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EVALUATION OF A MODIFICATION OF CURRENT MICRO-SURFACING MIX DESIGN PROCEDURES

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EVALUATION OF A MODIFICATION OF CURRENT MICRO-SURFACING MIX DESIGN PROCEDURES

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RÉSUME

Cette etude porte sur la modification des procedures de formulation de la *International Slurry Surfacing Association (ISSA)* pour les traitements de surface. Les procédures actuelles de formulation de traitement de surface ont été évaluées en détails. La première partie de ce travail démontre l'effet de la quantité d'émulsion, d'eau d'apport et de l'utilisation d'additifs (ciment) sur les paramètres de formulation des traitements de surface. La deuxième partie consiste principalement en l'établissement d'une méthode de formulation optimale selon quatre essais de l'*ISSA*, soit le TB 139, le TB 113, le TB 100 et le TB 109. Les résultats ont montrés que le TB 139 peut être utilisé pour trouver la teneur en eau optimale et que l'essai ISSA TB 147 devrait être utilisé pour trouver la teneur en émulsion optimale.

Mots clés : Entretien des chaussées, méthode de formulation, émulsion de bitume, traitement de surface

EVALUATION OF A MODIFICATION OF CURRENT MICRO-SURFACING MIX DESIGN PROCEDURES

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ABSTRACT

Although Micro-surfacing is widely used, current tests and mix design methods mostly rely on laboratory condition and the correlation between laboratory results and field performance is poor. Therefore, there is a need to develop new mix design procedures, specifications, and guidelines for Micro-surfacing. The research described in this thesis intended to review the current mix design procedures for Slurry Seal and Micro-surfacing and suggest modifications to the actual International Slurry Seal Association (ISSA) mix design procedure for micro-surfacing as a high performance surface treatment and pavement preservation method. The first part of study reports the findings of a detailed laboratory investigation concerning the effect of asphalt emulsion, added water content, and the use of additives (Portland cement) on the design parameters and properties of micro-surfacing mixtures. For this, one aggregate type, one asphalt emulsion type/grade, and one aggregate gradation were used in the study. The evaluation was conducted at one curing stages of the mix (24-Hours). Three levels of asphalt emulsion, four levels of added water content, and one level of Portland cement were used in order to evaluate role of asphalt emulsion, water, and cement. This part of study consisted mainly of establishing a method for preparing and testing micro-surfacing mixture using four main mixture design tests proposed by the ISSA (TB 139, TB 113, TB 100, and TB 109). The results obtained with ISSA TB 109 and ISSA TB 100 mixture design tests were found highly variable and not precise enough to suggest optimum mix design. For the second part of this study, different tests were also studied in order to refine the current mix design procedure. The results have shown that ISSA TB 139 can be used to define the optimum water content at which samples should be tested, and that ISSA TB 147 mix design test should be used to define the optimum asphalt emulsion content.

Keywords: pavement preservation, surface maintenance, micro-surfacing, asphalte mulsion

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INTRODUCTION

Roads are an essential component of Quebec's economy as they ensure the movement of passengers and goods. Road Transport plays an important role in the economy of Quebec’s province and provides the basic infrastructure for bringing the majority of the people who are living in far off villages into the mainstream of life by connecting them with the rest of the province. Quebec's road network includes approximately 185 000 kilometers of roads. Quebec Ministry of Transportation (MTQ) manages some 29 000 kilometers of freeways (commonly known in Quebec as autoroutes), national highways (Quebec's primary highways), regional highways (Quebec's secondary highways) and collector roads, as well as 4 700 bridges and overpasses, 1 200 kilometers of resource access roads and 3 600 kilometers of mining roads. The gross replacement cost of the road infrastructures under the MTQ’s responsibility is estimated at over $30 billion for the entire province .

Pavement preservation is defined as a program employing a network-level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety, and meet motorist expectations (FHWA, 2005). Actions used for pavement preservation include routine maintenance, preventive maintenance (PM), and corrective maintenance (Uzarowski et Bashir, 2007). Transportation agencies use chip seal, slurry seal, micro-surfacing, cape seal, fog seal, etc.

Slurry seal is a pavement coating that consists of fine and hundred percent crushed aggregates, emulsified asphalt and water which is applied to roadway. Slurry seals were developed and used for the first time in Germany, in the late 1920’s (International Slurry Surfacing Association, 2011). At that time, the product consisted of a mixture of very fine aggregates, asphalt binder, and water, and was mixed by introducing the components into a tank outfitted with an agitator. It proved to be a novel approach, a new and promising technique for maintaining road surfaces, and marked the beginning of slurry seal development. However, it was not until the 1960’s, with the introduction of improved emulsifiers and continuous flow machines, that real interest was shown in the usage of slurry seal as a maintenance treatment for a wide variety of applications (International Slurry Surfacing Association, 2011). Slurry seal can be used on the new pavements of both low and high volume roads and even airports runways and taxiways. It also can be used on parking areas and bike paths. However, one of the important applications of slurry seal is to form cape seal. Cape seal is a layer of chip seal which is followed by slurry seal or micro-surfacing and resulted in a high pavement delineation and preventative maintenance method (International Slurry Surfacing Association, 2011).

Micro-surfacing was developed in an attempt to form a thicker slurry seal that could be used in wheel paths and ruts in order to avoid long rehabilitation work on high traffic roads. To do this, high quality aggregates and advances emulsions were incorporated in order to reach a stable product which is applied in malty-stone thickness and provide rutting resistance. Micro-surfacing was pioneered also in Germany, in the late 1960's and early 1970's (International Slurry Surfacing Association, 2011). Micro-surfacing was the result of combining highly selected aggregates and bitumen, and then incorporating special polymers and emulsifiers that allowed the product to remain stable even when applied in multi-stone thicknesses. Micro-surfacing was introduced in the United States in 1980, as a cost-effective way to treat the surface wheel-rutting problem and a variety of other road surface problems (International Slurry Surfacing Association, 2011). Micro-surfacing is applied in double layer for addressing surface irregularities. Moreover, micro-surfacing has variety of applications where fast traffic times are of concern. It also can apply on concrete bridge decks, airports runways and night works.

Micro-surfacing is differing from Slurry seal in many areas. The emulsified asphalt used for Micro-surfacing has higher polymer content and higher asphalt residual content. Using faster setting chemical in the asphalt emulsion applied in Micro-surfacing allows faster break of this product rather than Slurry Seal. This ability makes Micro-surfacing able to support traffic as quick as one hour after placement while Slurry Seal required more time in order to support traffic. Moreover, Micro-surfacing use high quality aggregates rather than Slurry Seal and this provide higher skid resistance which allow Micro-surfacing to be used in wheel ruts.

Although there are several applications of Slurry Seal and Micro-surfacing, current tests and mix design methods mostly rely on laboratory condition and the correlations between laboratory results and field performance are very poor. Also, there are various environmental factors that influence performance of such products in the field. Therefore, there is a need to develop new mix design procedures, specifications, and guidelines for Slurry Seal and Micro-surfacing to improve reproducibility of the test methods and to provide a correct relationship between field performance and laboratory results. There are currently several procedures, guidelines and specifications for Slurry Seal and Micro-surfacing. International Slurry Seal Association (ISSA), American Society for Testing and Materials (ASTM), Texas Transport Institute (TTI), California Department of Transportation (Caltrans) and European Union has a similar set of specifications, guidelines and procedures on the design and use of Slurry seal and Micro-surfacing.

Recognizing the need for more rational design methods for Micro-surfacing, McAsphalt Industries Limited enlisted the École de Technologie Supéerieure, Montreal, Quebec (ETS) to form a pooled fund study to develop a new mix design procedure for Micro-surfacing that specifically address characterization of its field performance indicator. This report intended to review the current mix design procedures for Slurry Seal and Micro-surfacing and suggest a new mix design procedures, guideline and specifications for Micro-surfacing as a high performance surface treatment and pavement preservation method.

CHAPITRE 1

RESEARCH PROBLEMS, OBJECTIVES

1.1 Treatments of Asphalt Pavement Preservation

Pavement preservation is a planned system of treating pavements at the optimum time to maximize their useful life. Pavement preservation enhances pavement longevity at the lowest cost. Both rigid and flexible pavement must withstand wheel loads, environmental effects, and temperature variations. Factors deteriorating asphalt pavements include environmental and wheel load-related factors. Load-related stresses develop fatigue cracking and rutting, whereas environmental factors induce thermal cracking, block cracking, and weathering and raveling (Uzarowski et Bashir, 2007). Pavements must be treated in time in order to avoid increase of deterioration rates due to these cracks (Figure 1.1).

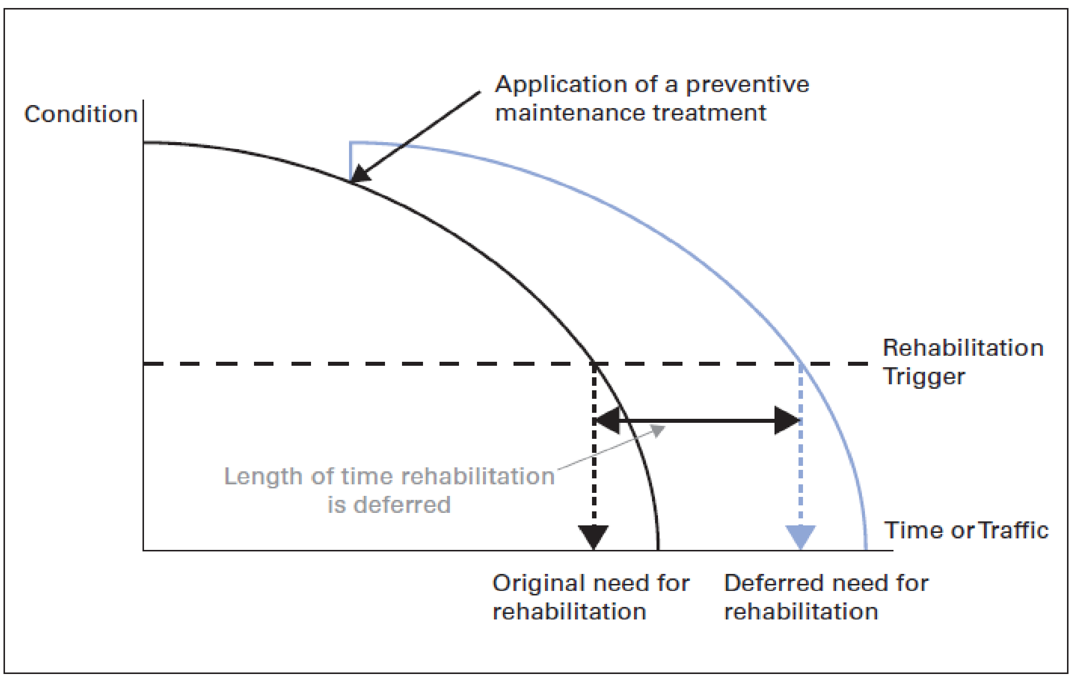

Figure 1.1 Use of preventive maintenance treatments to defer the need for rehabilitation (Katie Zimmerman, September, 2006)
Extracted from Pavement Preservation Compendium, U.S Department of Transportation, Federal Highway Administration (2006, p. 59)

Pavement condition changes with time and requires different types of treatments as shown in Figure 1.2. The Pavement Condition Index (PCI) is a numerical index between 0 and 100 and is used to indicate the condition of a roadway. The PCI provides a numerical rating for the condition of road segments within the road network, where 0 is the worst possible condition and 100 is the best. If pavement is seriously cracked, major rehabilitation is required.

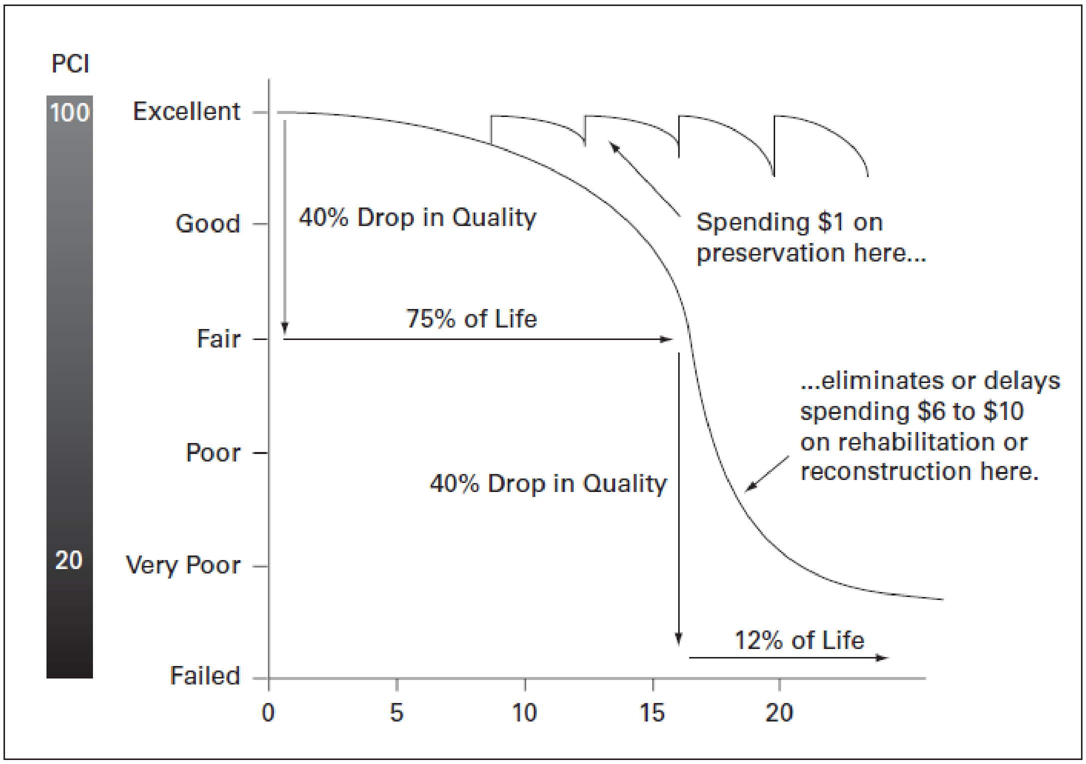

Figure 1.2 Pavement option curve (PCI= Pavement condition Index
(Larry Galehouse, 2006)
Extracted from Pavement Preservation Compendium, U.S Department of Transportation, Federal Highway Administration, Larry Galehouse (2006, p. 71)

Figure 1.2 shows how timely application of the right treatments to the right road at the right time can reduce the cost of pavement treatment. This figure is representative for a road with a design life of about 20 years. If *pavement preservation treatment* is applied before year 15, this kind of treatment will generally restore the pavement condition. In this case, pavement preservation treatment costs $1.00 per yd^2. However, if treatment is delayed, there should apply rehabilitation treatment, which generally cost 6 to 10 times more ($6 to $10 per yd^2) than the cost of pavement treatment.

Asphalt pavement preservation activities are divided into three major categories (Uzarowski et Bashir, 2007):

1. Routine Maintenance Treatment:
    i Crack filling/ sealing
    ii Patching

2. Preventive Maintenance Treatment:
    i Fog seals
    ii Surface rejuvenating
    iii Micro-milling
    iv Thin surfacing:
        a. Chip seal
        b. Slurry seal
        c. Micro-surfacing
        d. Metro-mat
        e. Nova chip
        f. Thin hot-mix asphalt overlay

3. Corrective Maintenance:
    i Full-depth patching
    ii Milling
    iii Overlays

Major rehabilitation treatments for pavements are divided into three major categories (Uzarowski et Bashir, 2007):

1. structural overlays

2. recycling:
   i Hot in-place recycling (HIR) with emulsion or foamed asphalt
   ii Cold in-place recycling (CIR) with emulsion or foamed asphalt
   iii Full-depth reclamation (FDR) with foamed asphalt

3. Reconstruction

1.2 Researches Problem

There are a number of mix design procedures for micro-surfacing developed by several agencies: International Slurry Surfacing Association (ISSA TB A143), American Society for Testing and Materials (ASTM 6372-99a), Texas Transportation Institute (TTI 1289), and California Department of Transportation (CALTRANS). Among these, only the ISSA mix design procedure for micro-surfacing (ISSA TB A143) is widely used. This mix design procedure mostly relies on laboratory condition, and the correlation between laboratory results and field performance is poor. Also, it does not offer procedure to select optimum mix proportions for micro-surfacing mixtures.

1.3 Research Objectives

The overall goal of this study is to improve the performance of micro-surfacing mixtures through the development of a rational mix design procedure, guidelines, and specifications. This overall goal should be achieved with the use of micro-surfacing equipment with the following specific objectives:

1. To evaluate the influence of several factors (aggregate type, asphalt emulsion content, added moisture content, and the use of Portland cement additives) on the properties and performance of asphalt emulsion treated mixture types especially used in Quebec.

2. To evaluate some additional mix design tests to select optimum mix proportions for micro-surfacing mixtures.

1.4 Organization of Thesis

This thesis is divided into seven chapters. Chapter 1 is an introduction to the study. It describes the concept of pavement preservation, benefits of preventive maintenance, background on Slurry Seal and Micro-surfacing, problem statement and objectives of the study. Chapter 2 is a literature review of the entire Slurry Seal and Micro-surfacing mix design procedures. It includes ISSA, ASTM, TTI, CALTRONS and other mix design procedure for Slurry Seal and Micro-surfacing. Chapter 3 describes the materials used in study. Chapter 4 is about design of the experiments. Chapter 5 is about description of ISSA mix design tests evaluated in study. Chapter 6 discusses the study of design parameters of Micro-surfacing mixtures. It includes preparing and testing Micro-surfacing mixture using four mixture design tests proposed by the ISSA. Chapter 7 describes modification to the micro-surfacing mix design procedures. Conclusions of this study and recommendations for future investigations are also presented at the end of this thesis.

CHAPITRE 2

LITERATURE REVIEW

2.1 Introduction

Among all mix design guidelines, ISSA and ASTM guidelines are the most accepted and practiced around the world. ISSA developed A105 guideline for Slurry Seal mix design (ISSA, 2005) and A143 guideline for Micro-surfacing (ISSA, 2005). ASTM suggested D3910 guideline for Slurry Seal (ASTM, 1998), and D6372 for Micro-surfacing (ASTM, 1999). Despite the differences between Slurry Seal and Micro-Surfacing (i.e., application thickness, traffic volume, and curing mechanisms), both ISSA and ASTM suggested similar test methods and design procedure to evaluate Slurry Seal and Micro-surfacing. In fact these procedures do not make any distinct between Slurry Seal and Micro-surfacing mix design and consider same test methods for both systems. While Texas Transport Institute (TTI) studies documented the problems associated with using the existing methods for micro-surfacing and suggested the development of a comprehensive mix design especially for Micro-surfacing (TTI, 1995). California Department of Transportation (Caltrans) has also studied both systems of Slurry Seal and Micro-surfacing together in order to provide a rational mix design procedure (Caltrans, 2004). The minister de transport Quebec (MTQ) has developed its own specification for micro-surfacing. The European Union has a similar set of standards and norms to design Slurry Seal and Micro-surfacing. Other countries such as Germany, France, United Kingdom, and South Africa have had experience with Slurry Seal and Micro-surfacing systems, and have developed specific guidelines for their specific use. However, among all these guidelines, ISSA and ASTM are commonly used worldwide. All the above mentioned standards are reviewed in this part of study.

2.2 Slurry Seal Mix Design Procedures:

2.2.1 ISSA Design Method for Slurry Seal, ISSA A105 (ISSA, 2005)

This guideline and specification is the most widely used procedure for the design of Slurry Seal. The components of the mix are tested first. Based on this standard, aggregate gradation has to be conform with one of the three gradations given in the table 2.1.

