00	LOW	0.23	15.00	4.57	5.09
	5.00	SS1	24.00	LOW	0.23	15.00	5.62	
SS1-75-5-30-100	5.00	SS1	24.00	LOW	0.23	30.00	4.22	5.09
	5.00	SS1	24.00	LOW	0.23	30.00	5.97	
SS1-75-5-60-100	5.00	SS1	24.00	LOW	0.23	60.00	13.17	14.32
	5.00	SS1	24.00	LOW	0.23	60.00	15.46	
SS1-75-9-15-100	5.00	SS1	24.00	LOW	0.41	15.00	4.92	4.74
	5.00	SS1	24.00	LOW	0.41	15.00	4.57	
SS1-75-9-30-100	5.00	SS1	24.00	LOW	0.41	30.00	4.57	4.66
	5.00	SS1	24.00	LOW	0.41	30.00	4.74	
SS1-75-9-60-100	5.00	SS1	24.00	LOW	0.41	60.00	4.57	6.76
	5.00	SS1	24.00	LOW	0.41	60.00	8.96	
SS1-75-13-15-100	5.00	SS1	24.00	LOW	0.59	15.00	3.69	3.69
	5.00	SS1	24.00	LOW	0.59	15.00	3.69	
SS1-75-13-30-100	5.00	SS1	24.00	LOW	0.59	30.00	4.39	4.66
	5.00	SS1	24.00	LOW	0.59	30.00	4.92	
SS1-75-13-60-100	5.00	SS1	24.00	LOW	0.59	60.00	4.57	5.62
	5.00	SS1	24.00	LOW	0.59	60.00	6.68	
SS1-110-5-15-100	5.00	SS1	43.00	MEDIUM	0.23	15.00	3.51	3.25
	5.00	SS1	43.00	MEDIUM	0.23	15.00	2.99	
SS1-110-5-30-100	5.00	SS1	43.00	MEDIUM	0.23	30.00	7.73	8.61
	5.00	SS1	43.00	MEDIUM	0.23	30.00	9.49	
SS1-110-5-60-100	5.00	SS1	43.00	MEDIUM	0.23	60.00	21.78	17.57
	5.00	SS1	43.00	MEDIUM	0.23	60.00	13.35	
SS1-110-9-15-100	5.00	SS1	43.00	MEDIUM	0.41	15.00	4.39	4.39
	5.00	SS1	43.00	MEDIUM	0.41	15.00	4.39	
SS1-110-9-30-100	5.00	SS1	43.00	MEDIUM	0.41	30.00	7.38	6.68
	5.00	SS1	43.00	MEDIUM	0.41	30.00	5.97	
SS1-110-9-60-100	5.00	SS1	43.00	MEDIUM	0.41	60.00	5.27	5.18
	5.00	SS1	43.00	MEDIUM	0.41	60.00	5.09	
SS1-110-13-15-100	5.00	SS1	43.00	MEDIUM	0.59	15.00	4.74	4.04
	5.00	SS1	43.00	MEDIUM	0.59	15.00	3.34	
SS1-110-13-30-100	5.00	SS1	43.00	MEDIUM	0.59	30.00	5.27	5.01
	5.00	SS1	43.00	MEDIUM	0.59	30.00	4.74	
SS1-110-13-60-100	5.00	SS1	43.00	MEDIUM	0.59	60.00	7.38	6.15
	5.00	SS1	43.00	MEDIUM	0.59	60.00	4.92	
SS1-150-5-15-100	5.00	SS1	66.00	HIGH	0.23	15.00	4.92	5.09
	5.00	SS1	66.00	HIGH	0.23	15.00	5.27	
SS1-150-5-30-100	5.00	SS1	66.00	HIGH	0.23	30.00	8.26	7.99
	5.00	SS1	66.00	HIGH	0.23	30.00	7.73	
SS1-150-5-60-100	5.00	SS1	66.00	HIGH	0.23	60.00	16.86	12.91
	5.00	SS1	66.00	HIGH	0.23	60.00	8.96	
SS1-150-9-15-100	5.00	SS1	66.00	HIGH	0.41	15.00	3.86	4.22
	5.00	SS1	66.00	HIGH	0.41	15.00	4.57	
SS1-150-9-30-100	5.00	SS1	66.00	HIGH	0.41	30.00	5.80	6.50
	5.00	SS1	66.00	HIGH	0.41	30.00	7.20	
SS1-150-9-60-100	5.00	SS1	66.00	HIGH	0.41	60.00	4.92	7.73
	5.00	SS1	66.00	HIGH	0.41	60.00	10.54	
SS1-150-13-15-100	5.00	SS1	66.00	HIGH	0.59	15.00	4.39	5.01
	5.00	SS1	66.00	HIGH	0.59	15.00	5.62	
SS1-150-13-30-100	5.00	SS1	66.00	HIGH	0.59	30.00	4.57	4.66
	5.00	SS1	66.00	HIGH	0.59	30.00	4.74	
SS1-150-13-60-100	5.00	SS1	66.00	HIGH	0.59	60.00	5.09	5.45
	5.00	SS1	66.00	HIGH	0.59	60.00	5.80	

Table B.3.1 Diluted Emulsion TCED Tensile Strength Results (Cont.)