Table 2.1 ISSA Types I, II, and III aggregate gradations for slurry seal
Adopted From (ISSA, 2005)

Sieve Size		**% Passing by Weight**			**Stockpile Tolerance,%**
In	**mm**	**Type I**	**Type II**	**Type III**	
3/8	9.500	100	100	100	
No. 4	4.750	100	90-100	70-90	+/- 5
No. 8	2.360	90-100	65-90	45-70	+/- 5
No. 16	1.180	65-90	45-70	28-50	+/- 5
No. 30	0.600	40-60	30-50	19-34	+/- 5
No. 50	0.300	25-42	18-30	12-25	+/- 4
No. 100	0.150	15-30	10-21	7-18	+/- 3
No.200	0.075	10-20	5-15	5-15	+/- 2

Also, the aggregate has to pass the tests and criteria listed in the table 2.2:

Table 2.2 Aggregate tests and criteria for slurry seal
Adopted From (ISSA, 2005)

AASHTO TEST NO	**ASTM TEST NO**	**QUALITY**	**SPECIFICATION**
ASHTO T-176	ASTM D 2419	Sand equivalent	45 Minimum
AASHTO T-104	ASTM C 88	Soundness	15% Maximum using Na_2SO_4 or 25% Maximum Using $MgSO_4$
AASHTO T-96	ASTM C 131	Abrasion Resistance	35% Maximum

The mineral filler can be any non-air entrained hydrated lime or Portland cement. This mineral filler has to conform with ASTM D-242 as well (Ramirez, 1994).

Based on the ISSA specification, the asphalt emulsions type can be: SS-1, SS-1h, CSS-1, CSS-1h, QS-1h, CQS-1h or Quick-Set Mixing Grade as specified in ASTM D977 (ASTM, 2003) and D2397 (ASTM, 1999), with the caveat that the cement mixing test can be waived.

Table 2.3 Asphalt Emulsion Specifications for Slurry Seal
Adopted From (ISSA, 2005)

	AASHTO TEST METHOD	**ASTM TEST METHOD**	**QUALITY**	**SPECIFICATIONS**
TEST ON EMULSION				
	AASHTO T59	ASTM D-244	Residue after Distilliation	60% Minimum
TEST ON EMULSION RESIDUE				
	AASHTO T49	ASTM 2397	Penetration at 77°F (25°C)	40-90

In addition, the asphalt emulsion must have a minimum of 60% residue (ASTM, 1999). The emulsion residue must have a penetration value of 40 to 90, which is 0.1 mm at 25°C (77°F), as shown in table 2.3. Table 2.4 gives the mix tests recommended for Slurry Seal.

Below is the description of tests based on mix test recommended by the ISSA for Slurry Seal. Again, in the ISSA mix design, not all tests are required and designers are permitted to eliminate tests based on their past experience with the material.

Table 2.4 Mix Tests Recommended by the ISSA for Slurry Seal
Adopted From (ISSA, 2005)

ISSA TEST NO	DESCRIPTION	SPECIFICATION
ISSA TB 106	Slurry Seal Consistency	Between 2 to 3 cm flow
ISSA TB 139 (For Quick-Traffic Systems)	Wet Cohesion 30 Minutes Minimum (Set) Wet Cohesion 60 Minute Minimum	12 kg-cm Minimum 20 kg-cm minimum
ISSA TB 109 (For Heavy-Traffic Areas Only)	Excess Asphalt by Loaded Wheel Test Sand Adhesion	538 g/m² Maximum
ISSA TB 114	Wet Stripping	Pass (90% Minimum)
ISSA TB 100	Wet Track Abrasion Lost, One-Hour Soak	807 g/m² Maximum
ISSA TB 113	Mix Time	Controllable to 180 second Minimum

1) Consistency Test, ISSA TB 106

Cone consistency test is used to determine proper amount of water at which mixture is workable (ISSA, 2005). Mixture designer prepares several trial mixtures using 400 grams dried aggregate with optimum asphalt emulsion, and different amount of water. The number of trial mixtures is not stated in ISSA TB 106 and designer can prepare as many samples as required to reach desired workable mixture. Based on ISSA TB 106, cone is centered on the flow scale and filled with mixture within 30 second. The con is then immediately removed and outflow of the slurry is measured at four points 90º apart. For a mix to pass the consistency test, the flow should be between 2 cm and 3 cm (ISSA, 2005) (see Figure 2.1, Figure 2.2).

Figure 2.1 Consistency test, mixture with 2cm Flow

Figure 2.2 Consistency test, mixture with 3cm Flow

2) Modified Cohesion Test, ISSA TB 139

Modified Cohesion Tester is used to measure cohesion of the mixture at suitable time intervals such as 30, 60, 90, 150, 210, and 270 minutes after casting (ISSA, 2005). To do this, a torque wrench is used to measure the torque required to rotate neoprene cylinder in contact with the specimen. Set time is defined as the elapsed time after casting when a slurry system may not be remixed into homogenous slurry. A plot of torque versus time is developed based on modified cohesion test results to classify the system in terms of set time and traffic time.

3) Mix Time Test, ISSA TB 113

This test makes use of trial mixtures to identify if the material can be mixed at temperature of 77ºF (25ºC) and 100ºF (37, 7ºC) for at least 120 and 180 seconds respectively (ISSA, 2005). It can be a good reference check to verify consistent sources of material.

4) Wet-Track Abrasion Loss Test, ISSA TB 100

Wet track abrasion test is a field simulation test to measure the wearing qualities of micro-surfacing mixture under wet abrasion conditions (ISSA, 2005). Wet track abrasion test establishes the minimum asphalt emulsion content necessary to prevent excessive raveling of cured micro-surfacing mixture. This test was conducted after curing the samples. Wet track abrasion test were performed on 1-hour soaked sample to determine susceptibility to short-term moisture exposure. The result of the test is the loss in weight of the specimen expressed in grams per square meter (or square foot) and is reported as the wear value, also denoted as WTAT loss. For a design to be acceptable, the one-hour soak WTAT wear value must be less than 807 g/m² or 75 g/ft².

5) Loaded Wheel Test, ISSA TB 109

Loaded wheel test measures the resistance of mixture against flushing under heavy traffic. This test establishes the maximum asphalt emulsion content necessary to prevent flushing of cured micro-surfacing mixtures (ASTM 1998). The mixture is compacted by means of a loaded, rubber tired, reciprocating wheel. The measured parameter is the sand adhesion, which is an indirect measure of the amount of excess asphalt in the mix. Sand adhesion value is a function of the number of cycles (usually 1,000 cycles conditioning and 100 for the test) and load (usually 57 kg [125 lbs] plus the weight of the frame). For a design to be acceptable, the LWT sand adhesion has to be less than 538 g/m^2 or 50 g/ft^2.

2.2.2 ASTM Design Method for Slurry Seal, ASTM D3910-98 (ASTM, 1998)

Similar to ISSA A105, ASTM D3910-98 guideline and specification are another widely used procedure for the design of Slurry Seal. Based on this standard, the components of the mix are tested first. Aggregate gradation has to conform to one of the three gradations give in the table 2.5.

Table 2.5 ASTM types I, II, and III aggregate gradations for Slurry Seal
Adopted From (ASTM, 1998)

Sieve Size		% Passing by Weight		
in	**mm**	**Type I**	**Type II**	**Type III**
3/8	9.500	100	100	100
No. 4	4.750	100	90-100	70-90
No. 8	2.360	90-100	65-90	45-70
No. 16	1.180	65-90	45-70	28-50
No. 30	0.600	40-60	30-50	19-34
No. 50	0.300	25-42	18-30	12-25
No. 100	0.150	15-30	10-21	7-18
No.200	0.075	10-20	5-15	5-15

The mineral filler can be any non-air entrained hydrated lime or Portland cement. This mineral filler has to conform with ASTM D-1073 as well. Based on the ASTM specification for slurry Seal, the asphalt emulsion has to be a SS-1h, CSS-1h, QS-1h or a CQS-1h.

Also, the aggregate has to pass the following tests and criteria:

1. Quality requirements of ASTM Specification D1073 (ASTM, 2001).
2. Sand equivalent no less than 45.
3. % of smooth-textured sand of less than 1.25.

4. Water absorption less than 50% of the total combined aggregate.

The tests recommended by the ASTM procedure for Slurry Seal are shown in table 2.6.

Table 2.6 Mix Tests Recommended by the ASTM for Slurry Seal
Adopted From (ASTM, 1998)

ASTM TEST RECOMMENDED FOR SLURRY SEAL	SPECIFICATION
Slurry Seal Consistency (ISSA TB 106)	Between 2 to 3 cm flow
Set Time	Less than 12 hours
Cure Time (ISSA TB 139)	Less than 24 hours
Wet Track Abrasion Lost, One-Hour Soak (ISSA TB 100)	807 g/m^2 Maximum

Below is the description of the ASTM tests for Slurry Seal. Among the four of ASTM mix design procedure, Slurry Seal consistency test (ISSA TB 106) and Wet Track Abrasion Lost, One-Hour Soak (ISSA TB 100) are exactly the same with the tests described in sections 2.2.1.2 and 2.2.1.4. However Set Time and Cure Time tests are different and described below.

1) Set Time Test

Set time test is used to determine the time required for mixture to reach initial set. Based on this test, the slurry is poured on a flat surface, screeded to 6mm (0.25 in) thickness, and the wet surface of mixture is dried by pressing a white paper towel at several time intervals. Set time is the time required to obtain a stain-free blot. For design to be acceptable, the initial set time of mixture must be less than 12 hours.

2) Cure Time Test, ISSA TB 139

Modified Cohesion Tester is used to measure cohesion of the mixture at the interface between a rotating neoprene cylinder and the test specimen (ISSA, 2005). Based on this test, the cure time is the time required to reach a constant maximum torque. For design to be acceptable, the cure time must be less than 24 hours.

2.2.3 ISSA TB111 – Outline Guide Design Procedure for Slurry Seal (ISSA, 2005)

ISSA TB 111 presents a different method of design procedure for Slurry Seal. This design procedure suggests ranges of variation for the input design variables and provides a method to choose the optimum design while ISSA A-105 does not suggest any method to choose the optimum design. ISSA TB 111 was developed from papers presented by Huffman, Benedict, Gordillo, and others at the ISSA World Congress in Madrid and the Asphalt Emulsion Manufacturers Association (AEMA) convention in Phoenix, in 1977. The method has two parts.

Part I is about primary design considerations. In this part, information such as pavement surface condition, climate condition, and traffic volume are considered. Then objective of surface treatments is stated. These objectives can be improving skid resistance of surface, crack filling, or rut correction. At the end part I suitable aggregate type, gradation and asphalt emulsion materials are selected.

Part II is about developing a job mix formula for the selected materials in part I. Firstly, theoretical bitumen requirement (BR) is obtained by adding the percent bitumen required for an 8μm coating and the percent required for absorption. Percent bitumen required for an 8μm coating is determined by Surface Area Method. The surface area of aggregate is calculated by multiplying the percent of aggregate passing a given sieve by a surface area factor based on the sieve size. The surface area of the aggregate is determined for each particle size and then summed to obtain the total surface area in square meter per kilogram (m^2/kg). Figure2.3 shows factors used in calculating surface area of slurry seal aggregates suggested by ISSA TB 118. The absorption requirements of the aggregate are determined by using the Centrifuge Kerosene Equivalent test. The amount of Kerosene retained by the aggregate is assumed to approximate the amount of bitumen that the aggregate will absorb.

Sieve Size	Surface Area Factors* ft²/lb	m²/kg
3/8-in. (9.5 mm)	2	.41
No. 4 (4.75 mm)	2	.41
No. 8 (2.36 mm)	4	.82
No. 16 (1.18 mm)	8	1.64
No. 30 (600 μm)	14	2.87
No. 50 (300 μm)	30	6.14
No. 100 (150 μm)	60	12.29
No. 200 (75 μm)	160	32.77

Figure 2.3 Factors Used in Calculating Surface Area of Slurry Seal
Extracted from Technical Bulletin (ISSA TB 118)
International Slurry Seal Associations (2005, p. 1)

Three level of BR is selected from surface area method, and then, the water and cement content for mixture is selected so that the minimum of 80 second mixing time is provided based on mix time test (ISSA TB 102). This 80 seconds minimum time is required to ensure that the mixture will be able to mix without breaking in the slurry machine. Then, for each BR level that was selected from previous step, optimum water content is selected. For this, a number of Consistency test (ISSA TB 106) are carried out. The water content for each BR level that results in a 2.5 cm flow is reported as optimum water content for each BR level. At this time, designers have three levels of PAR, and optimum water content for each PAR. In order to check whether or not the optimum water content is correctly selected, designer run three consistency test with different water content for each of three BR levels to find 2 to 3 cm, 4 to 5 cm, and 6 to 7 cm flow in specimen mixture. These three mixtures are air dried and saved at ambient temperature. Next step is compatibility tests. In this step, designer examine cross-section of each three consistency specimen mixtures, saved from previous step, to evaluate asphalt or aggregate migration to specimen surface (bleeding and segregation?). If suspicious non-uniformity is observed, consistency test is run again, and water contents are adjusted. Wet stripping test are also conducted to evaluate poor mixture formulation in each mixtures. If result of consistency test is less than 90%, consistency test is run again to adjust water content in mixtures. Finally, optimum BR is selected. For this, three formulations which meet requirements of two already described compatibility tests are selected for wet track abrasion (WTAT) and loaded wheel tests (LWT). A maximum limit of 807 g/m² for WTAT, and 538 g/m² for LWT is sated. A graph of physical test data is drawn and stated limit for PAR is superimposed. Designer read optimum asphalt content at the middle of stated limit (Figure 2.4). As it can be seen from figure 2.4, firstly, minimum asphalt emulsion is determined by wet track abrasion test. Then, loaded wheel test is used to establish maximum required asphalt emulsion for mixture. A graph of physical test data for wet track abrasion and loaded wheel test is superimposed. Designer read the optimum asphalt content as shown in figure 2.4.

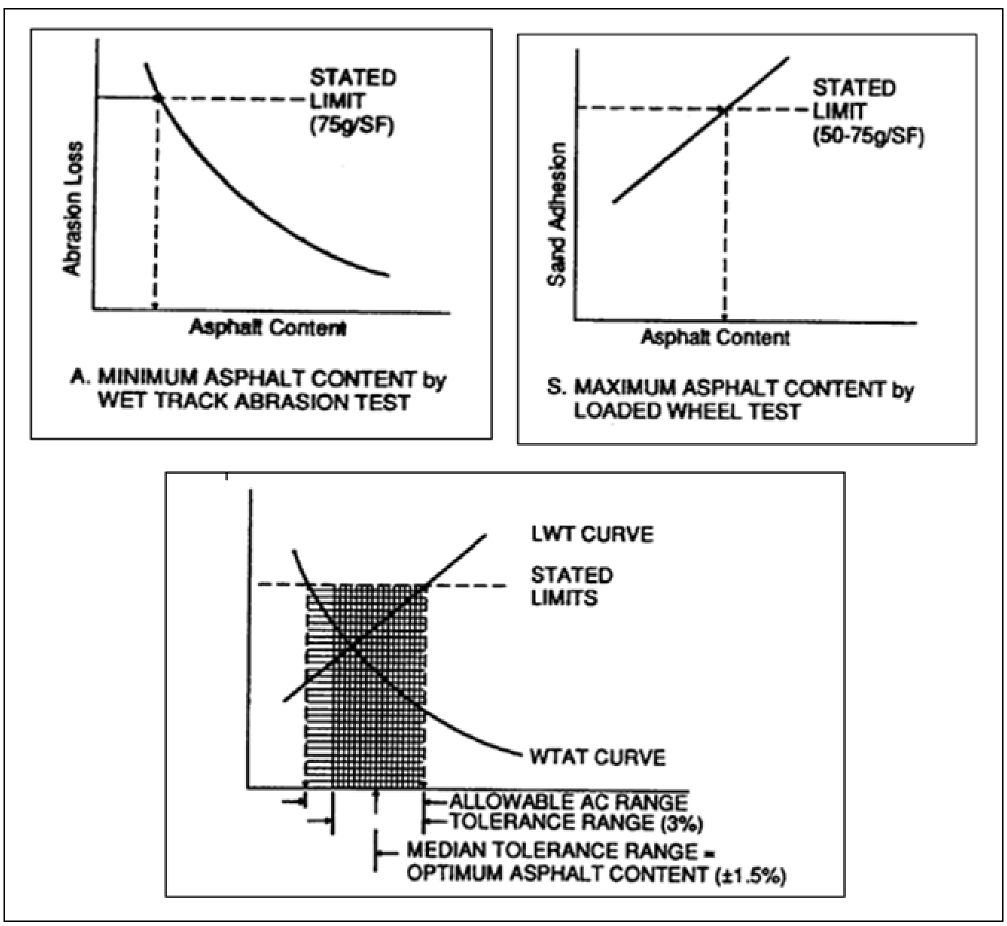

Figure 2.4 Graphical Determination of Optimum Asphalt Content
Extracted from Technical Bulletin (ISSA TB 111)
International Slurry Seal Associations (2005, p. 2)

2.3 Micro-Surfacing Mix Design Procedures:

2.3.1 ISSA Design Method for Micro-surfacing, ISSA A143

ISSA A143 guideline and specification is the most widely used mix design procedure for micro-surfacing. The components of the mix are tested first. Based on this standard, aggregate gradation has to conform to one of the two gradations given in table the 2.7.

Table 2.7 ISSA Type II and III aggregate gradation for Micro-surfacing
Adapted from (ISSA, 2005)

Sieve Size		% Passing by Weight		Stockpile Tolerance,%
in	**mm**	**Type II**	**Type III**	
3/8	9.500	100	100	
No. 4	4.750	90-100	70-90	+/- 5
No. 8	2.360	65-90	45-70	+/- 5
No. 16	1.180	45-70	28-50	+/- 5
No. 30	0.600	30-50	19-34	+/- 5
No. 50	0.300	18-30	12-25	+/- 4
No. 100	0.150	10-21	7-18	+/- 3
No.200	0.075	5-15	5-15	+/- 2

As it can be seen from table 2.7, in micro-surfacing, aggregate gradation has to conform only to type II and III aggregate gradations while for slurry seal has to conform to type I, II, and III gradations.

This is the first difference between ISSA mix design procedures for slurry seal and micro-surfacing. It should be noted that type III aggregate gradation is coarser and more appropriate for high traffic load and volume.

Also, the aggregate has to meet the specifications shown in table 2.8.

Table 2.8 Aggregate tests and criteria for Micro-surfacing
Adapted from (ISSA, 2005)

AASHTO TEST NO	ASTM TEST NO	QUALITY	SPECIFICATION
ASHTO T-176	ASTM D 2419	Sand equivalent	65 Minimum
AASHTO T-104	ASTM C 88	Soundness	15% Maximum using Na_2SO_4 or 25% Maximum Using $MgSO_4$
AASHTO T-96	ASTM C 131	Abrasion Resistance	30% Maximum

As it can be seen form Table 2.8, ISSA mix design procedure for micro-surfacing recommend the maximum sand equivalent of 65% for aggregate while the recommended amount for slurry seal is a maximum of 45% for sand equivalent. This indicates that the aggregate use for micro-surfacing should have less relative proportion of detrimental fine dust or clay-like particles in fine portion of aggregates. In other words, the quality of micro-surfacing aggregates should be higher than quality of aggregates use for slurry seal. It also can be seen from tables 2.2 and 2.8 that aggregates used for micro-surfacing must be tougher and have better abrasion resistance than for slurry seal in order to prevent crushing, degradation, and disintegration.

However, ISSA recommends same durability/soundness characteristics for aggregates used in micro-surfacing and slurry seal. The binder is normally a quick traffic, polymer modified, asphalt emulsion conforming to the requirements of ASTM D2397 for CSS-1h (the cement mixing test is waived).

In addition, the asphalt emulsion must have a minimum of 62% residue after distillation using ASTM D244 (14). This indicates that asphalt emulsion used in micro-surfacing should have higher asphalt residue. The emulsion residue has to meet the criteria shown in table 2.9.

Table 2.9 Asphalt Emulsion Specifications for Micro-surfacing
Adapted from (ISSA, 2005)

	AASHTO TEST METHOD	ASTM TEST METHOD	QUALITY	SPECIFICATIONS
TEST ON EMULSION				
	AASHTO T59	ASTM D-244	Residue after Distilliation	62% Minimum
TEST ON EMULSION RESIDUE				
	AASHTO T49	ASTM 2397	Penetration at 77°F (25°C)	40-90

It can be seen from table 2.9 that the asphalt emulsion used for micro-surfacing should be of better quality than for slurry seal. It should be noted that ISSA suggest the same penetration value at 25ºC for asphalt emulsion use in micro-surfacing and slurry seal. The mix design tests recommended by the ISSA for micro-surfacing are presented in table 2.10. As it can be seen from table 2.10, two more tests are recommended for micro-surfacing than for slurry-seal. These two tests are wet track abrasion test for six-day soaked sample and lateral displacement test. The reason for recommending lateral displacement test is because of the application of micro-surfacing for filling ruts. Also, ISSA recommends maximum 538 g/m² to evaluate short-term abrasion properties of mixture (one-hour soak sample), while this maximum limit for wet track abrasion one-hour soaked sample of slurry seal is 807 g/m².

Moreover, mix time for slurry seal mixture is recommended to be at least 180 seconds while this limit for micro-surfacing is 120 seconds. ISSA mix design procedure for micro-surfacing evaluates relative compatibility between the aggregate filler of a specific gradation and emulsified asphalt residue as well. The test recommended for this evaluation for micro-surfacing is ISSA TB 144. This test is not recommended for slurry seal. It should be noted that in ISSA mix design procedure for slurry seal, consistence test have been recommended, while for micro-surfacing, this test is not recommended.

Table 2.10 Mix Design Tests recommended by ISSA for Micro-surfacing
Adapted from (ISSA, 2005)

ISSA TEST NO	DESCRIPTION	SPECIFICATION
ISSA TB 139 (For Quick-Traffic)	Wet Cohesion 30 Minutes (Set) Wet Cohesion 60 Minute	12kg-cm Minimum 20kg-cm Minimum
ISSA TB 109 (For Heavy-Traffic)	Excess Asphalt by Loaded Wheel Test Sand Adhesion	538 g/m² Maximum
ISSA TB 114	Wet Stripping	Pass (90% Minimum)
ISSA TB 100	Wet Track Abrasion Lost, One-Hour Soak	538 g/m² Maximum
ISSA TB 100	Wet Track Abrasion Lost, Six-Days Soak	807 g/m² Maximum
ISSA TB 113	Mix Time at 25°C	Controllable to 180 second Minimum
ISSA TB 147	Lateral Displacement	5% Maximum
ISSA TB 144	Classification Test	Minimum 11 Points

Other test such as wet stripping test, cohesion test, and loaded wheel test are exactly the same with those recommended for slurry seal by ISSA mix design procedure and follow same limits. Below are the descriptions of two tests, ISSA TB 147 and 144, which are only recommended by ISSA mix design procedure for micro-surfacing.

1) Lateral Displacement Test, ISSA TB 147 (ISSA, 2005)

Multilayer Loaded Wheel test measures the amount of compaction or displacement characteristics of micro-surfacing under simulated rolling traffic compaction. Because micro-surfacing can be used for filling ruts, it should have proper resistance against vertical and lateral deformations under heavy traffic. This test establishes the minimum asphalt emulsion content necessary to prevent excessive deformation of micro-surfacing mixture. There are three test procedures used to measure the amount of compaction or displacement characteristics of micro-surfacing under simulated rolling traffic compaction.

1. The Loaded Wheel Test (LWT).
2. The Modified British Wheel Tracking Test.
3. The C-LAI/GA.DOT Modified Loaded Wheel Test.

A brief description of each test is presented below:

- The loaded wheel test is described in Section 2.2.1.5. In addition to the regular procedure, the width and height of the specimen are measured (in the wheel path) before and after 1000 cycles of LWT compaction, and the vertical and lateral displacement are calculated. Density (before and after compaction) is also to be calculated. For a design to be acceptable, lateral and vertical deformations must be less than respectively 5 and 10% of original width and thick at mid-length of specimen are not satisfactory for multi-layer applications.

- The modified British wheel tracking test has a long experience in the prediction of pavement rutting performance. This test was originally developed to measure the rate of loaded wheel penetration into compacted hot mixed asphaltic concrete. The wheel tracking test is similar to the LWT. The only difference is that in the loaded wheel test, the wheel moves to and fro in a rocking motion, however, in the wheel tracking test, the table moves to and fro while the wheel remains stationary and there is no rocking motion. The wheel tracking test is run at 45ºC (113ºF) and the load on the wheel is approximately half of that used in the LWT loading, 11.4 kg/cm (63.8 lbs/in) of tire width. For uncompacted mixes, the test is run for 1 hour or 2520 cycles. For pre-compacted samples, the test is run for 45 minutes or 1890 cycles. For a design to be acceptable, lateral and vertical displacements must not exceed 5 and 10% of original width and thick at mid length of specimen.

- The C-LAI/GA.DOT modified loaded wheel test is a modification of the LWT machine to accommodate the larger specimens, and test rutting characteristics of 76.2mm x 76.2mm x 381mm compacted hot mixed asphalt concrete fatigue beams. This test uses a variably pressured air hose between the loading wheel and the test specimen, and is run at a temperature of 105ºF (40.6ºC). The pressure in the hose is 100 ± 2 psi (689.5 kpa ± 13.8 kpa). Rut depth is measured after 1000 cycles of loading. Good correlation between Lai modified LWT laboratory rutting and field rutting potential have been found.

2) Classification Test, ISSA TB 144 (ISSA, 2005)

This test is used to determine the relative compatibility between the aggregate filler of a specific gradation and emulsified asphalt residue (24). As it can be seen from table 2.11 results of test are presented as a grading value, or rating system, for adhesion (in percent coated), abrasion loss (in grams lost), and high temperature cohesion characteristics (absorption in grams absorbed and integrity in percent retained mass). For a design to be acceptable, the mix must achieve 11 grade points minimum (i.e., AAA or AAB).

Table 2.11 Compatibility Classification system suggested by ISSA for Micro-surfacing Adapted from (ISSA, 2005)

Grade Rating each test	**Point Rating each test**	**Abrason Loss (grams)**	**Adhesion 30 Min Boil (% coated)**	**Integrity 30 min boil (% retained)**
A	4	0-0.7	90-100	90-100
B	3	0.7-1.0	75-95	75-90
C	2	1.0-1.3	50-75	50-75
D	1	1.3-2.0	10-50	10-50
E	0	> 2.0	0	0

2.3.2 ASTM Design Method for Micro-Surfacing, ASTM D 6372-99a (ASTM, 1999)

This guideline and specification is also from the most widely used procedure for the design of micro-surfacing. Similar to ISSA specification, the components of the mix are tested first. Based on this standard, aggregate gradation has to conform to one of the two gradations give in table the 2.12.

Table 2.12 ASTM type II and III for Micro-surfacing
Adapted from (ASTM, 1999)

Sieve Size		**% Passing by weight**	
in	**mm**	**Type II**	**Type III**
3/8	9.500	100	100
No. 4	4.750	90-100	70-90
No. 8	2.360	65-90	45-70
No. 16	1.180	45-70	28-50
No. 30	0.600	30-50	19-34
No. 50	0.300	18-30	12-25
No. 100	0.150	10-21	7-18
No.200	0.075	5-15	5-15

It should be noted that, ASTM design procedure for micro-surfacing recommend type II and III aggregate gradation while this procedure recommend type I, II, and III aggregate gradation for slurry seal. Also, tolerances are not specified in both ASTM mix design procedures for slurry seal and micro-surfacing.

The mineral filler can be any recognized brand non-air entrained hydrated lime or Portland cement. This filler should be free of lumps and accepted upon visual inspection. Based on this guideline, the asphalt emulsions should be a quick set, polymer modified, asphalt emulsion and have to conform to the requirements of ASTM D 2397for CSS-1h. Aggregates also have to meet the criteria shown in table 2.13.

Table 2.13 Aggregate tests and criteria for micro-surfacing
Adapted from (ASTM, 1999)

AASHTO TEST NO	ASTM TEST NO	QUALITY	SPECIFICATIONS
ASHTO T-176	ASTM D 2419	Sand equivalent	65 Minimum
AASHTO T-104	ASTM C 88	Soundness	15% Maximum using Na_2SO_4 or 25% Maximum Using $MgSO_4$
AASHTO T-96	ASTM C 131	Abrasion Resistance	30% Maximum

As it can be seen form Table 2.13, ASTM mix design procedure for micro-surfacing recommend maximum sand equivalent of 65% for aggregates while the recommended amount for slurry seal is a maximum of 45%. This indicates that the aggregates use for micro-surfacing should have less relative proportion of detrimental fine dust or clay-like particles. In other words, ASTM mix design indicates that the quality of micro-surfacing aggregates should be higher than quality of aggregates use for slurry seal. Following are the mix tests recommended by the ISSA procedure for Micro-surfacing (Table 2.14).

Table 2.14 Mix design tests recommended by ASTM for micro-surfacing
Adapted from (ASTM, 1999)

ISSA TEST NO	DESCRIPTION	SPECIFICATION
ISSA TB 139 (For Quick-Traffic)	Wet cohesion 30 Minutes (Set) Wet cohesion 60 Minute	12kg-cm Minimum 20kg-cm Minimum
ISSA TB 109 (For Heavy-Traffic)	Excess asphalt by loaded wheel test sand adhesion	538 g/m² Maximum
ISSA TB 100	wet track abrasion lost, one-hour soak	807 g/m² Maximum
ISSA TB 144	Classification test	Minimum 11 Points

As it shows from table 2.14, wet track abrasion lost one-hour soak test specimen is same in both ASTM mix design procedures for micro-surfacing and slurry seal. Maximum limit for abrasion loss of one-hour soak specimen for both ASTM slurry seal and micro-surfacing procedures is 807 g/m². ASTM mix design procedure for micro-surfacing recommend cohesion test (ISSA TB 139) to measure set and traffic characteristics of mixture while ASTM mix design procedure for slurry seal recommend set time test and suggest a limitation of less than 12 hours to evaluate set characteristics of mixture. Moreover, ASTM mix design procedure for micro-surfacing recommended two more tests which are excess asphalt by loaded wheel test sand adhesion for high traffic areas and classification test to evaluate relative compatibility between the aggregate filler and emulsified asphalt residue. These tests have not been recommended by ASTM mix design procedure for slurry seal.

2.3.3 TTI Design Method for Micro-surfacing, TTI 1289 (TTI, 2005)

Texas Transportation Institute (TTI) recommended a new mix design procedure for micro-surfacing in early 1994 (TTI, 2005). Following a study on reliability of determining mixture quality of micro-surfacing with the ISSA mix design procedure for micro-surfacing, they developed a new mix design procedure which is somewhat different from ISSA and ASTM mix design procedures. Similar to other ISSA and ASTM procedures, the components of the mix are tested first. The gradations proposed by TTI are shown in table 2.15.

Table 2.15 TTI Type II and III aggregate gradation for Micro-surfacing
Adopted from (TTI, 2005)

Sieve Size		% Passing by Weight		Stockpile Tolerance,%
In	mm	Type II	Type III	
3/8	9.500	100	100	+/- 5
No. 4	4.750	98-100	99-100	+/- 5
No. 8	2.360	75-90	45-65	+/- 5
No. 16	1.180	50-75	25-46	+/- 5
No. 30	0.600	30-50	15-35	+/- 3
No. 50	0.300	18-35	10-25	+/- 3
No. 100	0.150	10-21	7-18	+/- 3
No.200	0.075	5-15	5-15	+/- 2

It should be noted from table 2.15 that the aggregate gradation recommended by TTI design procedure for micro-surfacing is different from the gradations recommended by ISSA and ASTM. These aggregate gradations are finer for sieve sizes 3/8 in to #16 than those used in ASTM and ISSA methods. Aggregates also have to meet the criteria listed in table 2.16.

Also, the mineral filler can be any recognized brand of non-air entrained Portland cement or hydrated lime.

Table 2.16 TTI Aggregates specifications for micro-surfacing
Adopted from (TTI, 2005)

AASHTO TEST NO	ASTM TEST NO	QUALITY	SPECIFICATION
ASHTO T-176	ASTM D 2419	Sand equivalent	70 Minimum
AASHTO T-104	ASTM C 88	Soundness	15% Maximum using Na_2SO_4 or 25% Maximum Using $MgSO_4$
AASHTO T-96	ASTM C 131	Abrasion Resistance	30% Maximum

The emulsion should be a cationic, slow setting, polymer modified emulsion which is designated as CSS-1P. Also binder should meet the following criteria as well:

- minimum 3% polymer by weight,
- viscosity, Saybolt Furol at 25ºC (77ºF): 20 to 100 seconds,
- storage stability test, one day: 1% maximum,
- particle charge test: positive,
- sieve test: 0.1% maximum,
- oil distillate, by volume of emulsion: 0.5% maximum,
- residue: 62% minimum,
- base asphalt cement should meet the requirements of an AC-20.

The different tests for the design procedure are explained in the next section.

1) Estimation of Optimum Binder Content (TTI, 2005)

ASTM D5148-90 test method is used to determine Centrifuge Kerosene Equivalent index (CKE), which is the aggregate particle roughness and surface capacity based on porosity. CKE index is also used to determine the approximate bitumen ratio (ABR) by Hveem mix design procedure. TTI mix design method for micro-surfacing uses the ASTM D5148-90 test method to determine CKE index and ABR. The optimum residual asphalt cement (RAC) content for a given micro-surfacing mixture is ABR plus 2.0% (25). Designer can prepare seven trial mixtures that are mixture with optimum RAC value, with +/-2.0, +/-1.0, and +/-0.5% from the optimum RAC value.

2) Mixing Test (TTI, 2005)

Based on ISSA TB 102, mixing time test is used to determine the time required for slurry and recommends that the mixtures should be mixed at room temperature for at least 120 seconds without breaking (ISSA, 2005). After selection of optimum residual asphalt content, designer makes use of trial mixtures with different amounts of amounts (0.5, 1.0, 1.5 and 2.0%) of Portland cement and added water content. TTI mix design procedure recommends that the mixing test be performed at each RAC/cement/water combinations to select minimum required added water content at which the slurry mixture can be mixed at room temperature for at least 120 seconds without breaking. For this, designer has freedom to reduce the water content at 1.0% intervals in order to obtain this minimum water content.

3) Modified Cup Flow Test (TTI, 2005)

Modified cup flow test is used to determine the optimum water content. TTI mix design procedure recommends that the modified cup flow test be performed at each RAC/cement combinations used in the mixing test to select the amount of added water content at which the separation of fluids and solids in mixture is greater than 5mm (0.2 in). The optimum water continent is selected at 2% below this amount of added water content. TTI mix design procedure also recommend that the optimum added water content obtained from modified cup flow test reported should be greater than the minimum added water content obtained from mixing time test. If it is less, the design is rejected.

4) Modified Cohesion Test, ISSA TB 139

Based on TTI mix design procedure for micro-surfacing, modified cohesion test should be performed at each RAC/water content combination with various amount of Portland cement (0.25, 0.5, 0.75, 1.0, 1.5, 2.0 and 2.5%) to select required amount of Portland cement to obtain a cohesion torque greater than 12 kg-cm at 30 minutes and 20 kg-cm at 60 minutes. Modified cohesion test procedure was described in section 2.2.1.2.

5) Wet-Track Abrasion Loss Test, ISSA TB100

One of the differences between TTI mix design procedure for micro-surfacing and ISSA mix design procedure is about the procedure to select optimum binder content for mixture. In ISSA mix design procedure, the optimum binder content will be selected by evaluating the abrasion loss in the WTAT and the binder content versus pick up from the loaded wheel tester. However, TTI mix design procedure for micro-surfacing recommends only use of wet track abrasion test to select optimum RAC content for mixture. Similar to ISSA TB 100 mix design test procedure, the wet track abrasion test is performed for all RAC/cement/water combinations to select the minimum RAC content at which aggregate loss of sample is less than 807 g/m^2 ($75 g/ft^2$) for 6-day soaked samples (10). Then, the optimum RAC content is determined as minimum RAC content plus 0.5%. This 0.5% is accounted for variability. Wet track abrasion test was described in section 2.2.1.4.

2.3.4 Caltrans Mix Design Method for Slurry Seal and Micro-surfacing (Caltrans, 2004)

California Department of Transportation (Caltrans) developed a single mix design procedure for both slurry seal and micro-surfacing (Caltrans, 2005). The difference between slurry seal and micro-surfacing can be defined in terms of both chemical and performance differences.

Caltrans researchers concluded that for the purpose of mix design, these chemical differences are not relevant. Therefore, Caltrans research team considers that the procedures are the same for both slurry seal and micro-surfacing systems. Similar to other mix design procedures, the components of the mix are tested first. Aggregate gradation, asphalt emulsion and their chemical characteristics has to conform to ISSA specification for slurry seal and micro-surfacing. After the materials have been selected, the proportions of aggregate, water, emulsion, and additives are determined. For this, the German mix test is used to determine the mix and spread indices. German Mix Tester develop a graph from which the numbers for Mix and spread indices can be read. An example of output from the German Mix Test is given in figure 2.5. The mix index is the cohesion when full coating occurs and the mix flows easily, the spread index is the maximum cohesion when mixing is no longer possible, but the mix will spread. These numbers represent the conditions at which the materials can be mixed safely and placed in a timely fashion. These tests will be performed at standard laboratory conditions and repeated for selected mixes for a range of anticipated application conditions. The test data would be evaluated by observing the indices of the mixes noted above as compared to results from ISSA TB 113 (mixing time test) to visually evaluate the coating of the aggregates. German Mix Test would determine the preliminary range of mix proportions.

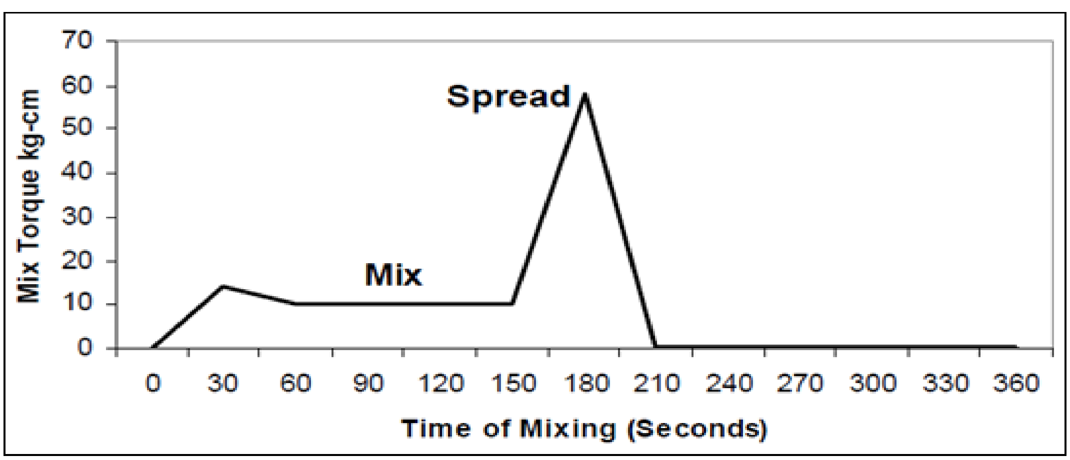

Figure 2.5 German Mix Test Cohesion Parameters versus Time
Extracted from Slurry/micro-surfacing mix design pooled fund study,
California Transportation, Pavement Preservation Compendium, (2006, p. 49)

This process should be repeated with different filler types (if necessary) to optimize the mixture for constructability and performance criteria. In the next step, designer should determine the short-term constructability properties of mixture. This step consists of taking the acceptable mixes and conducting cohesion testing to determine the cohesion at 60 minutes and after a 24-hour cure. If the results do not meet the standards, then the mixes and materials would be modified as required. In all cases, it is important to ensure that the mix time and spreadability are acceptable. Spreadability is a measure of the ability of the mix to be placed and finished on the pavement surface. After the proportions have been selected, the modified WTAT should be performed and repeated for anticipated curing conditions to evaluate short-term abrasion resistance properties.