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m2)	Set Time (min)	Tensile Strength (kPa)	Average Tensile Strength (kPa)
CRS2-120-5-15-10(	5.00	CRS2	49.00	LOW	0.23	15.00	6.85	6.59
	5.00	CRS2	49.00	LOW	0.23	15.00	6.32	
CRS2-120-5-30-10(	5.00	CRS2	49.00	LOW	0.23	30.00	7.73	6.94
	5.00	CRS2	49.00	LOW	0.23	30.00	6.15	
CRS2-120-5-60-10(	5.00	CRS2	49.00	LOW	0.23	60.00	11.59	10.80
	5.00	CRS2	49.00	LOW	0.23	60.00	10.01	
CRS2-120-9-15-10(	5.00	CRS2	49.00	LOW	0.41	15.00	6.50	6.24
	5.00	CRS2	49.00	LOW	0.41	15.00	5.97	
CRS2-120-9-30-10(	5.00	CRS2	49.00	LOW	0.41	30.00	21.08	15.46
	5.00	CRS2	49.00	LOW	0.41	30.00	9.84	
CRS2-120-9-60-10(	5.00	CRS2	49.00	LOW	0.41	60.00	21.26	15.90
	5.00	CRS2	49.00	LOW	0.41	60.00	10.54	
CRS2-120-13-15-10	5.00	CRS2	49.00	LOW	0.59	15.00	5.09	5.01
	5.00	CRS2	49.00	LOW	0.59	15.00	4.92	
CRS2-120-13-30-10	5.00	CRS2	49.00	LOW	0.59	30.00	21.08	13.17
	5.00	CRS2	49.00	LOW	0.59	30.00	5.27	
CRS2-120-13-60-10	5.00	CRS2	49.00	LOW	0.59	60.00	21.08	14.76
	5.00	CRS2	49.00	LOW	0.59	60.00	8.43	
CRS2-145-5-15-10(	5.00	CRS2	63.00	MEDIUM	0.23	15.00	22.73	14.35
	5.00	CRS2	63.00	MEDIUM	0.23	15.00	5.97	
CRS2-145-5-30-10(	5.00	CRS2	63.00	MEDIUM	0.23	30.00	7.03	6.50
	5.00	CRS2	63.00	MEDIUM	0.23	30.00	5.97	
CRS2-145-5-60-10(	5.00	CRS2	63.00	MEDIUM	0.23	60.00	13.17	13.00
	5.00	CRS2	63.00	MEDIUM	0.23	60.00	12.82	
CRS2-145-9-15-10(	5.00	CRS2	63.00	MEDIUM	0.41	15.00	3.86	3.78
	5.00	CRS2	63.00	MEDIUM	0.41	15.00	3.69	
CRS2-145-9-30-10(	5.00	CRS2	63.00	MEDIUM	0.41	30.00	21.08	13.44
	5.00	CRS2	63.00	MEDIUM	0.41	30.00	5.80	
CRS2-145-9-60-10(	5.00	CRS2	63.00	MEDIUM	0.41	60.00	21.08	21.43
	5.00	CRS2	63.00	MEDIUM	0.41	60.00	21.78	
CRS2-145-13-15-10	5.00	CRS2	63.00	MEDIUM	0.59	15.00	4.39	4.83
	5.00	CRS2	63.00	MEDIUM	0.59	15.00	5.27	
CRS2-145-13-30-10	5.00	CRS2	63.00	MEDIUM	0.59	30.00	23.01	14.23
	5.00	CRS2	63.00	MEDIUM	0.59	30.00	5.45	
CRS2-145-13-60-10	5.00	CRS2	63.00	MEDIUM	0.59	60.00	14.05	11.07
	5.00	CRS2	63.00	MEDIUM	0.59	60.00	8.08	
CRS2-170-5-15-10(	5.00	CRS2	77.00	HIGH	0.23	15.00	21.08	12.65
	5.00	CRS2	77.00	HIGH	0.23	15.00	4.22	
CRS2-170-5-30-10(	5.00	CRS2	77.00	HIGH	0.23	30.00	19.15	13.35
	5.00	CRS2	77.00	HIGH	0.23	30.00	7.55	
CRS2-170-5-60-10(	5.00	CRS2	77.00	HIGH	0.23	60.00	18.09	18.71
	5.00	CRS2	77.00	HIGH	0.23	60.00	19.32	
CRS2-170-9-15-10(	5.00	CRS2	77.00	HIGH	0.41	15.00	8.61	7.55
	5.00	CRS2	77.00	HIGH	0.41	15.00	6.50	
CRS2-170-9-30-10(	5.00	CRS2	77.00	HIGH	0.41	30.00	15.81	11.07
	5.00	CRS2	77.00	HIGH	0.41	30.00	6.32	
CRS2-170-9-60-10(	5.00	CRS2	77.00	HIGH	0.41	60.00	21.08	17.57
	5.00	CRS2	77.00	HIGH	0.41	60.00	14.05	
CRS2-170-13-15-10	5.00	CRS2	77.00	HIGH	0.59	15.00	4.57	4.39
	5.00	CRS2	77.00	HIGH	0.59	15.00	4.22	
CRS2-170-13-30-10	5.00	CRS2	77.00	HIGH	0.59	30.00	10.01	8.08
	5.00	CRS2	77.00	HIGH	0.59	30.00	6.15	
CRS2-170-13-60-10	5.00	CRS2	77.00	HIGH	0.59	60.00	21.61	14.49
	5.00	CRS2	77.00	HIGH	0.59	60.00	7.38	

APPENDIX B.4

DILUTED EMULSION TCED TORQUE-SHEAR STRENGTH RESULTS

Table B.4.1 Diluted Emulsion TCED Torque-shear Strength Results

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m2)	Set Time (min)	Torque (N-m)	Average Torque (N-m)	Shear Stress (kPa)	Average Shear Stress (kPa)
CSS1-75-5-15-100	5.00	CSS1	24.00	LOW	0.23	15.00	0.20	0.25	0.50	0.62
	5.00	CSS1	24.00	LOW	0.23	15.00	0.30		0.75	
CSS1-75-5-30-100	5.00	CSS1	24.00	LOW	0.23	30.00	5.20	4.70	12.93	11.69
	5.00	CSS1	24.00	LOW	0.23	30.00	4.20		10.44	
CSS1-75-5-60-100	5.00	CSS1	24.00	LOW	0.23	60.00	9.60	9.40	23.87	23.37
	5.00	CSS1	24.00	LOW	0.23	60.00	9.20		22.87	
CSS1-75-9-15-100	5.00	CSS1	24.00	LOW	0.41	15.00	0.40	0.40	0.99	0.99
	5.00	CSS1	24.00	LOW	0.41	15.00	0.40		0.99	
CSS1-75-9-30-100	5.00	CSS1	24.00	LOW	0.41	30.00	2.80	5.20	6.96	12.93
	5.00	CSS1	24.00	LOW	0.41	30.00	7.60		18.90	
CSS1-75-9-60-100	5.00	CSS1	24.00	LOW	0.41	60.00	5.60	6.65	13.92	16.53
	5.00	CSS1	24.00	LOW	0.41	60.00	7.70		19.14	
CSS1-75-13-15-100	5.00	CSS1	24.00	LOW	0.59	15.00	1.00	1.10	2.49	2.73
	5.00	CSS1	24.00	LOW	0.59	15.00	1.20		2.98	
CSS1-75-13-30-100	5.00	CSS1	24.00	LOW	0.59	30.00	1.20	2.55	2.98	6.34
	5.00	CSS1	24.00	LOW	0.59	30.00	3.90		9.70	
CSS1-75-13-60-100	5.00	CSS1	24.00	LOW	0.59	60.00	5.60	4.60	13.92	11.44
	5.00	CSS1	24.00	LOW	0.59	60.00	3.60		8.95	
CSS1-110-5-15-100	5.00	CSS1	43.00	MEDIUM	0.23	15.00	5.20	4.50	12.93	11.19
	5.00	CSS1	43.00	MEDIUM	0.23	15.00	3.80		9.45	
CSS1-110-5-30-100	5.00	CSS1	43.00	MEDIUM	0.23	30.00	5.30	5.10	13.18	12.68
	5.00	CSS1	43.00	MEDIUM	0.23	30.00	4.90		12.18	
CSS1-110-5-60-100	5.00	CSS1	43.00	MEDIUM	0.23	60.00	12.40	9.80	30.83	24.37
	5.00	CSS1	43.00	MEDIUM	0.23	60.00	7.20		17.90	
CSS1-110-9-15-100	5.00	CSS1	43.00	MEDIUM	0.41	15.00	3.00	2.30	7.46	5.72
	5.00	CSS1	43.00	MEDIUM	0.41	15.00	1.60		3.98	
CSS1-110-9-30-100	5.00	CSS1	43.00	MEDIUM	0.41	30.00	3.20	3.40	7.96	8.45
	5.00	CSS1	43.00	MEDIUM	0.41	30.00	3.60		8.95	
CSS1-110-9-60-100	5.00	CSS1	43.00	MEDIUM	0.41	60.00	8.30	7.45	20.64	18.52
	5.00	CSS1	43.00	MEDIUM	0.41	60.00	6.60		16.41	
CSS1-110-13-15-10	5.00	CSS1	43.00	MEDIUM	0.59	15.00	2.60	2.10	6.46	5.22
	5.00	CSS1	43.00	MEDIUM	0.59	15.00	1.60		3.98	
CSS1-110-13-30-10	5.00	CSS1	43.00	MEDIUM	0.59	30.00	1.10	1.70	2.73	4.23
	5.00	CSS1	43.00	MEDIUM	0.59	30.00	2.30		5.72	
CSS1-110-13-60-10	5.00	CSS1	43.00	MEDIUM	0.59	60.00	8.40	7.40	20.89	18.40
	5.00	CSS1	43.00	MEDIUM	0.59	60.00	6.40		15.91	
CSS1-150-5-15-100	5.00	CSS1	66.00	HIGH	0.23	15.00	3.30	3.85	8.20	9.57
	5.00	CSS1	66.00	HIGH	0.23	15.00	4.40		10.94	
CSS1-150-5-30-100	5.00	CSS1	66.00	HIGH	0.23	30.00	7.60	6.00	18.90	14.92
	5.00	CSS1	66.00	HIGH	0.23	30.00	4.40		10.94	
CSS1-150-5-60-100	5.00	CSS1	66.00	HIGH	0.23	60.00	5.30	5.35	13.18	13.30
	5.00	CSS1	66.00	HIGH	0.23	60.00	5.40		13.43	
CSS1-150-9-15-100	5.00	CSS1	66.00	HIGH	0.41	15.00	2.40	2.10	5.97	5.22
	5.00	CSS1	66.00	HIGH	0.41	15.00	1.80		4.48	
CSS1-150-9-30-100	5.00	CSS1	66.00	HIGH	0.41	30.00	4.20	3.70	10.44	9.20
	5.00	CSS1	66.00	HIGH	0.41	30.00	3.20		7.96	
CSS1-150-9-60-100	5.00	CSS1	66.00	HIGH	0.41	60.00	6.90	7.05	17.16	17.53
	5.00	CSS1	66.00	HIGH	0.41	60.00	7.20		17.90	
CSS1-150-13-15-10	5.00	CSS1	66.00	HIGH	0.59	15.00	1.40	1.45	3.48	3.61
	5.00	CSS1	66.00	HIGH	0.59	15.00	1.50		3.73	
CSS1-150-13-30-10	5.00	CSS1	66.00	HIGH	0.59	30.00	2.00	1.90	4.97	4.72
	5.00	CSS1	66.00	HIGH	0.59	30.00	1.80		4.48	
CSS1-150-13-60-10	5.00	CSS1	66.00	HIGH	0.59	60.00	4.40	4.90	10.94	12.18
	5.00	CSS1	66.00	HIGH	0.59	60.00	5.40		13.43	