In subsequent step, designer should determine the optimum binder content. Under this step the French WTAT will be performed at 1-hour and 6-day soak periods followed by tests using the LWT to determine the excess asphalt at the temperature that corresponds to the proposed traffic conditions (i.e., heavy at 35°C, moderate at 25°C, and low at 15°C). Finally, the optimum binder content will be selected by evaluating the abrasion loss in the French WTAT and the binder content versus pick up from the loaded wheel tester (Similar to ISSA TB 111 mix design procedure for Slurry Seal).

In the last step of Caltrans mix design procedure, designer should evaluate the Long Term Properties of the Mixture. This step would consist of measuring the following:

- abrasion: Using the French WTAT,
- water Resistance: Using the French WTAT,
- deformation (rut-filling mixes only): Using the Asphalt Pavement Analyzer,
- crack Resistance: Evaluated using the binder tests.

Finally, any necessary adjustments and recheck of the mixing indices (spreadability, traffic, and 24 hour cohesion) will be made.

One of the differences between Caltrans mix design procedure for slurry seal and micro-surfacing is to document the influence of temperature, humidity, and aging and day/night effects on the curing of samples. Sample preparation of ISSA mix design procedure for slurry seal and micro-surfacing is performed in constant during condition. However, in Caltrans mix design procedure, different curing condition is considered in sample preparation. The other difference is about using automated machines as the mix design tests. As ISSA mix design procedure is highly operator dependent, and the repeatability of the mix test in some cases is not satisfactory. Using automated mix design equipment seems to be a good idea. Following are descriptions of tests using in Caltrans mix design procedure.

1) Automated Mixing Test (AMT) (AASHTO, PTM 001)

This test determines mixability and workability of mixture, using German mix tester. Changes in viscosity (torque) with time are recorded by connecting the German mix tester to computer (Figure 2.6). The components of the micro-surfacing mixture at the prescribed temperature are weighed into separated containers. The other components of the mixture are added based on ISSA TB 113 mix design test using the hand mixing method. Firstly, the asphalt emulsion, water and additive are put into the mixing containers and placed into prescribed temperature-controlled water or air bath to reach specific temperature at which the test must be done. Then, the mixing container is centered under the stirrer of German mix tester. The stirrer must be exactly in the center of the mixing container. German mix tester is run and the speed of rotation of stirrer is maintained at 300 rpm. In the next step, the weighed aggregate are added into mixing contained within 5 seconds while the stirrer is rotating. The micro-surfacing mixture is stirred constantly until it is thick. Production time and breaking time are noted as the consistency of the mix thickens.

The compatibility and setting characteristics of asphalt emulsion and mineral aggregates can be measured by automated mixing test. This test can also document the influence of temperature on the consistency of mixtures and provide better correlation between field and laboratory performance of micro-surfacing mixtures.

Figure 2.6 German Mix Tester
Extracted from Slurry/Microsurface - Mix Design Procedure,
Jim Moulthrop, P.E., (2004, p. 15)

2) Automated Cohesion Test (ACT), (AASHTO, PTM 002)

The proportions of the components will be derived from the mix design and/or test results from AASHTO PTM 001. Figure 2.7 show Automated Cohesion Test (ACT). The mix components, at the prescribed temperature, humidity, compacted/uncompacted and day/night conditions, are cured for specific time periods. This test method documents the influences of different factors in cohesion characteristics of mixtures. This procedure helps designer to establish other mix design criteria such as temperature, humidity, aging, and daylight/darkness on the curing of the mix materials. Samples are cures at 35°C, 25°C, or 10°C temperature, and 50, 50-60, or 90% humidity for one or 24 hours by means of environmental chambers and forced air draft oven (figure 2.8). These curing conditions correspond to heavy, moderate, and low traffics. After curing, the specimen is placed in the apparatus and a 200 kPa clamping pressure is applied on it. A torque is automatically applied to the specimen at a specific rate and for a specific time. A PC interface with an electronic strain gauge will be used to measure torque over time and to calculate the peak of cohesion. This is then related to the specified traffic time.

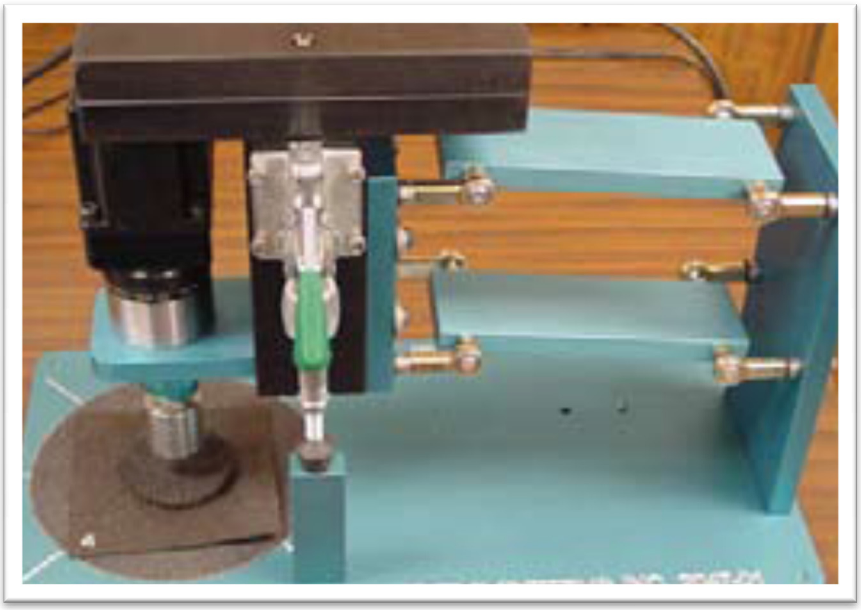

Figure 2.7 Automated Cohesion Tester (ACT)
Extracted from Slurry/Microsurface - Mix Design Procedure,
Jim Moulthrop, P.E., (2004, p. 15)

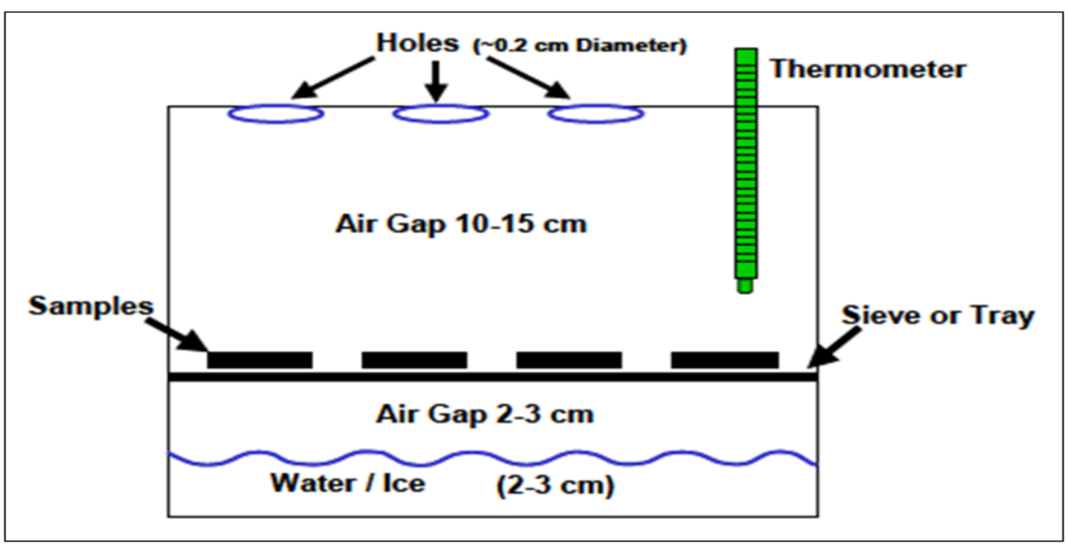

Figure 2.8 Humidity chamber for curing in high and low humidity conditions
Extracted from Slurry/micro-surfacing mix design pooled fund study,
California Transportation, Pavement Preservation Compendium, (2006, p. 52)

3) Modified Wet Track Abrasion Test (WTAT), (AASHTO, PTM 003)

Modified wet track abrasion test used to determine abrasion loss of a given slurry seal or micro-surfacing mixture using a French WTAT, shown in figure 2.9. The only difference between French WTAT and standards wet track abrasion machines such as Hobart C-100, N-50, and A-120 is that, in Hobart machines, a reinforced rubber covered hose is used to abrade the specimen surface.

However, in French WTAT machine, the specimen surface is abraded by means of an abrading dual wheel head (Figure 2.9). French WTAT will be examined and compared with existing ISSA TB 100 for reproducibility and actual abrasion loss value.

The proportions of the components will be derived after optimizing the binder content from previous testing as recommended in the mix design. The mix components, at the prescribed temperature, humidity, compacted/uncompacted and day/night conditions, are cured for specific time periods. After curing, the specimen is placed in a circular pan on a planetary type mechanical mixer. The specimen surface comes in contact with the abrading dual wheel head. The wheels move across the surface in a circular movement and abrasion occurs for 60 seconds.

After the end of abrasion, the specimen debris is washed off. The sample is dried with absorbent paper and this final weight is compared to the original weight before abrasion. According to AASHTO test method (PTM 003), a loss mass below 100 g is representative of a high cohesion slurry seal or micro-surfacing mix. A loss of mass of 300 g represents an average cohesion. When the loss of mass is close to 600 g, it is expected that the slurry seal or micro-surfacing mix will not resist traffic.

Figure 2.9 Modified wet track abrasion tester
Extracted from Slurry/Microsurface - Mix Design Procedure
Jim Moulthrop, P.E., (2004, p. 15)

CHAPITRE 3

MATERIALS USED IN STUDY

3.1 Mineral Aggregates

Three sources of aggregates obtained from the Raycar, Rive-sud, and Graham Pitt in Quebec were used in this investigation. Aggregate sizes range from 0-5 mm. These sources of contained mainly the crushed stone coarse aggregates, fine aggregates, and different types of mineral fillers. Fine aggregates were purchased from DJL Construction Company in Montreal, Quebec.

3.2 Aggregates gradation

Three types of aggregates obtained from Raycar, Graham Pitt, and rive-sud from Quebec, Canada, were used in this study. Aggregates were washed through sieve No.200 to remove all its filler and then sieve analysis were performed on dried aggregates in accordance with ISSA aggregate gradation for micro-surfacing mix design and using I.S.O. R-20 standard for sieve analysis in Quebec. When Raycar aggregate were used, commercial filler was added to aggregates to reach desired aggregate gradation.

However, when using Graham Pitt and rive-sud aggregates, same filler type contained in aggregates was used. Table 3.1 presents the percentage of aggregate passing through each sieve. Based on ISSA specifications for micro-surfacing, all three types of aggregates used in this study are considered as type III aggregate gradation which is suitable for areas with heavy traffic.

Figure 3.1 shows gradation curves of the aggregates used. This gradation is exactly in the middle of maximum and minimum aggregate gradation limits suggested by ISSA for Type III Micro-surfacing application and is considered as mid-range aggregate gradation (MG).

Table 3.1 Gradations of the aggregates used in this study

Sieve Size		% Passing by Weight		Stockpile Tolerance,%
in	**Mm**	**Ray-Car**	**Type III**	
3/8	9.500	100	100	
No. 4	4.750	88	70-90	+/- 5
No. 8	2.500	63	45-70	+/- 5
No. 16	1.250	44	28-50	+/- 5
No. 30	0.630	33	19-34	+/- 5
No. 50	0.315	23	12-25	+/- 4
No. 100	0.160	14	7-18	+/- 3
No.200	0.080	10	5-15	+/- 2

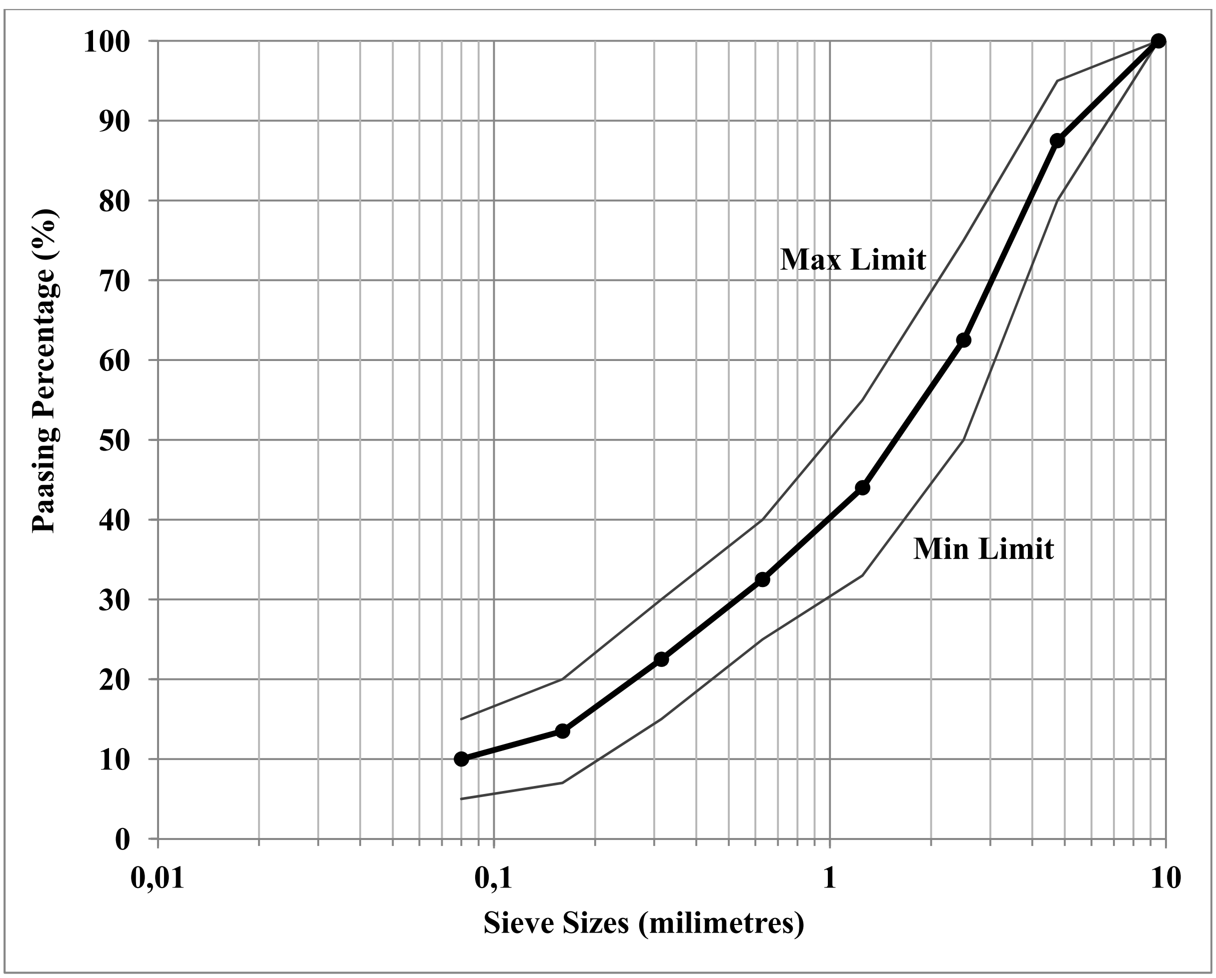

Figure 3.1 Gradation curve for Ray-Car 0-5 mm Aggregates

3.3 Asphalt Emulsion

Emulsified asphalt used in this part of study is CQS-1HP asphalt emulsion. The term CQS-1HP is the standard name for micro-surfacing emulsions used in the industry and it conforms to all ISSA specifications. Asphalt emulsion consists of asphalt binder and water that evaporates as the binder cures. Therefore, in designing micro-surfacing mixtures base on ISSA specifications, the residual asphalt content of the binder must be more than 62.0%. CQS-1HP emulsion used in this project has 65.1% residual asphalt content, according to test results provided by McAsphalt Engineering Services. Other properties of CQS-1HP asphalt emulsions have been listed in Table 3.2.

Table 3.2 CQS-1HP Asphalt Emulsion properties from supplier

Tests	**Results**	**ISSA Specifications**	
		min	max
Viscosity @ 25°, SSF	28.0	20	100
Sieve,%	0.04	-	0.10
Coating Test,%	90.0	80.0	-
Residue by Distiliation to 204.4°,% mass	65.1	62.0	-
Particle Charge	Positive	Positive	
Settlement, 5 day,%	0.9	-	5
Tests on Residue			
Softening Point by R 7 B, °C	63	57	-
Kinematic Viscosity @ 135°C, mm²/sec	1825	650	-
Penetration @ 25°C, 100 g, 5 sec	75	40	90
Ductility @ 25 °C, cm	110+	40	-

CHAPITRE 4

DESIGN OF THE EXPERIMENT

4.1 Introduction

This study consists mainly of six major sections. Sections one to four dealt with evaluating the role of asphalt emulsion residue, added water content, filler, cement and aggregate types on properties of Micro-surfacing mixtures. The Micro-surfacing mixtures were evaluated with emphasis on the cohesion, set time, mixing time, flushing, stone retention, and moisture retained in sample. Based on these characteristics of mixture, a method for selecting optimum mix proportions with regard to different types of aggregates used in study was determined in section five. In addition, a limited study was conducted in section six to evaluate repeatability and reproducibility of four mix test recommended by ISSA. The study consisted mainly of establishing a method for selecting optimum mix proportions of Micro-surfacing Mixture using four mixture design tests proposed by the ISSA. These tests examined include:

- ISSA TB No. 113: Test method for measurement of mixing time of micro-surfacing-mixtures.

- ISSA TB No. 139: Test method to classify emulsified asphalt/aggregate mixture systems using a modified cohesion tester and the measurement of set and cure characteristics,

- ISSA TB No. 100: Test method for wet track abrasion of slurry surfaces, one-hour soak and six-day soak,

- ISSA TB No. 109: Test method for measurement of excess asphalt in bituminous mixtures by use of a loaded wheel tester and sand adhesion, and,

- ISSA TB No. 147 (Method A): Test method for measurement of stability and resistance to compaction, vertical and lateral displacement of multilayered fine aggregate cold mixes.

4.2 Dependent Variables (Responses)

- wet track abrasion loss (measurement of the wearing qualities of slurry seal mixtures under wet abrasion conditions), 1-Hour and 6-Day soaked samples,
- cohesion at 30 minute and 60 minutes (measurement of set and curing characteristics),
- vertical and lateral deformation by Load Wheel Test Sand Adhesion (measurement of lateral and vertical deformation ISSA TB 147 method-A),
- sand adhesion by loaded wheel tester (measurement of excess asphalt in bituminous mixtures),
- estimate of the aggregates areas remaining coated with asphalt by Wet Stripping Test,
- percent Moisture retained in sample of loaded wheel test and wet track abrasion tests.

4.3 Independent Variables (Factors)

- asphalt emulsion residue content: three levels of asphalt emulsion residue content were used. The three levels are 7.6, 8.1, and 8.6% asphalt emulsion residue expressed as percent by weight of the dry aggregate,
- added water content: four levels of added water content were used in the study. The four levels are 8, 9, 10, and 11%, expressed as percent by weight of the dry aggregate,

- cement additives: two levels were used. In the first level no cement additives were used, while the second level represent the use of 1% Portland cement (by weight of dry aggregate) as an additive to the Micro-surfacing Mixtures,

- aggregate types: three sources of aggregates in Quebec were used in study. These sources are Ray-Car, Rive-sud, and Graham Pitt.

4.4 Study Design

This study is consisting of two phases. Following sections are description of each study phase.

4.4.1 Study Design, Phase I

The effect of asphalt emulsion residue and added water contents on the performance of Micro-surfacing mixtures was evaluated using a 3 x 4 multilevel nonrandomized design with three replicates per cell for each of mix combination. The two independent factors were:

- asphalt emulsion residue content: three levels of asphalt emulsion residue content were used. The three levels are 7.6, 8.1, and 8.6% asphalt emulsion residue expressed as percent by weight of the dry aggregate,

- added water content: four levels of added water content were used in the study. The four levels are 7, 8, 9, and 10%, expressed as percent by weight of the dry aggregate.

Effect of Cement Additives on set and traffic characteristics of micro-surfacing mixtures were also studied. Two levels of cement additives were used. In the first level, no cement additive was used, and in the second level, 1% Portland cement was used. Finally, optimum mix design was suggested with regard to four ISSA mix design tests. These tests are mixing time test (ISSA TB 113), modified cohesion test (ISSA TB 139), wet stripping test (ISSA TB

114) or Schulze-Breuer procedure (ISSA TB 144), and Vertical and Lateral Deformation by Load Wheel Test Sand Adhesion by Load Wheel Test (ISSA TB 147).

4.4.2 Study Design, Phase II

Phase II of study is about evaluation of a modification to ISSA mix design procedure for Micro-surfacing. The three independent factors were:

- aggregates types: three types of aggregates were used. These three types were Raycar, Graham Pitt, and Rive-sud aggregates sources from Quebec, Canada,

- asphalt emulsion residue content: three levels of asphalt emulsion residue content were used. The three levels are 7.6, 8.1, and 8.6% asphalt emulsion residue expressed as percent by weight of the dry aggregate,

- added water content: two levels of added water content were used in the study. First level was selected based on minimum of 120 seconds mixing time of mixture resulted from ISSA TB 113 mix design test. The second level was selected at maximum 30-min and 60-min cohesion of mixture resulted from ISSA TB 139 mix design test.

4.5 Statistical Analysis of Results

Analysis of results was conducted using Analysis of Variance (ANOVA) by STAT Graphic software (version 10). Analysis of variance (ANOVA) is generally used to analyze and identify those independent variables (Factors) that are related to the dependent variable (Responses). To do this, STAT Graphic software uses a Statistical Analysis System (SAS). ANOVA is also capable of determining any influence on results caused by interaction between different independent factors. Output of ANOVA is a model including independent variables (Factors) and dependent variable (Responses). In this model, those independent variables effecting on dependent variables are determined by ANOVA at a specified confidence level. ANOVA uses *R-square (R^2)* to predict the future outcomes of the model on the basis of other related information.

ANOVA is also capable of calculating the effect of different factors involved in study and their interactions on the results. ANOVA method firstly devide total variation in the results of the study into the different *group effects* such as the effect of asphalt emulsion residue content, added water content, interaction between them, and if aplicable, the effect of squared amount of asphalt emulsion residue and added water content. It firstly assumes a null hypothesis, which says that the means of different effect groups involved in study are same (H_o: $m\mu_1 = m\mu_2 = m\mu_3 = ... m\mu_k$). ANOVA then compares the variance of the mean of each effect group from the mean of the all results against the variance of the all results from the mean of the all results. Variance of the mean of each effect group is calculated by *estimated variance from standard error* and the variance of the all results is determined by calculating *average variance,*

Then, ANOVA determine the estimated variance from standard error, which is the difference of the mean of each effect group from the mean of all results. For this, ANOVA firstly determine the variance among the mean of different effect groups, which is called *variance of the means*. However, this variance should be converted to an estimate of the population variance by multiplying it by sample size for each group. This variance is also called *between groups variance* or *between groups mean square*, and is separately represented for each group in ANOVA table.

As it was mentioned, the second estimated variance is average variance, which is calculated by determining *within groups variance* and *within group mean square.* Within group mean square is known as *total error* in ANOVA table. ANOVA is capable of generating sum of squares values from results, and then, calculating within group variance by the sum of the sum of the squares across all effect groups. Thus, within group variance is also called *sum of squares* in ANOVA table. To calculate within group mean square (mean square), ANOVA firstly determine *within groups degrees of freedom*, which is the total number of results minus the number of effect groups. Then, within group mean square is determined by dividing within groups variance by the within group degree of freedom. At the end of this part of calculation, total error or total variation is reported in ANOVA table.

After determining the estimated variance from standard error for each group effect and the average variance of all results, ANOVA compare these two variances together in order to accept or reject the null hypothesis that all means in a study are equal (H_o: $m\mu_1 = m\mu_2 = m\mu_3 = ... m\mu_k$). If the estimated variance from standard error for each group effect and average variance of all results are approximately equal, then it can be concluded that the means of the different effect groups in study are equal together, and the null hypothesis is accepted. However, if these two variances are not equal, it can be concluded that the means of the different effect groups in study are different from each other, and the null hypothesis is rejected. Rejecting the null hypothesis for each of different effect groups means that the considered effect group significantly affects the results. ANOVA uses *F-value* and compares that with its critical value to estimate the significance level of effect. F-value is the ratio of the estimated variance from standard error to the average variance. ANOVA then set the confidence level at 95% and determine the critical F-value on the basis of $P = 0.05$, within group and between group degrees of freedom. ANOVA also uses table of critical F-values to directly calculate the critical F-value. The obtained F-value for each effect group is then compared with critical F-value, and if it is much more than the critical F-value, that effect group significantly affects the results.

Outputs of ANOVA used in this study are ANOVA table, standardized Pareto chart, main effect plot, and estimated response. ANOVA table show the statistical calculation of R-square, sum of square, mean of square, and F-value. Standardized Pareto chart evident standardaized effect of each effect group on the results. The red line on standardized Pareto chart represent the estimated critical F-value. Main effect plot and estimated response tabulate the actual effect of factors involved in study on the results.

CHAPITRE 5

DESCRIPTION OF ISSA MIXTURE DESIGN TESTS EVALUATED

5.1 Introduction

The International Slurry Surfacing Association design technical bulletin A143, published in May 2005, contains guidelines for the laboratory evaluation of micro-surfacing mixture designs. The tests examined include ISSA TB 113, 139, 100, 109, 147 (Method A). Generally, apparatus, materials, sample preparation, and testing procedures are the same as those in the International Slurry Surfacing Association design technical bulletin A143, published in May 2005.

- ISSA TB No. 113: Test method for measurement of mixing time of micro-surfacing-mixtures.

- ISSA TB No. 139: Test method to classify emulsified asphalt/aggregate mixture systems using a modified cohesion tester and the measurement of set and cure characteristics.

- ISSA TB No. 100: Test method for wet track abrasion of slurry surfaces, one-hour soak and six-day soak.

- ISSA TB No. 109: Test method for measurement of excess asphalt in bituminous mixtures by use of a loaded wheel tester and sand adhesion.

- ISSA TB No. 147 (Method A): Test method for measurement of stability and resistance to compaction, vertical and lateral displacement of multilayered fine aggregate cold mixes.

- in conjunction with the preceding work, relative moisture retained in samples at time of testing for samples of loaded wheel test and wet track abrasion test were studied.

5.2 Technical descriptions of the test apparatus and procedures

Technical descriptions of the test apparatus and procedures to perform those micro-surfacing mix design tests used in this study are described in the following sections.

5.2.1 Mixing Time Test (ISSA TB 113)

This test makes use of trial mixtures to identify if the material can be mixed at temperature of 77ºF (25ºC) and 100ºF (37.7ºC) for at least 120 and 180 seconds respectively.

Apparatus and Materials

1. A 6 oz. (177 ml) Dixie #2336 plastic-lined paper hot drink cup for 100 gram mixes.
2. A 4 inch (10 cm) steel spatula mixing blade.
3. A scale capable of weighing 500 grams with sensitivity of 0.1 gram.
4. ASTM E-11 sieves #20 (850 µm) and #50 (300 µm).
5. A supply of high wet-strength roofing felt paper.
6. An ASTM low softening Thermometer.
7. A timer.

Sample Preparation and Testing Procedure

Aggregates were washed through sieve #200 to remove all its filler content and dried in an l40°F (60°C) oven to a constant weight for a period of 24 hours. Aggregate was then screened through sieves #3/8 (9.5 mm), 4 (4.75 mm), 8 (2.5 mm), 18 (1.25 mm), 16 (0.63 mm), 30 (0.6 mm), 50 (0.315), 100 (0.16 mm), #200 (0.08 mm) respectively to obtain desired aggregate gradation within the maximum and minimum aggregate gradation limits suggested by ISSA for type III Micro-surfacing application. Desired amount of commercial filler were added to aggregates when using Ray-Car aggregates to obtain correct amount of filler based on specific aggregate gradations used in different phase of study. When Rive Sud and

Graham Pitt aggregate were used, same filler as those included in aggregate were used to obtain desire aggregate gradation. 100 grams of aggregates were weighed into 6 oz. (177 ml) plastic-lined paper hot drink cup. If cement was required, desired amount of cement additives was added to aggregates and was mixed for 10 seconds with stele spatula at 60-70 RPM in a circular motion. Desired amount of water was added to mixture and mixed until distribution of water in the mix was complete and uniform. Then, required amount of emulsified asphalt was added to the mixture and mixed for 30 seconds with stele spatula at 60-70 RPM in a circular motion or until mixture is completely homogenous. At the end of initial mixing cycle, about half of the mix was casted on the high wet-strength roofing felt paper and spread the mix to the depth of 1/4 to 3/8 inch (6.4 to 10 mm). Mixing of the portion remaining in the cup was continued until the mix was broken. A timer was used to measure the time corresponding to breaking of mixture. This time was recorded as mixing time of mixture.

5.2.2 Modified Cohesion Test (ISSA TB 139)

The cohesion test is used to classify emulsified asphalt/aggregate mixture to slow or fast setting systems. It also can be used to establish baseline formulations of asphalt emulsion, water, aggregate, and cement additives suitable for further testing. In other words, suitable asphalt emulsion-water combination is selected based on results obtained after 30 and 60 minutes of curing at room temperature, 25°C (77°F). The minimum values required are 12 kilogram-centimeters for the 30 minutes test, 20 kg-cm for 60 minutes. Figure 5.1 shows the modified cohesion tester used in this study.

<u>Apparatus and Materials</u>

1. Modified cohesion tester, similar to the ASTM D 3910-80 but modified as follow:
    a. 1 to 1.8 inch (28.5 mm) double rod air cylinder with 5/16 in (8 mm) rods, and 3 inch (75 mm) stroke,
    b. 1/4 inch (6.3 mm) x 1-1/8 inch (28.5 mm) diameter, 60 durometer neoprene rubber foot,

c. Air pressure regulator with a variable downstream bleed valve so that the constant pressure is maintained,
d. Four-way directional control valve with exhaust port regulating valves,
e. Air pressure gauge with a 0 to 700 k Pa pressure gauge,
f. 700 K Pa (100 psi) air supply, and
g. Torque meter capable of measuring and marking at least 3.5 Nm (35 kg-cm) torque.

2. A supply of 1.55 in² (10 cm²), 15 lb (6.8 kg) saturated roofing felt to be used as specimen mounting pads.
3. Specimen molds 6 mm x 60 mm diameter.
4. ASTM E-11 sieves #4 (4.75 mm), and #200 (0.75 mm).
5. 10 mm x 60 mm diameters specimen mold.
6. Steel spatula for mixing and for scraping off neoprene foot.
7. A scale capable of weighing 500 grams with sensitivity of 1 gram.
8. Forced draft oven set at 60°C (140°F).
9. For Calibration :
    a. 20-30 mesh standard ASTM C-190 Ottawa Sand,
    b. Load cell to periodically check the cohesion meter pressure.
    c. 100 grit silicon carbide Carborundum™ brand sand paper, and
    d. 220 grit silicon carbide 3-M™ brand sand paper.

<u>Sample Preparation and Testing Procedure</u>

Sample preparation for Modified Cohesion test is exactly same as for mixing time test. The only difference is that the type III aggregate gradation obtained from aggregate screening was then screened again through sieves #5/16 (8 mm) and the portion retained was discarded. A suitable number of identical specimens were mixed and casted in 10 mm x 60 mm diameters ring mold centered on the roofing felt squares and allowed to cure at room temperature. Torque measurement was made at suitable time intervals such as 30, 60, 90, 150, 210, and 270 minutes after casting. The specimen was centered under the neoprene foot and the instrument air pressure was set at 200 kPa. The neoprene foot was lowered against the specimen at a rate of 8 to 10 cm per second. After 5 to 6 seconds of compaction the torque meters was zeroed and placed on the top cylinder rod-end and twisted horizontally through 90º to 120º arc for 0.5 to 0.7 seconds. The torque was recorded along with the time. Finally, cylinder raised and foot cleaned by scrapping.

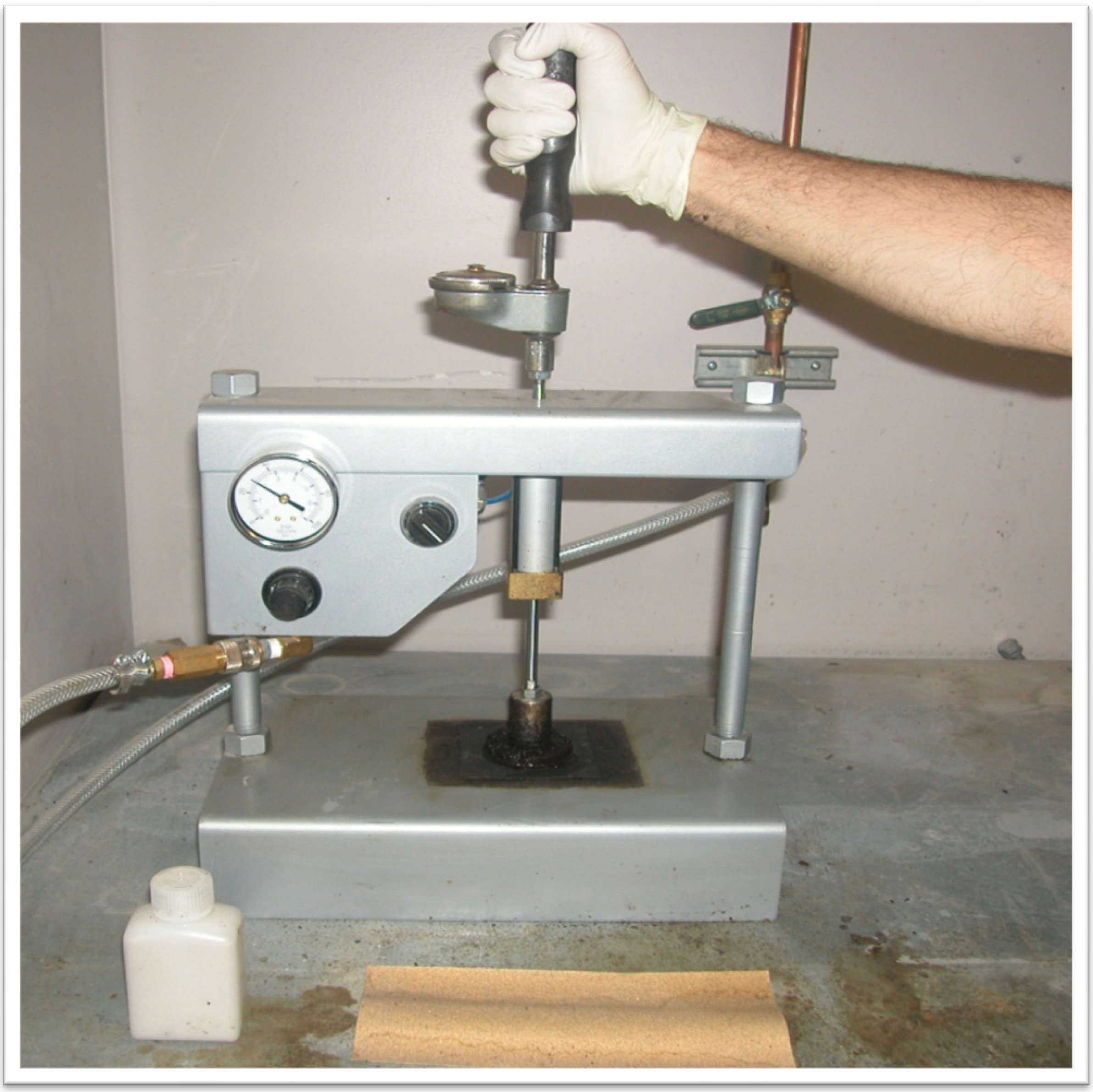

Figure 5.1 Modified Cohesion Tester

5.2.3 Wet Track Abrasion Test (ISSA TB 100)

Wet track abrasion test is a field simulation test to measure the wearing qualities of micro-surfacing mixture under wet abrasion conditions. Wet track abrasion test establishes the minimum asphalt emulsion content necessary to prevent excessive raveling of cured micro-surfacing mixture. This test was conducted after curing the samples. Wet track abrasion test were performed on 1-hour and 6-day soaked sample to determine susceptibility to long-term moisture exposure. Figure 5.2 shows the wet track abrasion machine used in this study.

Apparatus and Materials

1. A scale capable of weighing 5000 grams with sensitivity of 1 gram.
2. Rust resistant metal flat surfaced mold, depth 6.35 mm and diameter 247.7 mm.
3. A Hobart N-50 mixer, equipped with a 2.27 kg abrasion head, quick clamp mounting plate and 300 mm depth flat bottom metal pan.
4. Roofing felt squares 300 mm x 300 mm.
5. Forced draft oven set at 140 ºF (60°C).
6. 127 length reinforced rubber covered hose with 19 mm internal diameter and 6.25 mm wall thickness.
7. Forced draft oven set at 140°F (60°C).
8. Constant temperature water bath controlled at 77°F (25°C) ± 1.8°F (1°C).
9. A 30 mm window squeegee with 25 mm diameter x 350 mm wooden dowel.

Sample Preparation and Testing Procedure

Sample preparation for Wet Track Abrasion Test was also same as for modified cohesion and mixing time tests. However, there are some differences in the process of sample preparation. After initial screening of dried aggregates to obtain desired aggregate gradation, obtained type III aggregate gradation was again screened through sieves #4 (4.75 mm) and the portion retained was discarded.

700 gram of dried aggregate was weighted into the mixing bowl. Portland cement mixed into aggregate until uniformly distributed by using the spoon. Predetermined amount of asphalt emulsion and water were added to mixture. As the asphalt emulsion used in study was Quick-set system, the mixture was mixed and cast in less than 45 seconds. The micro-surfacing mixture was then rapidly poured out onto the felt pad. The mixture was then level off by means of the window squeegee. After the mixture broke, the mold was removed and the molded sample was then placed in an l40°F (60°C) oven to dry to a constant weight for a period of 24 hours. After 24 hours curing in forced draft, the dried samples were removed from the oven and allowed to cool for 30 minutes. The edges of felt pad were then cut off and the sample was immediately weighted, and the weight recorded.

After weighing of sample, it was placed in the 77°F (25°C) water bath at room temperature for one hour or six days. At the end of the soaking period, the sample was removed from water bath and placed in the 330 mm flat bottom pan of the abrasion tester. The sample was then clamped to the mounting plate by tightening the quick clamps, and completely covered by 6.35 mm water at room temperature. Rubber hose abrasion head was locked on the shaft of the Hobart machine. Platform of the Hobart machine was elevated until the unused rubber hose contact freely on the surface of the specimen. The timer was set for five minutes and fifteen seconds. Hobart machine switched to low speed, and allowed to abrade the sample for the set time. The rubber hose rotated after each test run to its fresh side for the next specimen.