Table B.4.1 Diluted Emulsion TCED Torque-shear Strength Results (Cont.)

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m2)	Set Time (min)	Torque (N-m)	Average Torque (N-m)	Shear Stress (kPa)	Average Shear Stress (kPa)
SS1-75-5-15-100	5.00	SS1	24.00	LOW	0.23	15.00	3.40	3.40	8.45	4.23
	5.00	SS1	24.00	LOW	0.23	15.00			0.00	
SS1-75-5-30-100	5.00	SS1	24.00	LOW	0.23	30.00	4.00	5.50	9.95	13.67
	5.00	SS1	24.00	LOW	0.23	30.00	7.00		17.40	
SS1-75-5-60-100	5.00	SS1	24.00	LOW	0.23	60.00	7.50	6.50	18.65	16.16
	5.00	SS1	24.00	LOW	0.23	60.00	5.50		13.67	
SS1-75-9-15-100	5.00	SS1	24.00	LOW	0.41	15.00	2.30	1.90	5.72	4.72
	5.00	SS1	24.00	LOW	0.41	15.00	1.50		3.73	
SS1-75-9-30-100	5.00	SS1	24.00	LOW	0.41	30.00	1.40	1.30	3.48	3.23
	5.00	SS1	24.00	LOW	0.41	30.00	1.20		2.98	
SS1-75-9-60-100	5.00	SS1	24.00	LOW	0.41	60.00	1.40	1.80	3.48	4.48
	5.00	SS1	24.00	LOW	0.41	60.00	2.20		5.47	
SS1-75-13-15-100	5.00	SS1	24.00	LOW	0.59	15.00	1.60	1.50	3.98	3.73
	5.00	SS1	24.00	LOW	0.59	15.00	1.40		3.48	
SS1-75-13-30-100	5.00	SS1	24.00	LOW	0.59	30.00	1.80	1.70	4.48	4.23
	5.00	SS1	24.00	LOW	0.59	30.00	1.60		3.98	
SS1-75-13-60-100	5.00	SS1	24.00	LOW	0.59	60.00	2.20	1.95	5.47	4.85
	5.00	SS1	24.00	LOW	0.59	60.00	1.70		4.23	
SS1-110-5-15-100	5.00	SS1	43.00	MEDIUM	0.23	15.00	1.60	3.00	3.98	7.46
	5.00	SS1	43.00	MEDIUM	0.23	15.00	4.40		10.94	
SS1-110-5-30-100	5.00	SS1	43.00	MEDIUM	0.23	30.00	5.40	7.00	13.43	17.40
	5.00	SS1	43.00	MEDIUM	0.23	30.00	8.60		21.38	
SS1-110-5-60-100	5.00	SS1	43.00	MEDIUM	0.23	60.00	9.40	10.30	23.37	25.61
	5.00	SS1	43.00	MEDIUM	0.23	60.00	11.20		27.85	
SS1-110-9-15-100	5.00	SS1	43.00	MEDIUM	0.41	15.00	1.50	1.65	3.73	4.10
	5.00	SS1	43.00	MEDIUM	0.41	15.00	1.80		4.48	
SS1-110-9-30-100	5.00	SS1	43.00	MEDIUM	0.41	30.00	1.60	1.45	3.98	3.61
	5.00	SS1	43.00	MEDIUM	0.41	30.00	1.30		3.23	
SS1-110-9-60-100	5.00	SS1	43.00	MEDIUM	0.41	60.00	1.70	1.65	4.23	4.10
	5.00	SS1	43.00	MEDIUM	0.41	60.00	1.60		3.98	
SS1-110-13-15-100	5.00	SS1	43.00	MEDIUM	0.59	15.00	1.50	1.65	3.73	4.10
	5.00	SS1	43.00	MEDIUM	0.59	15.00	1.80		4.48	
SS1-110-13-30-100	5.00	SS1	43.00	MEDIUM	0.59	30.00	1.60	1.75	3.98	4.35
	5.00	SS1	43.00	MEDIUM	0.59	30.00	1.90		4.72	
SS1-110-13-60-100	5.00	SS1	43.00	MEDIUM	0.59	60.00	1.30	1.65	3.23	4.10
	5.00	SS1	43.00	MEDIUM	0.59	60.00	2.00		4.97	
SS1-150-5-15-100	5.00	SS1	66.00	HIGH	0.23	15.00	2.20	3.05	5.47	7.58
	5.00	SS1	66.00	HIGH	0.23	15.00	3.90		9.70	
SS1-150-5-30-100	5.00	SS1	66.00	HIGH	0.23	30.00	2.80	4.55	6.96	11.31
	5.00	SS1	66.00	HIGH	0.23	30.00	6.30		15.66	
SS1-150-5-60-100	5.00	SS1	66.00	HIGH	0.23	60.00	11.70	11.45	29.09	28.47
	5.00	SS1	66.00	HIGH	0.23	60.00	11.20		27.85	
SS1-150-9-15-100	5.00	SS1	66.00	HIGH	0.41	15.00	1.90	1.70	4.72	4.23
	5.00	SS1	66.00	HIGH	0.41	15.00	1.50		3.73	
SS1-150-9-30-100	5.00	SS1	66.00	HIGH	0.41	30.00	3.20	2.80	7.96	6.96
	5.00	SS1	66.00	HIGH	0.41	30.00	2.40		5.97	
SS1-150-9-60-100	5.00	SS1	66.00	HIGH	0.41	60.00	6.00	6.25	14.92	15.54
	5.00	SS1	66.00	HIGH	0.41	60.00	6.50		16.16	
SS1-150-13-15-100	5.00	SS1	66.00	HIGH	0.59	15.00	1.20	1.35	2.98	3.36
	5.00	SS1	66.00	HIGH	0.59	15.00	1.50		3.73	
SS1-150-13-30-100	5.00	SS1	66.00	HIGH	0.59	30.00	1.20	1.60	2.98	3.98
	5.00	SS1	66.00	HIGH	0.59	30.00	2.00		4.97	
SS1-150-13-60-100	5.00	SS1	66.00	HIGH	0.59	60.00	5.80	5.40	14.42	13.43
	5.00	SS1	66.00	HIGH	0.59	60.00	5.00		12.43	

Table B.4.1 Diluted Emulsion TCED Torque-shear Strength Results (Cont.)