After completing the abrasion cycle, the specimen was removed from the pan and washed off debris with slow running water. The specimen was then placed in an l40°F (60°C) oven to dry to a constant weight, and allowed to reach temperature and weighted. The difference between this new weight and the weight in grams obtained from before placing the sample in77°F (25°C) water bath was reported as abrasion loss of specimen.

Figure 5.2 Wet Track Abrasion Testing Machine (Hobart N-50)

5.2.4 Loaded Wheel Test (ISSA TB 109)

Loaded wheel test measures the resistance of mixture against flushing under heavy traffic. This test establishes the maximum asphalt emulsion content necessary to prevent flushing of cured micro-surfacing mixtures. The mixture is compacted by means of a loaded, rubber tired, reciprocating wheel. The measured parameter is the sand adhesion, which is an indirect measure of the amount of excess asphalt in the mix. Figure 5.3 shows the loaded wheel test machine used in this study.

<u>Apparatus and Materials</u>

1. A wheel testing machine designed based on specifications recommended by ISSA technical bulletin A143, May 2005.
2. Specimen mold 12.5 mm thick, 3 in x 16 in (76.2 mm x 406.4 mm) outside, and 2 in x 15 in (50.8 mm x 381 mm) inside dimensions.
3. Galvanized Steel specimen mounting plates 0.6 mm (0.024 in), 3 in x 16 in (76.2 mm x 406.4 mm).
4. 56.7 kg (125 lb) of lead weights.
5. Steel sand frame, 0.188 in x 2.5 in x 15 in (4.76 mm x 63.5 mm x 381 mm) outside, and 1.5 in x 14 in (38.1 mm x 355.6 mm) inside dimensions. One side of the frame should be completely lined with 1/2 inch x 1/2 inch (12.5 mm x 12.5 mm) adhesive backed foam rubber insulation and hold down clamps.
6. 1 (25.4 mm) diameter x 6 (152.4 mm) long wood strike off dowel.
7. A flat platform scale capable of weighing 250 lb (113.4 grams) with sensitivity of 1 lb (0.45 gram).

<u>Sample Preparation and Testing Procedure</u>

Sample preparation for Loaded Wheel test was exactly same as for wet track abrasion test described in section 5.2.3. The temperature was maintained at 77°F (25°C) during the test. The wheel was inspected and thoroughly cleaned with evaporative solvent and water. The wheel was placed on a platform scale so that the connecting arms were parallel with the frame. The lead weights are added to the weight box until the 125 lb (56.7 kg) weight was obtained. After the sample had cured for 24 hours and cooled to room temperature, it was firmly clamped to the frame. The counter was returned to zero and the compaction was started with the electrical switch. 1000 cycles of the 125 lb (56.7 kg) loaded wheel with 44 cycle per minute speed were completed on the specimen. At some point during the compaction an audible tackiness and visible shine was noted. At this point, sufficient water to prevent adhesion of the specimen to the wheel wad added from the wash bottle. After 1000 cycles, the machine was stopped and unloaded. The specimen was removed from unit, and washed of loose particles and dried at 140°F (60°C) to constant weight. The weight of this compacted sample was then recorded. After weighting the specimen, it was again mounted on the mounting plate in its original position. The sand frame was centered the specimen and secured with the foam rubber against the specimen to prevent loss of sand. Two hundred grams of fine Ottawa sand (ASTM Designation C-I09 graded standard) and metal strip were heated to 180°F (82.2°C) was uniformly spread over the sample surface that appears within the frame. Metal strip was then placed over the sand covered sample surface and the wheel was immediately loaded to 125 lb (56.7 kg) and placed on the sample. The counter was returned to zero and the compaction was started with the electrical switch. The compaction wheel then rides on the metal strip for 100 cycles. After 100 cycles, the machine was stopped and unloaded. The specimen was removed from unit, and disassembled over a waste container and gently tapped to remove the unadhered sand. The sample was again weighted, and new weight recorded. The difference between this new weight and the weight in grams obtained from after completion of 1000 cycles of the 125 lb (56.7 kg) loaded wheel was reported as sand adhered to the specimen, which is an indirect measure of the amount of excess asphalt in the mix. The temperature at which the tests have been performed must be reports as well. This test was conducted at 25°C that correspond to moderate traffic.

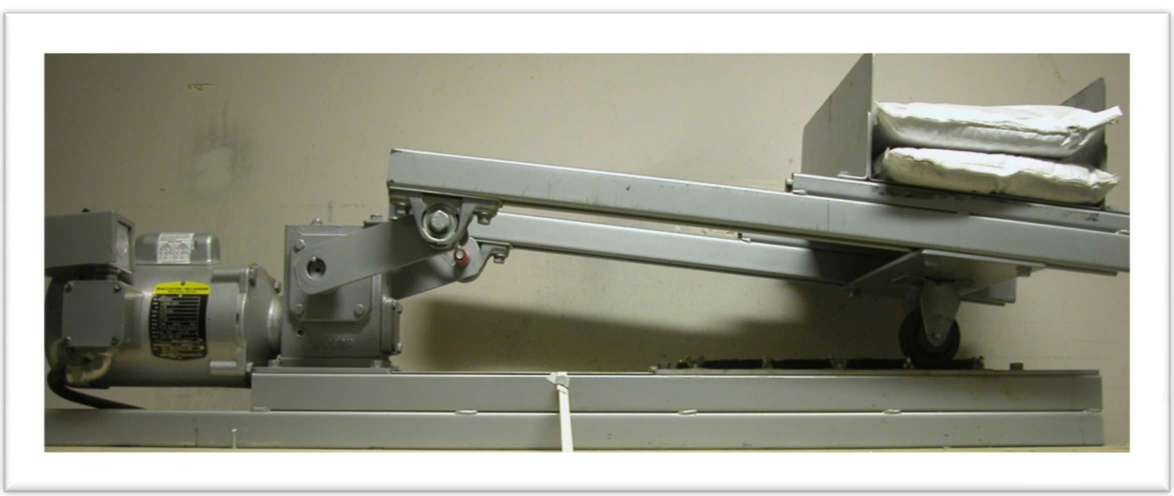

Figure 5.3 Loaded Wheel Testing Machine

5.2.5 Multilayer Loaded Wheel Test Vertical & Lateral Displacement (Method A-ISSA TB 109)

Multilayer Loaded Wheel test measures the amount of compaction or displacement characteristics of micro-surfacing under simulated rolling traffic compaction. Because micro-surfacing can be used for filling ruts, it should have proper resistance against vertical and lateral deformations under heavy traffic. This test establishes the minimum asphalt emulsion content necessary to prevent excessive deformation of micro-surfacing mixture. When a series of specimens, containing a different range of asphalt emulsion contents are tested, optimum emulsion content for rutting resistance can be determined at the minimum vertical and lateral displacements.

Apparatus and Materials

1. A wheel testing machine designed based on specifications recommended by ISSA technical bulletin A143, May 2005.
2. Specimen mold 12.5 mm thick, 3 in x 16 in (76.2 mm x 406.4 mm) outside, and 2 in x 15 in (50.8 mm x 381 mm) inside dimensions.
3. Galvanized Steel specimen mounting plates 0.6 mm (0.024 in), 3 in x 16 in (76.2 mm x 406.4 mm).
4. 56.7 kg (125 lb) of lead weights.
5. 1 (25.4 mm) diameter x 6 (152.4 mm) long wood strike off dowel.
6. A flat platform scale capable of weighing 250 lb (113.4 grams) with sensitivity of 1 lb (0.45 gram).
7. Gauge block 0.188 x 0.5 x 14 in (4.8 mm x 12.7 mm, 101.6 mm) with 1/4 in (6.35 mm) slot and calipers capable of measuring specimen width and depth to within 0.001 in (0.01 mm)

Sample Preparation and Testing Procedure

The sample preparation and test procedure is exactly same as for loaded wheel test except that the specimen was firstly air cured at room temperature for 18 hours, and then was placed in forced draft oven to cure for a period of 24 hours. The test procedure was same as for the loaded wheel test is described in Section 5.2.4 In addition to the regular Procedure, the width and height of the specimen are measured (in the wheel path and at the mid-point of specimen length) before and after 1000 cycles of the 125 lb (56.7 kg) loaded wheel compaction. In this report, the width and height of the specimen were measured after 1000, 2000, and 3000 cycles of the 125 lb (56.7 kg) loaded wheel compaction. Base on ISSA technical bulletin, May 2005, it has been found that unconfined vertical and lateral deformations that exceed 10% and 5% respectively are not satisfactory for compacted, multi-layer applications. Multilayer Loaded Wheel Test Vertical & Lateral Displacement was conducted at 25°C that correspond to moderate traffic.

5.2.6 Wet Stripping Test

This test is designed to help designer to select a compatible slurry system with a given aggregate. Filler/additives should remain coated by asphalt emulsion under the test condition. Incompatibility between filler/additives and asphalt emulsion can result in uncoated area on the specimen surface.

Apparatus and Materials

1. 600 ml Pyrex beaker.
2. Adjustable temperature hot plate or Bunson burner, and wire mesh.
3. Absorbent, high wet strength paper such as common household paper towels.

Sample Preparation and Testing Procedure

10 grams ± 1 gram of cured micro-surfacing mixture, representative of the entire specimen were obtained from samples of mixing time test, and allowed to cure for 24 hours in 60°C forced draft oven. 400 ml of tap water was added to the 600 ml Pyrex beaker and was placed on the hot plate to bring to vigorous boil. The 10 grams specimen was dropped into the boiling water, and was allowed to boil in the water for 3 minutes. At the end of 3 minutes boiling period, the beaker with its contents were removed from the hot plate, and were allowed to cool. After the beaker and its content were cool enough, cold tap water were run

into the surface of water inside the beaker and continued until any free asphalt on the surface of the water flows over the side of the beaker. The water inside the beaker was then decanted and the contents were removed from the beaker and placed on the absorbent paper toweling. After drying, sample was examined for uncoated areas, and an estimate was made of the aggregates areas remaining coated with asphalt.

CHAPITRE 6

STUDY OF MICRO-SURFACING DESIGN PARAMETERS

6.1 Introduction

This part of study reports the findings of a detailed laboratory investigation concerning the effect of asphalt emulsion and added water content and the use of additives (1% Portland cement) on the design parameters and properties of micro-surfacing mixtures. For this, one aggregate type (Raycar), one asphalt emulsion type/grade (CQS-1HP), and one aggregate gradation (Mid-range gradation) were used in the study. The evaluation was conducted at one curing stages of the mix (24-Hours). The study consisted mainly of establishing a method for preparing and testing micro-surfacing mixture using four mixture design tests proposed by the ISSA. These tests used include:

- ISSA TB No. 109: Method for measurement of excess asphalt in bituminous mixtures by use of a loaded wheel tester and sand adhesion.

- ISSA TB No. 100: Method for wet track abrasion of slurry surfaces, one-hour soak and six-day soak.

- ISSA TB No. 139: Method to classify emulsified asphalt/aggregate mixture systems using a modified cohesion tester and the measurement of set and cure characteristics.

- ISSA TB No. 113: Practice for Design, Testing and Construction of Micro-surfacing Mixtures.

6.2 Loaded wheel test result analysis

In this section, results from the loaded wheel test (sand adhesion) are presented to discuss the effects of variations in asphalt emulsion and added water content on the test results of specific micro-surfacing formulations. Three asphalt emulsion residue contents (7.6, 8.1, and 8.6%) and four added water contents (7, 8, 9, and 10%) are the independent variables to estimate the amount of excess asphalt of specific micro-surfacing formulations. Three replications were made for each asphalt emulsion residue-water combination. Table 6.1 shows summary of test results of loaded wheel test.

Table 6.1 Summary of test results of loaded wheel test (sand adhesion)

Asphalt Residue Content (%)	**Added Water Content** (%)	**Loaded Wheel Test (Sand Adhesion)**			
		Mean Sand Adhered (g/m^2)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
7.6	**7**	300.16	8.52	2.84	3
8.1	**7**	371.51	11.27	3.03	3
8.6	**7**	496.99	8.53	1.72	3
7.6	**8**	366.59	11.27	3.07	3
8.1	**8**	496.99	15.37	3.09	3
8.6	**8**	514.21	11.27	2.19	3
7.6	**9**	302.62	7.38	2.44	3
8.1	**9**	492.06	11.28	2.29	3
8.6	**9**	440.40	11.27	2.56	3
7.6	**10**	496.98	11.28	2.27	3
8.1	**10**	469.92	17.04	3.63	3
8.6	**10**	580.64	17.05	2.94	3

Figure 6.1 is a plot of raw data for sand adhered values versus asphalt emulsion residue at 7, 8, 9, and 10% added water content. As it can be seen from this figure when mixtures contain low amounts of water (7 and 8%), there is a sharp increase in sand adhered. But, mixtures with 9 and 10% water, behave in a different manner. This graph indicates that there is

substantial increase in sand adhered as different asphalt emulsion residue contents are added to the mixtures. It also shows that the amount of adhered sand increases as added water content increases in the mixture.

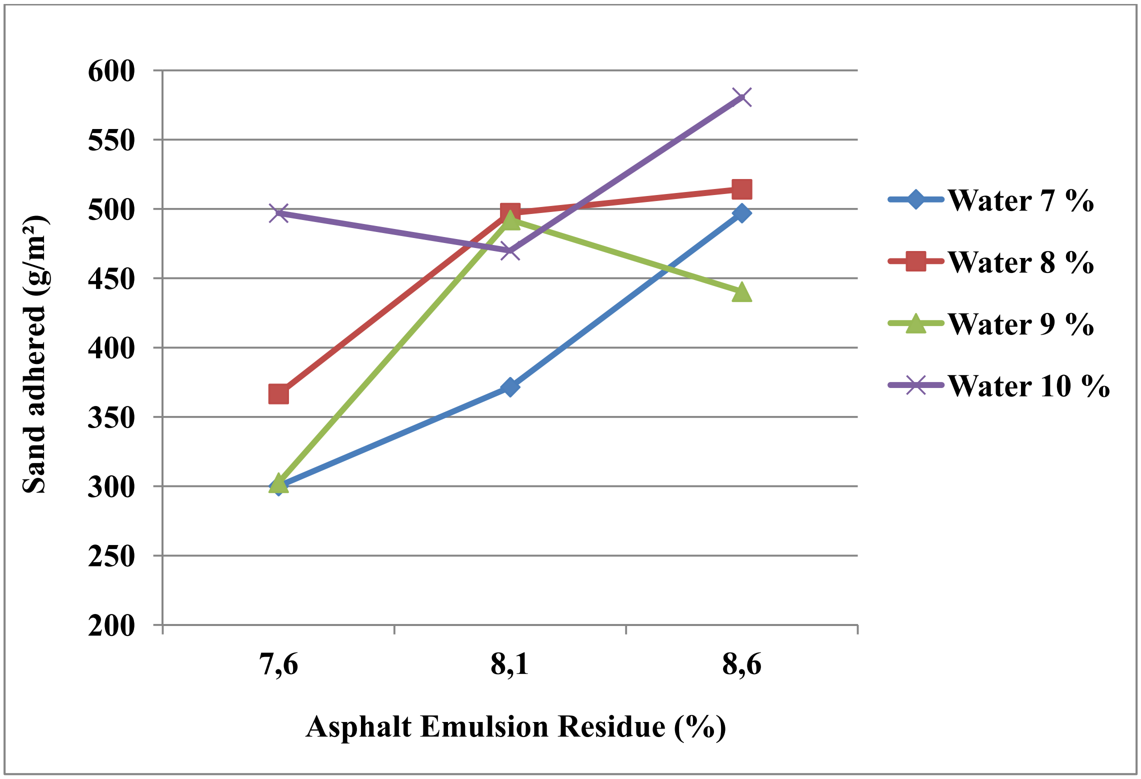

Figure 6.1 Loaded wheel test sand adhesion values
against asphalt emulsion residue with 7, 8, 9, and 10% added water content

The ANOVA model for this experiment is:

$$Y_{ijk} = \mu + A_i + E_j + (AE)_{ij} + \varepsilon_{ijk} \tag{6.1}$$

Where Y_{ijk} = adhered sand after 100 cycle compaction (g/m²), μ = mean sand adhered (g/m²), A_i = effect of i^{th} asphalt emulsion residue content, E_j = effect of j^{th} added water content, AE_{ij} = effect of interaction between i^{th} asphalt emulsion residue content and j^{th} added water content, and ε_{ijk} = random error for the i^{th} asphalt emulsion residue content and jth added water content, and k^{th} replicate.

Final ANOVA model for this experiment is:

Sand Adhered (g/m²) = – 8157.16 + 975.045×A_i + 561.98×E_j – 62.7414×AE_{ij}

As it can be seen from ANOVA table (Table 6.2), R-Squared is 73.9348%. The R-squared statistics indicates that this model as fitted explains 73.9348% of the variability.

Table 6.2 ANOVA Table,Output of LWT Results

Analysis of Variance for LWT (sand adhesion)					
Dependent Variable: Sand adhesion					
R-squared = 73.9348%					
R-squared (adjusted for d.f.) = 64.1604%					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Value**	**P-Value**
A:Asphalt	53947.9	1	53947.9	11.89	0.0087
B:Water	39662.8	1	39662.8	8.74	0.0183
AB	9384.11	1	9384.11	2.07	0.1884
Total error	36310.1	8	4538.76		

Output of ANOVA table for LWT results show that two effects have P-value less than 0.05, indicating that they are significantly different from zero at the 95.0% confidence level.

These two effects are of the amount of asphalt emulsion residue (A_i), and added water content (E_j), Figure 6.2 shows the significant effect of asphalt emulsion residue and added water content on result of loaded wheel test.

Determined F-value for asphalt and waer effects are respectively 11.89 and 8.47, which are greater than critical F-value. However, asphalt effect has greater F-value than water, showing its greater effect.

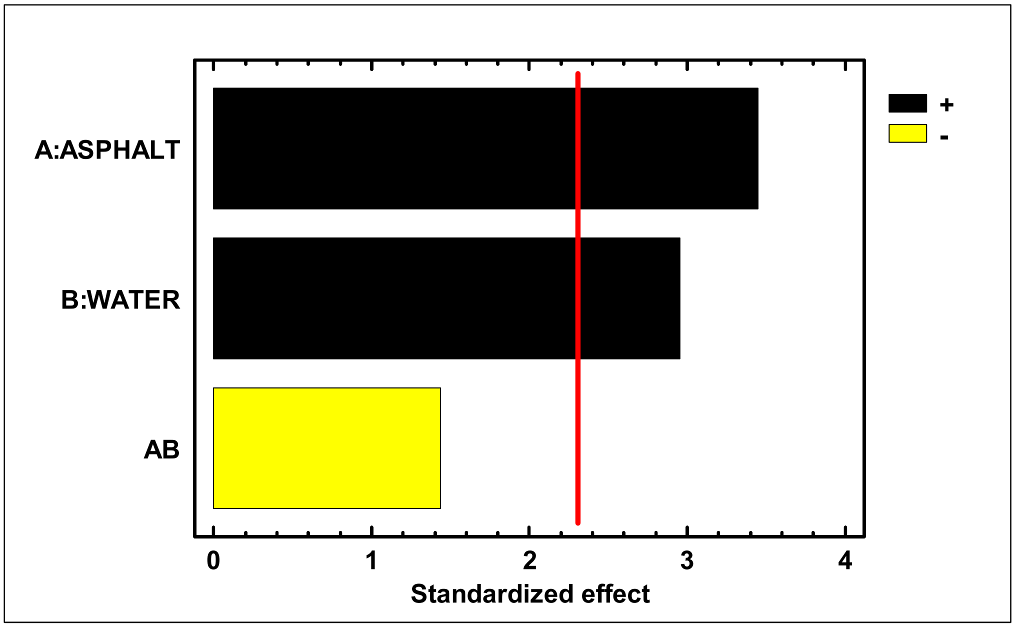

Figure 6.2 Standardized Pareto chart for Loaded Wheel Test Results
(The red line represent the estimated critical F value)

Figure 6.3 and 6.4 show the main effect plot and estimated response of asphalt emulsion and added water contents for LWT results. As it can be seen from these figures the amount of water in the mixture has a profound influence on the sand adhesion. By changing only the quantity of water in the mixtures with the same quantity of emulsion, the amount of sand adhered increased or decreased. It appears that the amount of sand adhered to the sample is sensitive not only to the amount of asphalt emulsion, but also sensitive to the amount of added water. Figure 6.4 evident that the effect of asphalt emulsion residue on LWT tests responses is more than the influence of water. The primary purpose of LWT is to determine maximum limit for adding asphalt emulsion in the mixture and is used in ISSA TB 111 and ISSA TB 143 mix design procedures for slurry seal and micro-surfacing to determine optimum binder content. In these guidelines, the WTAT will be performed at 1-hour and 6-day soak periods followed by tests using the LWT to determine the excess asphalt at the temperature that corresponds to the proposed traffic conditions (i.e., heavy at 35°C, moderate at 25°C, and low at 15°C). Finally, the optimum binder content will be selected by evaluating the abrasion loss in the WTAT and the binder content versus pick up from the loaded wheel tester. Designer should prepare trial mixtures with different amount of asphalt emulsion and added water contents to perform loaded wheel test, while, the results of this test are significantly influence by different amount of water in those trial mixes. Thus the consistency for the loaded wheel test is poor which implies that the test method is vague and permits a wide range of interpretation.