Study Combination	Contact Plate Diameter (in)	Tack Coat Type	Temperature (C)	Temperature Level	Application Rate (L/m2)	Set Time (min)	Torque (N-m)	Average Torque (N-m)	Shear Stress (kPa)	Average Shear Stress (kPa)
CRS2-120-5-15-100	5.00	CRS2	49.00	LOW	0.23	15.00	7.50	7.65	18.65	19.02
	5.00	CRS2	49.00	LOW	0.23	15.00	7.80		19.39	
CRS2-120-5-30-100	5.00	CRS2	49.00	LOW	0.23	30.00	5.70	7.55	14.17	18.77
	5.00	CRS2	49.00	LOW	0.23	30.00	9.40		23.37	
CRS2-120-5-60-100	5.00	CRS2	49.00	LOW	0.23	60.00	11.40	10.15	28.34	25.24
	5.00	CRS2	49.00	LOW	0.23	60.00	8.90		22.13	
CRS2-120-9-15-100	5.00	CRS2	49.00	LOW	0.41	15.00	2.30	2.65	5.72	6.59
	5.00	CRS2	49.00	LOW	0.41	15.00	3.00		7.46	
CRS2-120-9-30-100	5.00	CRS2	49.00	LOW	0.41	30.00	7.20	6.20	17.90	15.42
	5.00	CRS2	49.00	LOW	0.41	30.00	5.20		12.93	
CRS2-120-9-60-100	5.00	CRS2	49.00	LOW	0.41	60.00	11.60	12.20	28.84	30.33
	5.00	CRS2	49.00	LOW	0.41	60.00	12.80		31.83	
CRS2-120-13-15-10	5.00	CRS2	49.00	LOW	0.59	15.00	2.60	2.40	6.46	5.97
	5.00	CRS2	49.00	LOW	0.59	15.00	2.20		5.47	
CRS2-120-13-30-10	5.00	CRS2	49.00	LOW	0.59	30.00	3.40	3.30	8.45	8.20
	5.00	CRS2	49.00	LOW	0.59	30.00	3.20		7.96	
CRS2-120-13-60-10	5.00	CRS2	49.00	LOW	0.59	60.00	10.40	10.70	25.86	26.60
	5.00	CRS2	49.00	LOW	0.59	60.00	11.00		27.35	
CRS2-145-5-15-100	5.00	CRS2	63.00	MEDIUM	0.23	15.00	7.00	8.40	17.40	20.89
	5.00	CRS2	63.00	MEDIUM	0.23	15.00	9.80		24.37	
CRS2-145-5-30-100	5.00	CRS2	63.00	MEDIUM	0.23	30.00	6.00	7.65	14.92	19.02
	5.00	CRS2	63.00	MEDIUM	0.23	30.00	9.30		23.12	
CRS2-145-5-60-100	5.00	CRS2	63.00	MEDIUM	0.23	60.00	8.20	8.05	20.39	20.01
	5.00	CRS2	63.00	MEDIUM	0.23	60.00	7.90		19.64	
CRS2-145-9-15-100	5.00	CRS2	63.00	MEDIUM	0.41	15.00	2.50	2.40	6.22	5.97
	5.00	CRS2	63.00	MEDIUM	0.41	15.00	2.30		5.72	
CRS2-145-9-30-100	5.00	CRS2	63.00	MEDIUM	0.41	30.00	7.00	7.15	17.40	17.78
	5.00	CRS2	63.00	MEDIUM	0.41	30.00	7.30		18.15	
CRS2-145-9-60-100	5.00	CRS2	63.00	MEDIUM	0.41	60.00	12.80	11.90	31.83	29.59
	5.00	CRS2	63.00	MEDIUM	0.41	60.00	11.00		27.35	
CRS2-145-13-15-10	5.00	CRS2	63.00	MEDIUM	0.59	15.00	2.20	2.05	5.47	5.10
	5.00	CRS2	63.00	MEDIUM	0.59	15.00	1.90		4.72	
CRS2-145-13-30-10	5.00	CRS2	63.00	MEDIUM	0.59	30.00	3.60	8.20	8.95	20.39
	5.00	CRS2	63.00	MEDIUM	0.59	30.00	12.80		31.83	
CRS2-145-13-60-10	5.00	CRS2	63.00	MEDIUM	0.59	60.00	10.80	11.80	26.85	29.34
	5.00	CRS2	63.00	MEDIUM	0.59	60.00	12.80		31.83	
CRS2-170-5-15-100	5.00	CRS2	77.00	HIGH	0.23	15.00	7.80	9.40	19.39	23.37
	5.00	CRS2	77.00	HIGH	0.23	15.00	11.00		27.35	
CRS2-170-5-30-100	5.00	CRS2	77.00	HIGH	0.23	30.00	9.40	10.90	23.37	27.10
	5.00	CRS2	77.00	HIGH	0.23	30.00	12.40		30.83	
CRS2-170-5-60-100	5.00	CRS2	77.00	HIGH	0.23	60.00	12.50	8.85	31.08	22.00
	5.00	CRS2	77.00	HIGH	0.23	60.00	5.20		12.93	
CRS2-170-9-15-100	5.00	CRS2	77.00	HIGH	0.41	15.00	5.40	8.95	13.43	22.25
	5.00	CRS2	77.00	HIGH	0.41	15.00	12.50		31.08	
CRS2-170-9-30-100	5.00	CRS2	77.00	HIGH	0.41	30.00	6.80	8.45	16.91	21.01
	5.00	CRS2	77.00	HIGH	0.41	30.00	10.10		25.11	
CRS2-170-9-60-100	5.00	CRS2	77.00	HIGH	0.41	60.00	12.50	12.45	31.08	30.95
	5.00	CRS2	77.00	HIGH	0.41	60.00	12.40		30.83	
CRS2-170-13-15-10	5.00	CRS2	77.00	HIGH	0.59	15.00	1.60	2.00	3.98	4.97
	5.00	CRS2	77.00	HIGH	0.59	15.00	2.40		5.97	
CRS2-170-13-30-10	5.00	CRS2	77.00	HIGH	0.59	30.00	5.20	7.10	12.93	17.65
	5.00	CRS2	77.00	HIGH	0.59	30.00	9.00		22.38	
CRS2-170-13-60-10	5.00	CRS2	77.00	HIGH	0.59	60.00	9.30	10.45	23.12	25.98
	5.00	CRS2	77.00	HIGH	0.59	60.00	11.60		28.84	

APPENDIX B.5

PERFORMANCE GRADE BINDER TCED TENSILE STRENGTH RESULTS

Table B.5.1 Performance Grade Binder TCED Tensile Strength Results

Study Combination	Spindle Diameter (mm)	Temperature (^oC)	Application Rate (L/m^2)	Tensile Strength (kPa)	Average Tensile Strength (kPa)
PG 67-22-300-4	13	149	0.18	1844.4	1835.7
	13	149	0.18	1826.9	
PG 67-22-300-4	13	149	0.32	1725.0	1740.8
	13	149	0.32	1756.6	
PG 67-22-300-7	13	149	0.46	1703.9	1677.6
	13	149	0.46	1651.2	

APPENDIX B.6

PERFORMANCE GRADE BINDER TCED TORQUE-SHEAR

STRENGTH RESULTS

Table B.6.1 Performance Grade Binder TCED Torque-Shear Strength Results

Study Combination	Spindle Diameter (mm)	Temperature (C)	Application Rate (L/m^2)	Torque (N-m)	Average Torque (N-m)	Shear Stress (kPa)	AverageShear Stress (kPa)
PG 67-22-300-4	13	149	0.18	3.6	4.5	8950.80	11188.50
	13	149	0.18	5.4		13426.20	
PG 67-22-300-4	13	149	0.32	3.7	4.8	9199.43	11810.08
	13	149	0.32	5.8		14420.73	
PG 67-22-300-7	13	149	0.46	7.5	7.1	18647.50	17528.65
	13	149	0.46	6.6		16409.80	
PG 67-22-300-4	25	149	0.18	2.6	2.8	808.06	870.22
	25	149	0.18	3.0		932.37	
PG 67-22-300-4	25	149	0.32	3.1	3.1	963.45	947.91
	25	149	0.32	3.0		932.37	
PG 67-22-300-7	25	149	0.46	3.3	3.3	1025.61	1010.07
	25	149	0.46	3.2		994.53	

APPENDIX C.1

LBISD MAXIMUM SHEAR STRENGTH RESULTS

Table C.1.1 LBISD Maximum Shear Strength Results

Tack Material	GRADATION	Application Rate (L/m^2)	Application Rate Level	MaxLoad (kN)
CSS1	Fine	0.23	L	35.53
CSS1	Fine	0.23	L	31.97
CSS1	Fine	0.41	M	31.33
CSS1	Fine	0.41	M	32.53
CSS1	Fine	0.59	H	32.99
CSS1	Fine	0.59	H	34.97
CRS2	Fine	0.23	L	33.74
CRS2	Fine	0.23	L	36.11
CRS2	Fine	0.41	M	40.01
CRS2	Fine	0.41	M	42.59
CRS2	Fine	0.59	H	42.15
CRS2	Fine	0.59	H	41.30
SS1	Fine	0.23	L	35.91
SS1	Fine	0.23	L	41.21
SS1	Fine	0.41	M	34.91
SS1	Fine	0.41	M	40.22
SS1	Fine	0.59	H	41.78
SS1	Fine	0.59	H	42.82
PG67-22	Fine	0.18	L	36.74
PG67-22	Fine	0.18	L	42.92
PG67-22	Fine	0.32	M	42.86
PG67-22	Fine	0.32	M	42.03
PG67-22	Fine	0.45	H	45.02
PG67-22	Fine	0.45	H	40.55
CSS1	Coarse	0.23	L	36.28
CSS1	Coarse	0.23	L	39.09
CSS1	Coarse	0.41	M	39.88
CSS1	Coarse	0.41	M	34.93
CSS1	Coarse	0.59	H	38.01
CSS1	Coarse	0.59	H	41.90
CRS2	Coarse	0.23	L	36.05
CRS2	Coarse	0.23	L	36.05
CRS2	Coarse	0.41	M	35.89
CRS2	Coarse	0.41	M	33.66
CRS2	Coarse	0.59	H	32.78
CRS2	Coarse	0.59	H	36.80
SS1	Coarse	0.23	L	36.59
SS1	Coarse	0.23	L	38.53
SS1	Coarse	0.41	M	34.99
SS1	Coarse	0.41	M	35.22
SS1	Coarse	0.59	H	32.28
SS1	Coarse	0.59	H	30.39
PG67-22	Coarse	0.18	L	37.65
PG67-22	Coarse	0.18	L	41.67
PG67-22	Coarse	0.32	M	43.34
PG67-22	Coarse	0.32	M	44.23
PG67-22	Coarse	0.45	H	41.28
PG67-22	Coarse	0.45	H	41.24

APPENDIX C.2

LBISD REACTION INDEX RESULTS

Table C.2.1 LBISD Reaction Index Results

Tack Material	GRADATION	Application Rate (L/m^2)	Application Rate Level	MaxLoad (kN)	Displacement At Max Load (mm)	Reaction Index (kN/mm)
CSS1	Fine	0.23	L	35.53	3.94	9.03
CSS1	Fine	0.23	L	31.97	4.42	7.23
CSS1	Fine	0.41	M	31.33	3.76	8.33
CSS1	Fine	0.41	M	32.53	3.99	8.16
CSS1	Fine	0.59	H	32.99	3.99	8.27
CSS1	Fine	0.59	H	34.97	4.04	8.66
CRS2	Fine	0.23	L	33.74	3.35	10.06
CRS2	Fine	0.23	L	36.11	3.53	10.23
CRS2	Fine	0.41	M	40.01	3.96	10.10
CRS2	Fine	0.41	M	42.59	3.99	10.68
CRS2	Fine	0.59	H	42.15	4.27	9.88
CRS2	Fine	0.59	H	41.30	4.17	9.91
SS1	Fine	0.23	L	35.91	3.12	11.49
SS1	Fine	0.23	L	41.21	3.86	10.68
SS1	Fine	0.41	M	34.91	4.57	7.63
SS1	Fine	0.41	M	40.22	4.83	8.33
SS1	Fine	0.59	H	41.78	4.80	8.70
SS1	Fine	0.59	H	42.82	3.89	11.02
PG67-22	Fine	0.18	L	36.74	3.23	11.39
PG67-22	Fine	0.18	L	42.92	4.29	10.00
PG67-22	Fine	0.32	M	42.86	4.19	10.23
PG67-22	Fine	0.32	M	42.03	5.18	8.11
PG67-22	Fine	0.45	H	45.02	3.78	11.90
PG67-22	Fine	0.45	H	40.55	4.01	10.10
CSS1	Coarse	0.23	L	36.28	4.72	7.68
CSS1	Coarse	0.23	L	39.09	4.37	8.95
CSS1	Coarse	0.41	M	39.88	4.24	9.40
CSS1	Coarse	0.41	M	34.93	4.75	7.35
CSS1	Coarse	0.59	H	38.01	4.09	9.29
CSS1	Coarse	0.59	H	41.90	3.81	11.00
CRS2	Coarse	0.23	L	36.05	4.47	8.06
CRS2	Coarse	0.23	L	36.05	4.17	8.65
CRS2	Coarse	0.41	M	35.89	3.89	9.23
CRS2	Coarse	0.41	M	33.66	4.22	7.98
CRS2	Coarse	0.59	H	32.78	4.09	8.02
CRS2	Coarse	0.59	H	36.80	4.17	8.83
SS1	Coarse	0.23	L	36.59	4.93	7.43
SS1	Coarse	0.23	L	38.53	4.06	9.48
SS1	Coarse	0.41	M	34.99	4.45	7.87
SS1	Coarse	0.41	M	35.22	4.65	7.58
SS1	Coarse	0.59	H	32.28	3.96	8.15
SS1	Coarse	0.59	H	30.39	3.99	7.62
PG67-22	Coarse	0.18	L	37.65	3.73	10.08
PG67-22	Coarse	0.18	L	41.67	3.94	10.58
PG67-22	Coarse	0.32	M	43.34	4.17	10.40
PG67-22	Coarse	0.32	M	44.23	4.14	10.68
PG67-22	Coarse	0.45	H	41.28	4.42	9.34
PG67-22	Coarse	0.45	H	41.24	4.60	8.97