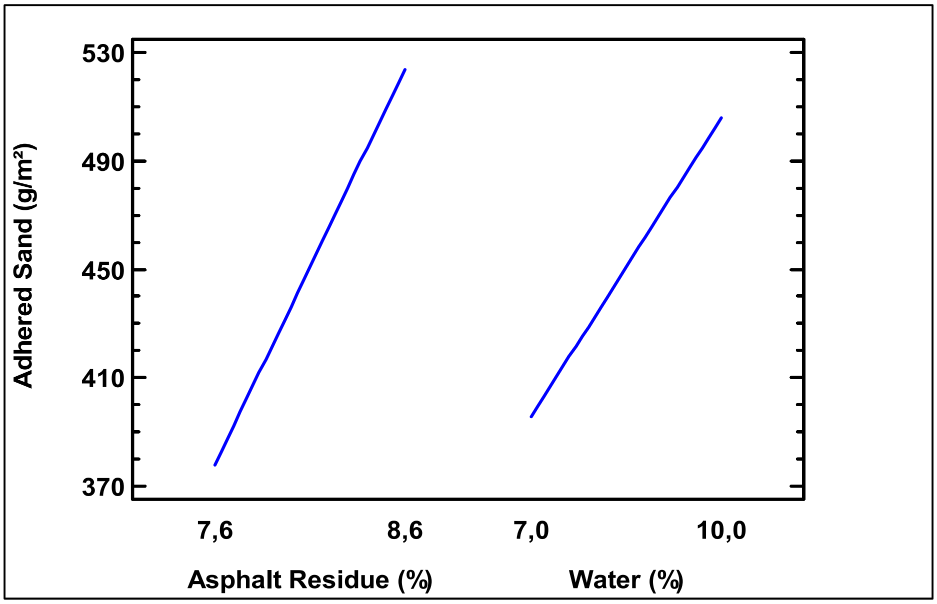

Figure 6.3 Effects of Asphalt Emulsion Residue and Water on LWT test Results (Main Effect Plot)

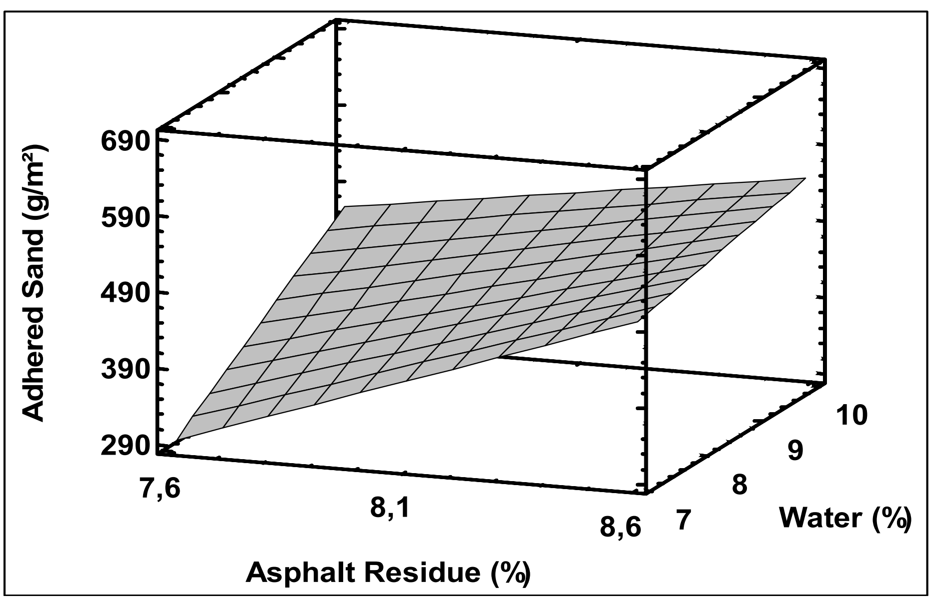

Figure 6.4 Effects of Asphalt Emulsion Residue and Water on LWT test Results (Estimates Response)

6.3 Wet Track Abrasion Test Result Analysis

Results from the Wet Track Abrasion Test (1-Hour and 6-Day Soaked Sample) are presented to evaluate the effects of variations in asphalt emulsion and added water content on the test results of specific micro-surfacing formulations. Three asphalt emulsion residue contents (7.6, 8.1, and 8.6%), and four added water contents (7, 8, 9, and 10%) are the independent variables to estimate the aggregate loss of specific micro-surfacing formulations. Three replications were made for each asphalt emulsion residue-water combination.

6.3.1 Test Result Analysis of 1-Hour Soaked Samples

Summary of test results and aggregate loss for 1-Hour soaked sample of each asphalt emulsion residue-water combination are presented in table 6.3. Three replications were tested for each asphalt emulsion residue-water combination.

Table 6.3 Summary of results for Wet Track Abrasion Test (1-Hour Soaked)

Asphalt Residue Content (%)	**Added Water Content** (%)	**Wet Track Abrasion Test (Aggregate Loss), 1-Hour Soaked Sample**			
		Mean Aggregate Loss (g/m^2)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
7.6	**7**	87.73	1.90	2.17	3
8.1	**7**	54.83	7.60	13.86	3
8.6	**7**	54.83	5.03	9.17	3
7.6	**8**	74.57	8.28	11.10	3
8.1	**8**	37.29	3.80	10.19	3
8.6	**8**	52.64	3.29	6.25	3
7.6	**9**	76.77	3.80	4.95	3
8.1	**9**	68.76	3.80	5.53	3
8.6	**9**	28.51	8.28	29.04	3
7.6	**10**	53.74	1.90	3.54	3
8.1	**10**	47.16	3.80	8.06	3
8.6	**10**	37.29	3.80	10.19	3

Figure 6.5 is a plot of raw data for aggregate loss values versus asphalt emulsion residue at 7, 8, 9, and 10% added water content. As asphalt emulsion residue increased, the amount of aggregate loss decreased. However, a uniform pattern of abrasion loss versus added water content was not achieved in this test.

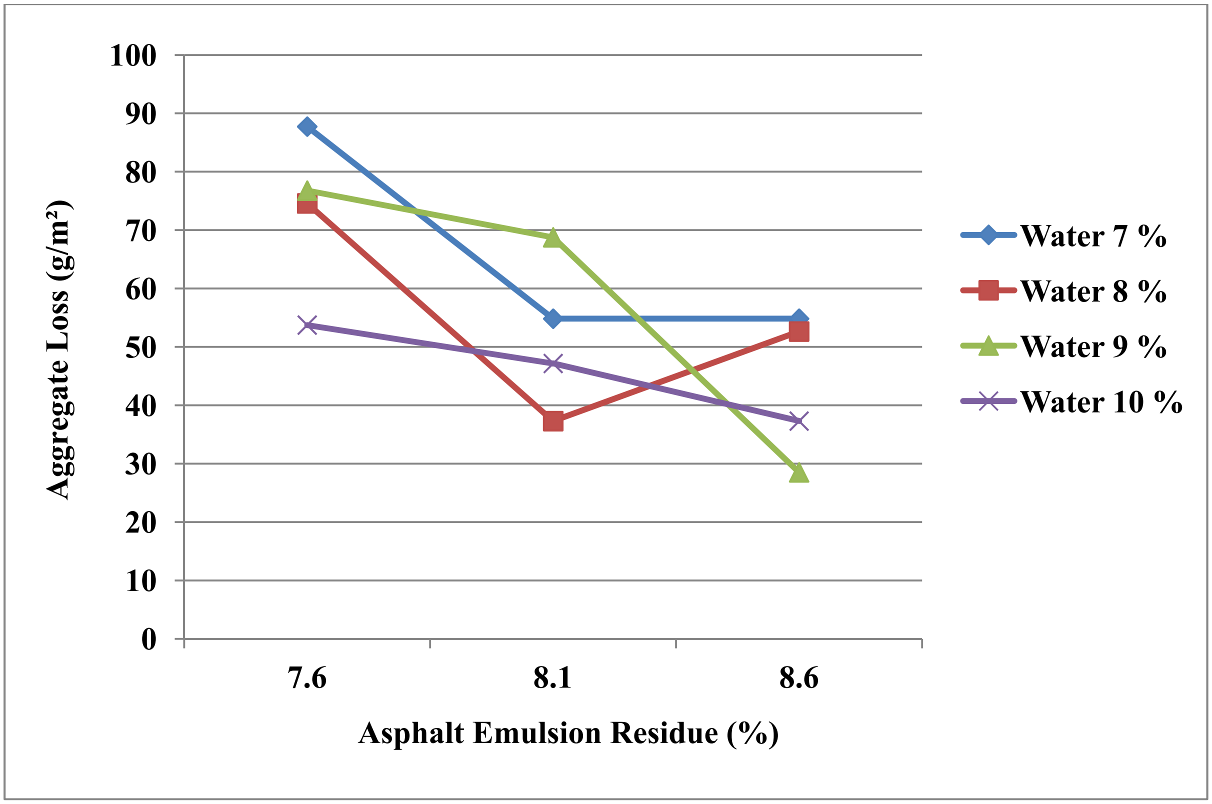

Figure 6.5 1-hour soak wet track abrasion values
against asphalt emulsion residue with 7, 8, 9, and 10% added water

The ANOVA model for this experiment is:

$$Y_{ijk} = \mu + A_i + E_j + \varepsilon_{ijk} \qquad (6.2)$$

Where Y_{ijk} = Aggregate Loss (g/m²), μ = mean aggregate loss (g/m²), A_i = effect of i^{th} asphalt emulsion residue content, E_j = effect of j^{th} added water content, and ε_{ijk} = random error for the i^{th} asphalt emulsion residue content and j^{th} added water content, and k^{th} replicate.

Final ANOVA model for this experiment is:

Aggregate Loss (g/m^2) = 351.736 – 29.4803× A_i – 6.394× E_j

Table 6.4 presents ANOVA table for result of Loaded Wheel Test. As it can be seen from ANOVA table, R-Squared is 67.3313%. The model as fitted explains 67.3313% of the variability, showing relatively low R-square. This indicates that with material combination used in this study, the 1-hour soak wet track abrasion test may yield some unexpected results. Therefore, the use of the 1-hour soak wet track abrasion test to determine minimum asphalt emulsion and short-term water susceptibility of micro-surfacing mixtures is not suggested.

Table 6.4 ANOVA Output of Analysis of Variance for WTAT (1-Hour Soaked)

Analysis of Variance for Wet Track Abrasion (1-Hour Soaked)					
Dependent Variable: Aggregate Loss					
R-Squared = 67. 3313%					
R-squared (adjusted for d.f.) = 60. 0716%					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Value**	**P-Value**
A:Asphalt	1657.44	1	1657.44	13.54	0.0051
B:Water	613.249	1	613.249	5.01	0.0520
Total error	1101.72	9	122.413		

Output of ANOVA table for Wet Track Abrasion test (1-Hour Soaked) results show that, one effect has P-value less than 0.05, This one effect is effect of asphalt emulsion residue, (A_i). However, P-value of added water content is close to 0.05, indicating the importance of this effect. Figure 6.6 shows standardized effect of asphalt and water on test results. Estimated F-value for effect of asphalt and water are equal to 13.54 and 5.01. Effect of asphalt is relatively more than effect of water, because, it has greater F-value than water. It should be noted that the effect of water is also large. Figure 6.6 shows that the estimated F-value for effect of water is close to critical F-value, showing its relatively large effect.

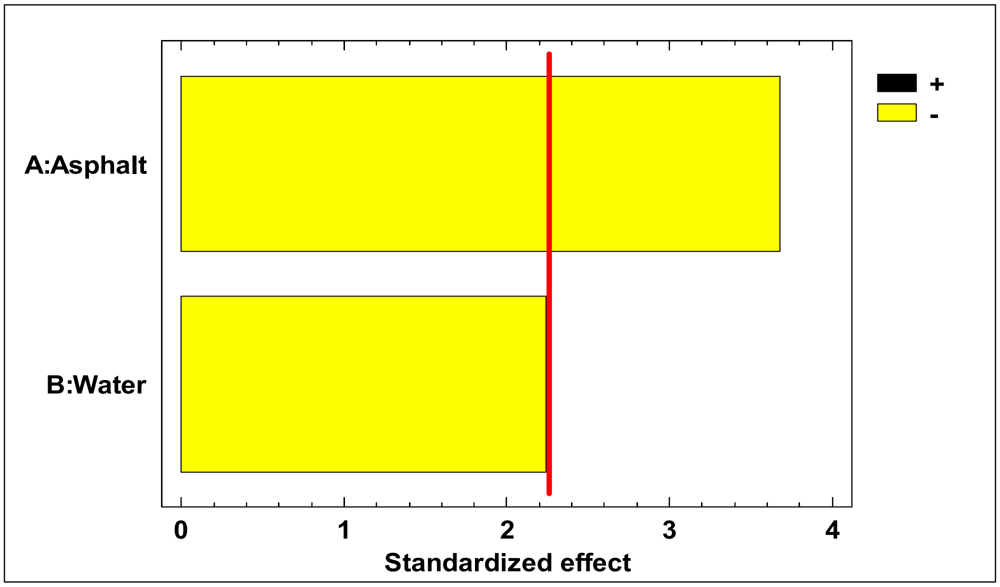

Figure 6.6 Standardized Pareto chart for Wet Track Abrasion Test Results (1-Hour Soaked Samples) (The red line represent the estimated critical F value)

Figure 6.7 and 6.8 show the main effect plot and estimated response for Wet Track Abrasion test results (1-Hour Soaked Samples). By increasing in asphalt emulsion residue and added water content, aggregate loss decreases. As it also can be seen from these figures the amount of water in the mixture has a profound influence on the aggregate loss of samples. By changing only the quantity of water in mixtures with the same quantity of emulsion, the amount of aggregate loss increased or decreased. It appears that the amount of aggregate loss of sample is sensitive not only to the amount of asphalt emulsion, but also is too sensitive to the amount of added water content. Figure 6.8 show that the effect of asphalt emulsion residue is more than the effect of added water content on WTAT (1-Hour Soaked Samples). The primary purpose of Wet Track Abrasion Test is to determine minimum limit for adding asphalt emulsion in the mixture. In ISSA TB 111 and ISSA TB 143 guidelines, the optimum binder content will be selected by evaluating the abrasion loss in the Wet Track Abrasion Test and the binder content versus pick up from the loaded wheel tester. Designer should prepare trial mixtures with different amount of asphalt emulsion and added water contents to perform Wet Track Abrasion test results (1-Hour Soaked Samples) while the results of this test are significantly influence by different amount of water in those trial mixes. Thus the consistency for the loaded wheel test is poor which implies that the test method is vague and permits a wide range of interpretation.

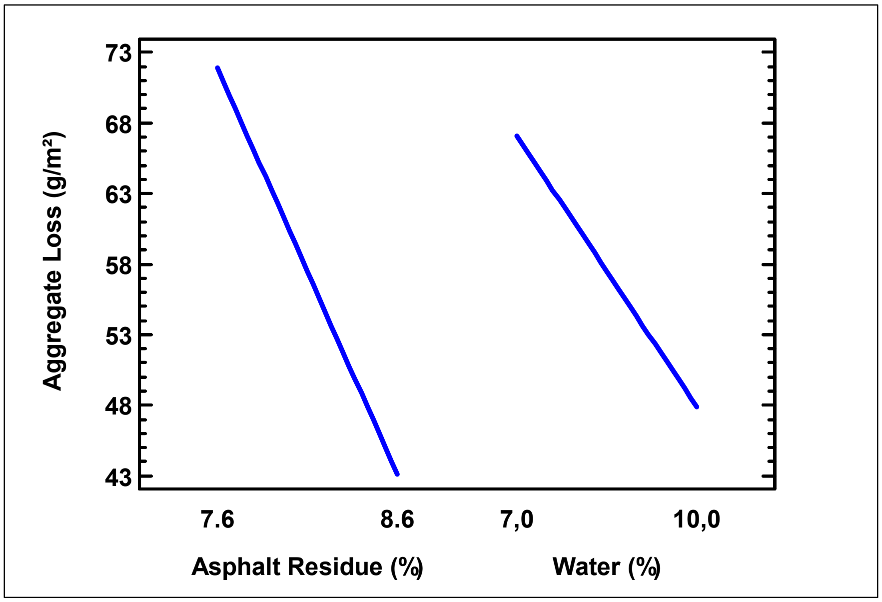

Figure 6.7 Effects of Asphalt Emulsion Residue and
Water on Wet Track Abrasion Test
(1-Hour Soaked) (Main Effect Plot)

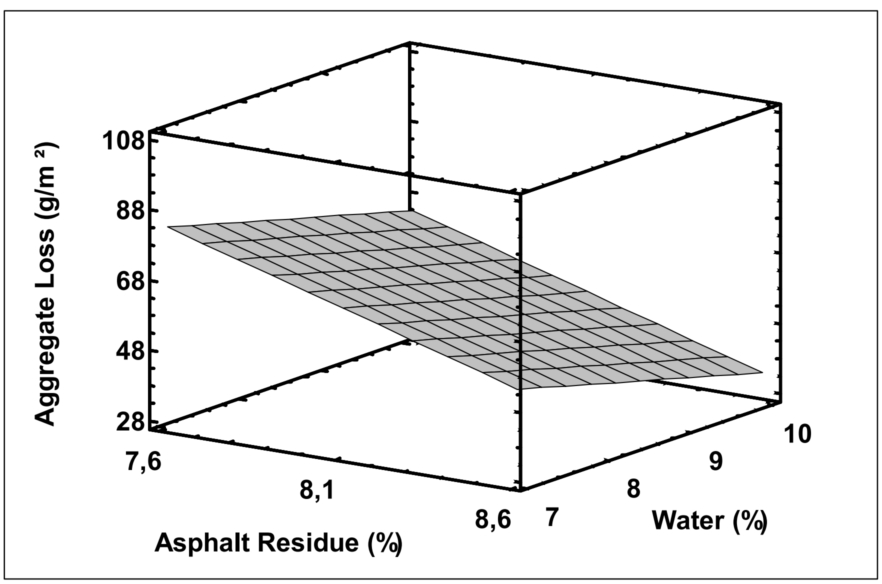

Figure 6.8 Effects of Asphalt Emulsion Residue and
Water on Wet Track Abrasion Test
(1-Hour Soaked) (Estimates Response)

6.3.2 Test Result Analysis of 6-Day Soaked Samples

Summary of test results and aggregate loss for 6-Day soaked sample of each asphalt emulsion residue-water combination are presented in table 6.5. Three replicates were made for each asphalt emulsion residue-water combination.