APPENDIX D

EMULSION MASS LOSS RESULTS

Table D.1 Emulsion Mass Loss Results (% Moisture)*

Emulsion Type			SS1					
Application Rate			0.05		0.09		0.13	
Time			Trial					
Seconds	Minutes	Hours	1	2	1	2	1	2
0	0.00	0.000	33.696	34.483	32.497	32.643	33.128	33.167
15	0.25	0.004	33.551	34.483	32.497	32.643	33.069	33.111
30	0.50	0.008	33.551	34.341	32.416	32.561	33.011	33.055
45	0.75	0.013	33.551	34.199	32.335	32.479	32.952	32.999
60	1.00	0.017	33.406	34.056	32.254	32.479	32.892	32.943
75	1.25	0.021	33.406	33.913	32.254	32.396	32.892	32.943
90	1.50	0.025	33.260	33.769	32.173	32.313	32.833	32.831
105	1.75	0.029	33.114	33.769	32.091	32.313	32.774	32.831
120	2.00	0.033	32.819	33.624	32.091	32.230	32.714	32.775
180	3.00	0.050	32.373	33.333	31.846	31.980	32.535	32.548
240	4.00	0.067	31.920	32.892	31.598	31.813	32.295	32.321
300	5.00	0.083	31.614	32.594	31.432	31.559	32.114	32.149
360	6.00	0.100	31.151	32.294	31.181	31.390	31.932	31.976
420	7.00	0.117	30.839	31.839	31.013	31.133	31.749	31.803
480	8.00	0.133	30.365	31.532	30.845	30.961	31.626	31.628
540	9.00	0.150	30.046	31.222	30.675	30.788	31.441	31.453
600	10.00	0.167	29.561	30.909	30.504	30.615	31.256	31.277
660	11.00	0.183	29.070	30.594	30.333	30.440	31.131	31.159
720	12.00	0.200	28.738	30.115	30.074	30.265	30.944	30.981
780	13.00	0.217	28.404	29.954	29.901	30.088	30.818	30.802
840	14.00	0.233	28.066	29.630	29.726	29.911	30.629	30.623
900	15.00	0.250	27.725	29.138	29.551	29.733	30.502	30.503
1200	20.00	0.333	25.971	27.619	28.752	28.829	29.732	29.772
1500	25.00	0.417	24.318	25.854	27.934	27.995	28.945	29.089
1800	30.00	0.500	22.589	24.190	27.191	27.237	28.208	28.457
3600	60.00	1.000	11.850	16.022	22.390	22.331	24.354	24.836
7200	120.00	2.000	2.866	6.173	11.856	11.378	15.632	15.756
14400	240.00	4.000	2.556	5.296	0.528	0.540	2.561	2.552
18000	300.00	5.000	5.280	5.000	1.568	0.360	2.185	2.195
21600	360.00	6.000	5.280	5.000	1.396	0.540	2.059	1.956
25200	420.00	7.000	4.984	4.702	1.396	0.181	1.933	1.956
28800	480.00	8.000	4.688	4.403	1.224	0.000	1.806	1.836
32400	540.00	9.000	4.389	4.403	1.224	1.426	1.680	1.716
36000	600.00	10.000	4.389	4.101	1.051	1.950	1.680	1.595
39600	660.00	11.000	4.088	4.101	1.051	1.776	1.425	1.595
43200	720.00	12.000	4.088	1.299	0.877	1.601	0.653	0.496
46800	780.00	13.000	3.785	0.328	0.877	1.426	0.131	0.249
50400	840.00	14.000	3.785	1.299	0.877	1.250	0.393	0.496
54000	900.00	15.000	3.785	1.618	0.877	1.073	0.911	1.110
57600	960.00	16.000	0.000	2.251	0.703	1.073	1.040	1.353

*Condensed for space

Table D.1 Emulsion Mass Loss Results (% Moisture) [Cont.] *

Emulsion Type			CSS1					
Application Rate			0.05		0.09		0.13	
Time			Trial					
Seconds	Minutes	Hours	1	2	1	2	1	2
0	0.00	0.000	34.821	34.110	36.343	35.006	36.653	34.134
15	0.25	0.004	34.821	34.110	36.270	35.006	36.601	34.080
30	0.50	0.008	34.676	33.970	36.270	34.932	36.549	34.025
45	0.75	0.013	34.529	33.830	36.197	34.857	36.498	33.970
60	1.00	0.017	34.382	33.689	36.197	34.783	36.446	33.915
75	1.25	0.021	34.382	33.689	36.124	34.708	36.446	33.915
90	1.50	0.025	34.086	33.547	36.124	34.633	36.393	33.860
105	1.75	0.029	33.937	33.405	36.051	34.558	36.341	33.805
120	2.00	0.033	33.937	33.405	35.977	34.558	36.289	33.805
180	3.00	0.050	33.485	32.974	35.755	34.256	36.132	33.639
240	4.00	0.067	33.028	32.684	35.532	34.028	35.921	33.473
300	5.00	0.083	32.564	32.391	35.383	33.798	35.762	33.361
360	6.00	0.100	32.093	31.947	35.157	33.566	35.602	33.249
420	7.00	0.117	31.776	31.498	35.006	33.333	35.441	33.081
480	8.00	0.133	31.294	31.195	34.778	33.177	35.279	32.968
540	9.00	0.150	30.969	30.889	34.624	32.941	35.171	32.855
600	10.00	0.167	30.476	30.425	34.393	32.704	35.008	32.684
660	11.00	0.183	30.144	30.112	34.238	32.544	34.899	32.570
720	12.00	0.200	29.808	29.797	34.083	32.384	34.790	32.455
780	13.00	0.217	29.469	29.478	33.926	32.143	34.680	32.340
840	14.00	0.233	29.126	28.995	33.769	31.981	34.570	32.225
900	15.00	0.250	28.780	28.670	33.611	31.818	34.459	32.109
1200	20.00	0.333	27.000	26.995	32.892	30.993	33.845	31.583
1500	25.00	0.417	25.510	25.420	32.238	30.061	33.333	30.990
1800	30.00	0.500	23.958	23.775	31.488	29.280	32.872	30.507
3600	60.00	1.000	14.370	13.611	27.190	24.303	30.090	27.464
7200	120.00	2.000	3.311	0.955	18.448	14.286	24.293	21.131
14400	240.00	4.000	1.684	0.639	4.131	2.896	10.907	7.558
18000	300.00	5.000	4.575	0.955	3.800	2.564	4.079	1.852
21600	360.00	6.000	4.886	0.955	3.130	2.397	0.513	0.126
25200	420.00	7.000	4.575	0.321	2.792	2.397	0.129	0.873
28800	480.00	8.000	4.262	3.115	4.296	2.230	0.129	1.119
32400	540.00	9.000	3.947	3.115	4.296	2.230	1.146	0.996
36000	600.00	10.000	3.947	2.813	4.131	2.062	1.146	0.873
39600	660.00	11.000	3.630	2.508	4.131	2.062	1.020	0.873
43200	720.00	12.000	3.311	2.508	3.966	1.893	1.020	0.873
46800	780.00	13.000	3.311	2.508	3.966	1.724	0.894	0.749
50400	840.00	14.000	3.311	2.201	3.966	1.554	0.894	0.749
54000	900.00	15.000	3.311	2.201	3.800	0.000	0.767	0.749
57600	960.00	16.000	0.000	2.201	3.800	0.350	0.767	0.625

*Condensed for Space

Table D.1 Emulsion Mass Loss Results (% Moisture) [Cont.]*

Emulsion Type			**CRS2**					
Application Rate			**0.05**		**0.09**		**0.13**	
Time			**Trial**					
Seconds	**Minutes**	**Hours**	**1**	**2**	**1**	**2**	**1**	**2**
0	0.00	0.000	33.268	32.731	32.980	32.816	31.709	31.499
15	0.25	0.004	33.268	32.579	32.980	32.736	31.653	31.499
30	0.50	0.008	33.136	32.426	32.901	32.656	31.653	31.499
45	0.75	0.013	33.004	32.426	32.822	32.575	31.596	31.441
60	1.00	0.017	33.004	32.273	32.742	32.494	31.540	31.441
75	1.25	0.021	32.871	32.118	32.663	32.413	31.540	31.383
90	1.50	0.025	32.871	31.963	32.583	32.413	31.483	31.383
105	1.75	0.029	32.738	31.963	32.583	32.332	31.426	31.324
120	2.00	0.033	32.470	31.808	32.503	32.250	31.369	31.266
180	3.00	0.050	32.064	31.494	32.181	32.005	31.198	31.149
240	4.00	0.067	31.653	31.019	32.019	31.840	31.083	31.032
300	5.00	0.083	31.377	30.536	31.693	31.592	30.968	30.914
360	6.00	0.100	30.957	30.211	31.446	31.341	30.795	30.736
420	7.00	0.117	30.675	29.717	31.280	31.174	30.621	30.617
480	8.00	0.133	30.247	29.384	31.030	30.920	30.504	30.498
540	9.00	0.150	29.959	28.878	30.863	30.665	30.387	30.379
600	10.00	0.167	29.522	28.537	30.610	30.494	30.211	30.259
660	11.00	0.183	29.228	28.019	30.355	30.322	30.093	30.138
720	12.00	0.200	28.931	27.845	30.184	30.149	29.915	30.017
780	13.00	0.217	28.632	27.317	29.926	29.888	29.737	29.896
840	14.00	0.233	28.330	26.961	29.753	29.713	29.617	29.713
900	15.00	0.250	28.025	26.601	29.579	29.537	29.497	29.591
1200	20.00	0.333	26.304	24.937	28.518	28.553	28.768	29.035
1500	25.00	0.417	24.667	23.196	27.516	27.448	28.087	28.344
1800	30.00	0.500	23.129	21.164	26.486	26.501	27.520	27.703
3600	60.00	1.000	13.959	9.422	19.859	20.142	23.567	24.109
7200	120.00	2.000	3.966	0.997	7.178	8.007	14.830	16.855
14400	240.00	4.000	4.507	0.334	2.401	1.573	2.706	2.177
18000	300.00	5.000	5.042	0.334	1.386	1.401	2.130	1.701
21600	360.00	6.000	4.507	0.667	0.871	0.880	1.781	1.341
25200	420.00	7.000	4.507	0.334	0.698	0.705	1.313	1.100
28800	480.00	8.000	4.237	0.334	0.524	0.530	0.958	0.858
32400	540.00	9.000	4.237	0.667	0.524	0.530	0.839	0.736
36000	600.00	10.000	4.237	0.334	0.524	0.354	0.601	0.492
39600	660.00	11.000	3.966	0.334	0.524	0.177	0.601	0.369
43200	720.00	12.000	3.966	0.334	0.524	0.530	0.361	0.369
46800	780.00	13.000	3.966	1.325	0.524	0.705	0.121	0.247
50400	840.00	14.000	3.693	1.325	0.350	1.054	0.121	0.123
54000	900.00	15.000	1.453	0.334	0.175	1.228	0.481	0.123
57600	960.00	16.000	0.294	1.650	0.175	1.054	0.241	0.000

*Condensed for Space

Table D.2 Emulsion Evaporation Rate Data

Emulsion Type	Application Rate (L/m^2)	Original % Moisture	% Moisture at end of linear behavior	Time at end of linear behavior (h)	Evaporation rate (% Moisture / Hour)
SS-1	0.23	33.70	7.30	1.25	21.12
SS-1	0.23	34.48	7.60	1.62	16.63
SS-1	0.41	32.50	6.77	2.48	10.38
SS-1	0.41	32.64	5.95	2.49	10.73
SS-1	0.59	33.13	5.70	3.14	8.74
SS-1	0.59	33.17	4.30	3.34	8.64
CSS-1	0.23	34.82	9.03	1.33	19.46
CSS-1	0.23	34.11	7.72	1.29	20.43
CSS-1	0.41	36.34	8.84	3.07	8.96
CSS-1	0.41	35.01	9.95	2.45	10.23
CSS-1	0.59	36.65	5.94	4.71	6.52
CSS-1	0.59	34.13	6.69	4.12	6.66
CRS-2	0.23	33.27	7.38	1.39	18.60
CRS-2	0.23	32.73	5.99	1.18	22.76
CRS-2	0.41	32.98	7.18	2.00	12.88
CRS-2	0.41	32.82	7.10	2.08	12.37
CRS-2	0.59	31.71	8.92	2.66	8.56
CRS-2	0.59	31.50	5.60	3.31	7.83

APPENDIX E

ANALYSIS OF EMULSION MASS LOSS DATA

Table E.1 Analysis of Emulsion Breaking Mass Loss Data

Emulsion	Desired Application Rate (L/m^2)	Actual Application Rate (L/m^2)	Visual Break Time (min)	% Moisture When Broken
SS1	0.226	0.255	87	3.27
SS1	0.226	0.240	72	4.64
SS1	0.226	0.230	88	4.87
SS1	0.407	0.395	105	3.39
SS1	0.407	0.434	112	3.03
SS1	0.407	0.408	125	2.52
SS1	0.589	0.634	172	3.00
SS1	0.589	0.583	149	3.13
SS1	0.589	0.590	148	3.59

APPENDIX F

ANALYSIS OF EMULSION BREAKING TCED RESULTS

Table F.1 Analysis of Emulsion Breaking TCED Tensile Results

Application Rate (gal/yd^2)	Breaking Level	Break Time (min)	Tensile Strength (kPa)
0.05	t_0	7.0	19.75
0.05	t_0	3.0	16.46
0.05	$t_{1/2}$	25.5	69.13
0.05	$t_{1/2}$	25.5	119.61
0.05	t_{FULL}	47.5	102.05
0.05	t_{FULL}	53.5	79.01
0.05	$t_{FULL+10}$	48.5	72.42
0.05	$t_{FULL+10}$	49.5	59.26
0.09	t_0	26.0	48.28
0.09	t_0	27.0	62.55
0.09	$t_{1/2}$	83.0	138.26
0.09	$t_{1/2}$	84.5	125.10
0.09	t_{FULL}	112.5	179.96
0.09	t_{FULL}	119.0	151.43
0.09	$t_{FULL+10}$	116.0	164.60
0.09	$t_{FULL+10}$	124.0	175.57
0.13	t_0	54.0	61.45
0.13	t_0	54.5	68.03
0.13	$t_{1/2}$	89.5	138.26
0.13	$t_{1/2}$	94.5	89.98
0.13	t_{FULL}	106.0	153.63
0.13	t_{FULL}	127.0	161.31
0.13	$t_{FULL+10}$	133.5	160.21
0.13	$t_{FULL+10}$	147.0	155.82

Table F.2 Analysis of Emulsion Breaking TCED Torque-shear Results

Application Rate (gal/yd^2)	Breaking Level	Break Time (min)	Torque - shear Strength (kPa)
0.05	t_0	7.0	15.54
0.05	t_0	3.0	7.77
0.05	$t_{1/2}$	25.5	81.58
0.05	$t_{1/2}$	25.5	69.93
0.05	t_{FULL}	47.5	93.24
0.05	t_{FULL}	53.5	132.09
0.05	$t_{FULL + 10}$	48.5	77.70
0.05	$t_{FULL + 10}$	49.5	116.55
0.09	t_0	26.0	54.39
0.09	t_0	27.0	42.73
0.09	$t_{1/2}$	83.0	85.47
0.09	$t_{1/2}$	84.5	112.66
0.09	t_{FULL}	112.5	128.20
0.09	t_{FULL}	119.0	132.09
0.09	$t_{FULL + 10}$	116.0	213.67
0.09	$t_{FULL + 10}$	124.0	139.86
0.13	t_0	54.0	77.70
0.13	t_0	54.5	23.31
0.13	$t_{1/2}$	89.5	66.04
0.13	$t_{1/2}$	94.5	85.47
0.13	t_{FULL}	106.0	69.93
0.13	t_{FULL}	127.0	85.47
0.13	$t_{FULL + 10}$	133.5	128.20
0.13	$t_{FULL + 10}$	147.0	116.55

APPENDIX G

RECOMMENDED TACK COAT EVALUATION DEVICE (TCED) TEST METHOD

RECOMMENDED TACK COAT EVALUATION DEVICE (TCED) TEST METHOD

1. SCOPE

1.1 This method covers a procedure and apparatus for evaluating the strength of asphalt tack coat applications by determining either the maximum perpendicular tensile load or the maximum torque-shear value required to separate two flat aluminum test surfaces bonded with tack coat.

2. REFERENCED DOCUMENTS

2.1 ASTM D 4541 Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

3. SUMMARY OF TEST METHOD

3.1 The general tack coat evaluation test is performed by securing a loading fixture to a smooth flat aluminum testing surface on which tack coat has been applied, and compressing the specimen with a smooth flat circular contact plate. After compressing the tack coat specimen for a specified time, tack coat strength is determined either by determining the maximum perpendicular tensile load or the maximum torque-shear value required to separate the two flat aluminum surfaces bonded with tack coat. Tensile strength is computed based on the maximum tensile load and the contact plate surface area, and torque-shear strength computed based on the torque value required to separate the two surfaces bonded with tack coat.

4. SIGNIFICANCE AND USE

4.1 Asphalt tack coats are applied during pavement construction to help ensure bond between pavement layers. This test method serves as a means for evaluating tack coat applications and their ability to develop a bond between two smooth flat aluminum surfaces.

5. APPARATUS

5.1 *Test Plate*, flat smooth metal surface large enough to provide a surface for tack coat application.

5.2 *Contact Plate*, flat smooth circular metal surface of known diameter. Contact plate diameter should be consistent for comparison of results.

5.3 *Force Gauge*, capable of indicating the maximum force exhibited on the specimen perpendicular (normal) to the test plate, in both compression and tension. Gauge must have a capacity large enough to withstand anticipated loading and be accurate to at least 2 N (0.5 lb).

5.4 *Torque-gauge*, capable of indicating the maximum torque force required to shear the tack coat specimen. Gauge must have a capacity large enough to withstand anticipated loading and be accurate to at least 0.2 N-m or 1.0 in-lb.

NOTE – A suggested test device, Instrotek®, Inc.'s ATacker™, is provided in Figure 3.2.

6. TEST PREPARATION

6.1 The method for selecting the tack coat materials, application rates, and application temperatures depends on the test objectives. If the tack coat to be tested is an asphalt emulsion, dilution rates and set times should also be selected based on the test objectives.

6.2 Both the test plate and contact plate should be cleaned with water prior to testing to ensure that no residue from previous tests or cleaning remain on either surface.

6.3 Once a tack coat material, application rate, and application temperature have been selected, tack coat samples should be obtained for heating.

6.4 Once samples have reached the desired application temperature, tack coat should be applied to the test surface evenly in a circular pattern of diameter equivalent to the contact plate diameter, as shown in Figure G.1.

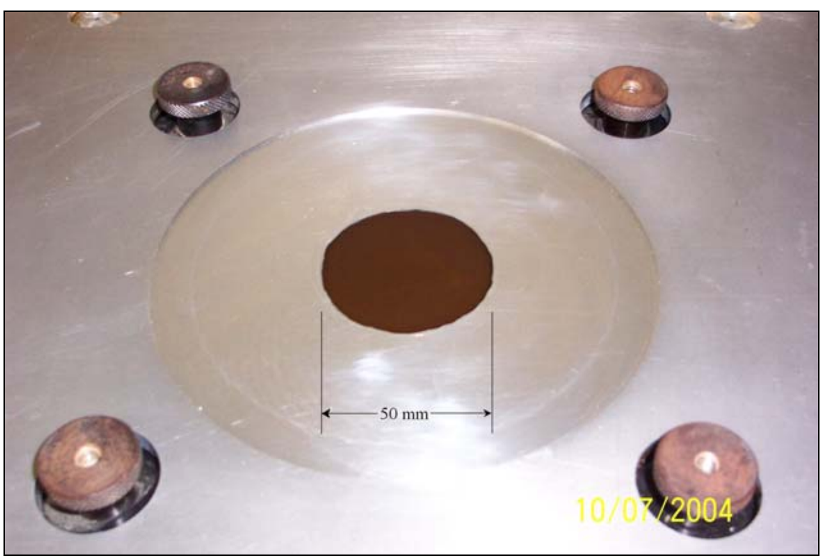

Figure G.1 TCED Test Specimen

6.5 The volume of tack coat required for specimens can be determined based on the desired application rate and the contact plate area.

7. TEST PROCEDURE

7.1 Place the fixture with attached contact plate over the test plate so that the contact plate is lined up with the tack coat specimen of equivalent diameter and the test plate and contact plate are parallel to one another.

7.2 Lower the contact plate until it comes in contact with the tack coat specimen and increase loading up to 178 N (40 lbf) of compressive force.

7.3 Wait 60 seconds prior to testing.

7.4 It must be predetermined whether the specimen is to be tested for tensile or torque-shear strength.

7.4.1 *Tensile strength testing*. The contact plate should be removed from the test specimen and test plate in a direction perpendicular to the test plate and the tensile force required to break the bond between the two surfaces should be recorded. The maximum tensile force required to separate the two surfaces should be recorded as the tensile value.

7.4.2 *Torque-shear testing*. The compression between the two surfaces should be reduced until no compressive force is being exerted on the specimen, without separating the test surface and the contact plate.

7.4.3 The contact plate should be rotated until the bond between the test surface and the contact plate is broken and the maximum torque value from the torque gauge should be recorded.

8. CALCULATION OF RESULTS

8.1 Compute the maximum tensile strength as follows:

$$X = 4\ F_T / \pi\ d^2$$

where:

X = maximum tensile strength, Pa (psi)

F_T = maximum tensile value obtained from testing, N (lbf)

d = diameter of the contact plate, units of mm or in

8.2 Compute the maximum torque-shear strength as follows:

$$Y = T*\rho / J$$

where:

Y = maximum torque-shear strength, Pa (psi)

T = maximum torque value obtained from testing, N-m (lb-in)

J = polar moment of inertia, $\pi R^4/2$, m^4 (in^4)

ρ = distance from turning axis = R = radius of the contact plate, m (in)