Table 6.5 Summary of test results for WTAT (6-Day Soaked)

Asphalt Residue Content (%)	**Added Water Content** (%)	**Wet Track Abrasion Test (Aggregate Loss). 6-Day Soaked Sample**			
		Mean Aggregate Loss (g/m^2)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
7.6	**7**	128.31	6.58	5.13	3
8.1	**7**	114.05	5.03	4.41	3
8.6	**7**	108.57	5.70	5.25	3
7.6	**8**	91.02	5.03	5.53	3
8.1	**8**	72.38	3.29	4.55	3
8.6	**8**	66.90	1.90	2.84	3
7.6	**9**	70.19	15.55	22.15	3
8.1	**9**	83.35	1.90	2.28	3
8.6	**9**	39.48	3.29	8.33	3
7.6	**10**	62.51	5.70	9.12	3
8.1	**10**	47.16	6.85	14.53	3
8.6	**10**	30.71	6.85	22.31	3

Figure 6.9 is graph that shows 6-day wet track abrasion values versus asphalt emulsion residue at 7, 8, 9, and 10% added water content. As asphalt emulsion residue increase, the amount of aggregate loss decreases. A uniform pattern of abrasion loss versus added water content was achieved. This graph also shows that there is a definite decrease in abrasion loss as water content is increased. Overall water content seems to have the greatest effect on micro-surfacing mixtures. It would appear that we need a method to define the best water content at which to conduct the test. By increasing only the quantity of added water content

in the mixtures with the same quantity of asphalt emulsion, the amount of aggregate loss decrease in the samples of wet track abrasion test.

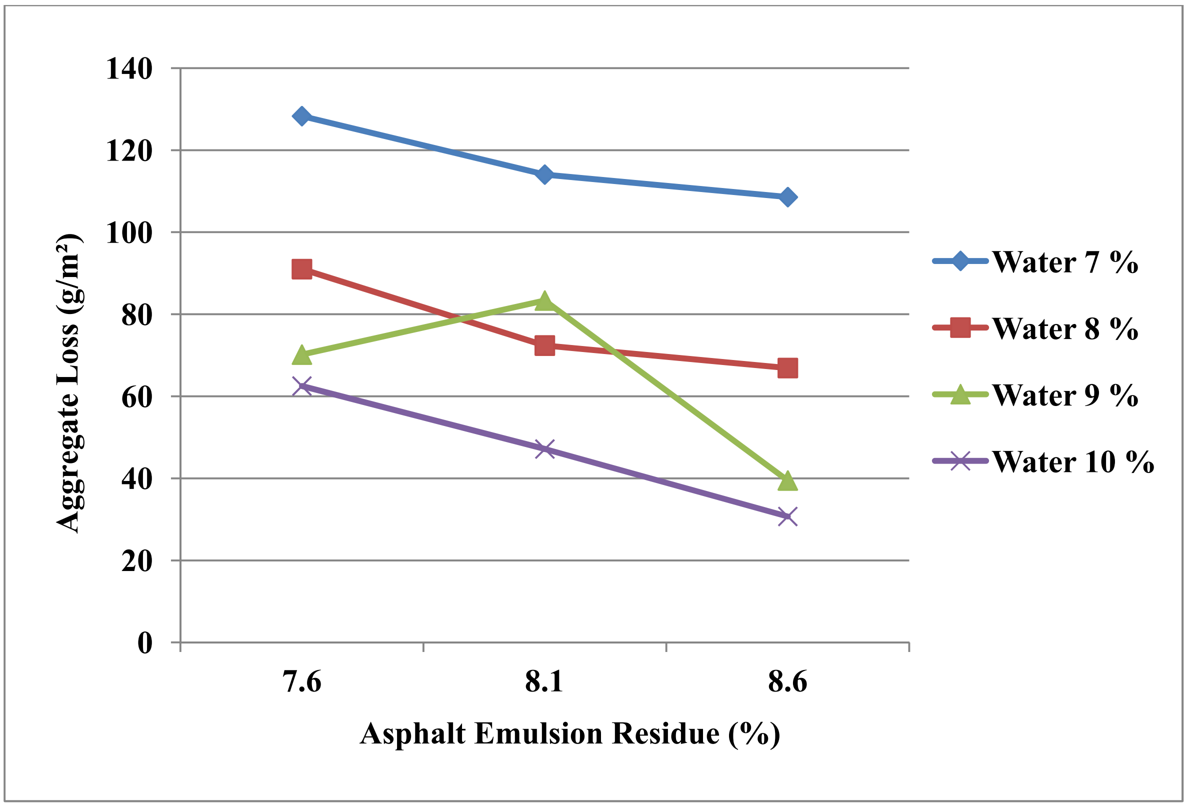

Figure 6.9 6-day soak wet track abrasion values against asphalt emulsion residue with 7, 8, 9, and 10% added water

The ANOVA model for this experiment is:

$$Y_{ijk} = \mu + A_i + E_j + \varepsilon_{ijk} \qquad (6.3)$$

Where Y_{ijk} = Aggregate Loss (g/m²), μ = mean aggregate loss (g/m²), A_i = effect of i^{th} asphalt emulsion residue content, E_j = effect of j^{th} added water content, and εijk = random error for the i^{th} asphalt emulsion residue content and j^{th} added water content, and k^{th} replicate.

Final ANOVA model for this experiment is:

Aggregate Loss (g/m²) = 498.49 – 29.4803× A_i – 21.1657× E_j

Table 6.6 is ANOVA table for this study. As it can be seen from ANOVA table, R-Squared is 87.8564%. The R-squared statistics indicates that this model as fitted explains 87.8564% of the variability, which shows relatively a high R-square. The 6-day soak wet track abrasion test relatively yields uniform results than 1-hour soak test. As it can be seen from ANOVA table, there is significant interaction between asphalt emulsion and added water content. This interaction exists at the 95% confidence level, showing that the selection of asphalt emulsion content and water is dependent on each other.

Table 6.6 ANOVA Output of Analysis of Variance for WTAT (6-Day Soaked)

Analysis of Variance for Wet Track Abrasion (6-Day Soaked)					
Dependent Variable: Aggregate Loss					
R-Squared = 87.8564%					
R-squared (adjusted for d.f.) = 85.1578%					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Value**	**P-Value**
A:Asphalt	1657.44	1	1657.44	12.88	0.0058
B:Water	6719.78	1	6719.78	52.23	0.0000
Total error	1157.91	9	128.656		

Output of ANOVA table for Wet Track Abrasion test (6-Day Soaked) results show that two effects have P-value less than 0.05, indicating that they are significantly different from zero at the 95.0% confidence level. These two effects are effect of asphalt emulsion residue, (A_i) and added water content, (E_j). The estimated F-value for effect of asphalt emulsion residue and added water content are 12.88 and 52.23 respectively. It indicated that the effect of water is much greater than the effect of phalt emulsion. Therefore, the use of 6-day wet track abrasion test to determine minimum asphalt emulsion content for micro-surfacing mixtures is not suggested, because, test results are highly influenced by added water content.

Figure 6.10 shows the significant effect of asphalt emulsion residue and added water content on result of Wet Track Abrasion test (6-Day Soaked). This figure shows that the effect of added water content is well beyond of red line (critical F-value), and is much greater than the effect of asphalt emulsion residue.

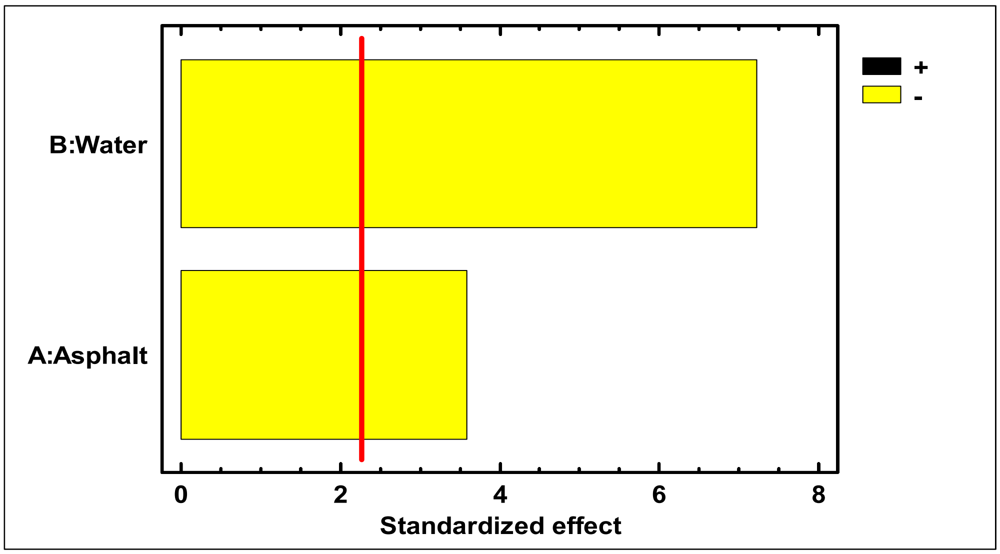

Figure 6.10 Standardized Pareto chart for Wet Track Abrasion Test Results
(6-day Soaked Samples) (The red line represent the estimated critical F value)

Figure 6.11 and 6.12 show the main effect plot and estimated response for Wet Track Abrasion Test (6-Day Soaked sample) results. Similar to wet track abrasion loss of 1-Hour soaked sample, by increasing in asphalt emulsion residue and added water content, aggregate loss decreases. The amount of water in the mixture has also a profound influence on the aggregate loss of samples. Figure 6.12 shows how the effect of added water content is much more than the effect of asphalt emulsion residue. It appears that the amount of aggregate loss of sample is sensitive not only to the amount of asphalt emulsion, but also is too sensitive to the amount of added water content. Thus the consistency for the Wet Track Abrasion (6-Day Soaked sample) is also poor which implies that the test method is vague and permits a wide range of interpretation. The use of this test to determine minimum asphalt emulsion for micro-surfacing mixtures is not recommended. It would appear that a method to define the best water content at which to conduct the test is needed. At that level of added water content, 6-day wet track abrasion test may use to determine minimum asphalt emulsion residue.

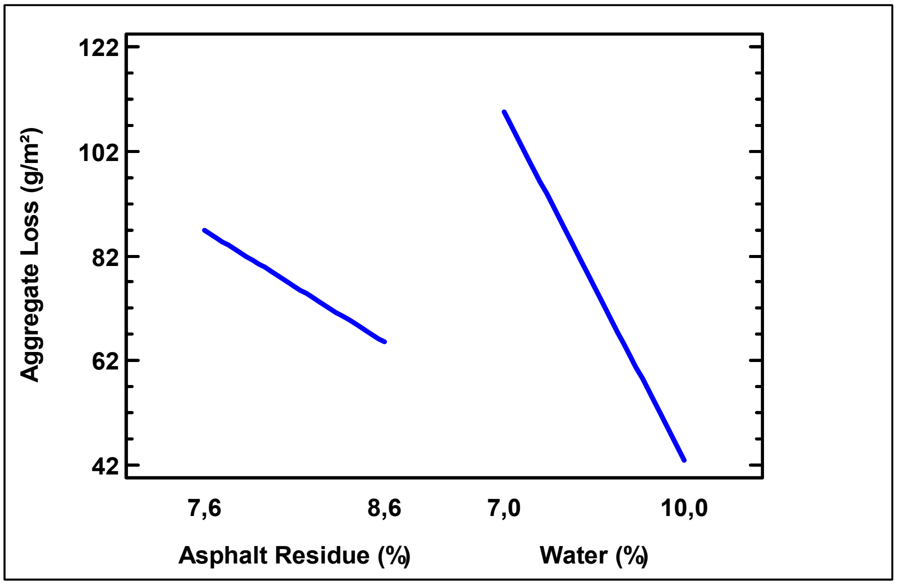

Figure 6.11 Effects of Asphalt Emulsion Residue and
Water on Wet Track Abrasion Test
(6-Day Soaked) (Main Effect Plot)

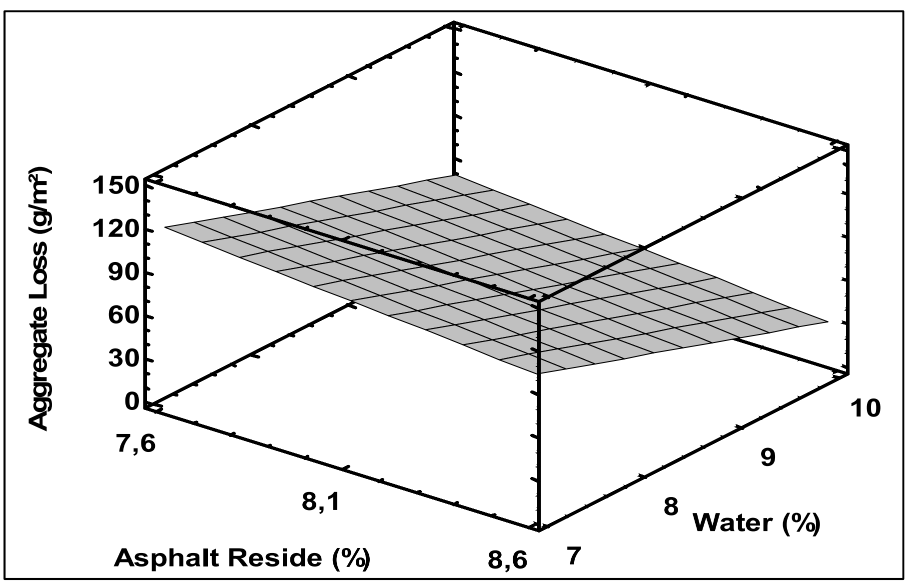

Figure 6.12 Effects of Asphalt Emulsion Residue and
Water on Wet Track Abrasion Test
(6-Day Soaked) (Estimates Response)

6.4 Relative Moisture Retained in the samples

Together with developing the preparation and mixing procedure it was necessary to study the effect of asphalt residue and added water content on the relative moisture retained in the samples of Loaded Wheel Test and Wet Track Abrasion Test. In conjunction with the preceding work, a limited number of samples were studied using 7.6, 8.1, and 8.6% asphalt residue and 7, 8, and 9% of added moisture with the same aggregate gradation. The specimens were cured for 24 hour at 140°F (60°C). The weight of loaded wheel test and wet track abrasion test samples before and after 24 hours curing in forced draft oven were recorded. Percentage of moisture retained in sample was expressed as percent by weight of the mixture before 24 hours curing.

6.4.1 Relative Moisture Retained in the samples of Loaded Wheel Test

Summary of test results to determine relative moisture retained in samples are presented in table 6.7. Three replications were made for each asphalt emulsion residue-water combination.

Table 6.7 Summary of test results of Relative Moisture Retained in LWT test Samples

Asphalt Residue Content (%)	**Added Water Content** (%)	**Moisture Retained in Loaded Wheel Test Sample**			
		Mean Moisture (kg-cm)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
7.6	**7**	1.137	0.031	2.73	3
8.1	**7**	1.290	0.017	1.32	3
8.6	**7**	1.357	0.038	2.80	3
7.6	**8**	1.540	0.017	1.10	3
8.1	**8**	1.697	0.012	0.71	3
8.6	**8**	1.850	0.035	1.89	3
7.6	**9**	2.143	0.025	1.17	3
8.1	**9**	2.277	0.015	0.66	3
8.6	**9**	2.523	0.025	0.99	3

Figure 6.13 is a plot of raw data for relative moisture retained in samples of loaded wheel test versus asphalt emulsion residue. Moisture retained in loaded wheel test increase as added water content increase from 7 to 9%. Also, as asphalt emulsion residue increase, the amount of relative moisture retained in loaded wheel test increases.

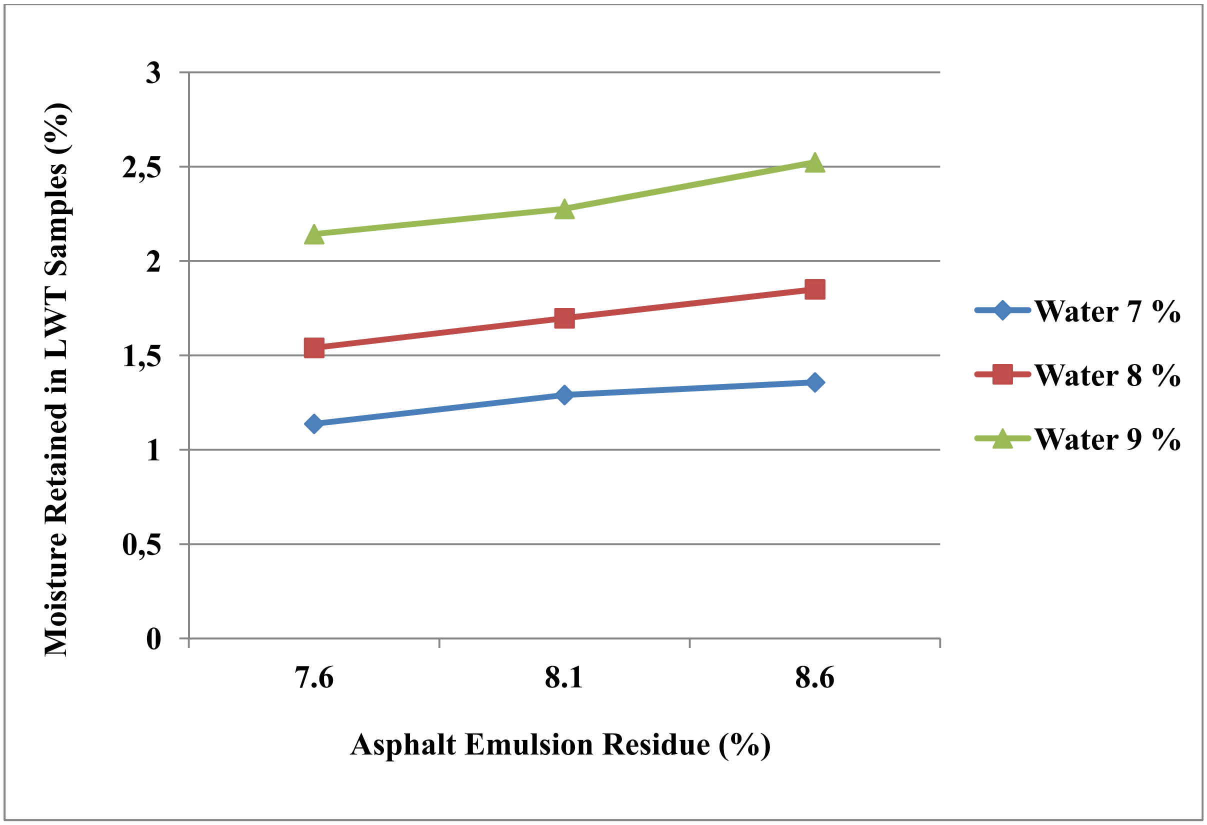

Figure 6.13 Relative moisture retained (in loaded wheel test samples) values against asphalt emulsion residue with 7, 8, and 9% added water

The ANOVA model for this experiment is:

$$Y_{ijk} = \mu + A_i + E_j + \varepsilon_{ijk} \quad (6.4)$$

Where Yijk = Moisture (%), μ = mean moisture (%), A_i = effect of ith asphalt emulsion residue content, Ej = effect of j^{th} added water content, and ε_{ijk} = random error for the i^{th} asphalt emulsion residue content and j^{th} added water content, and k^{th} replicate.

Final ANOVA model for this experiment is:

Relative Moisture Retained (%) = – 5.00667 + 0.30722× A_i + 0.531667× E_j

As it can be seen from ANOVA table (Table 6.8), R-Squared is 99.0274%, which shows that the model as fitted explains 99.0274% of the variability. The R-square for this experiment is relatively high.

Table 6.8 ANOVA Output of Analysis of Variance Moisture Retained in LWT Sample

Analysis of Variance for Moisture Retained in the sample					
Dependent Variable: Moisture					
R-squared = 99.0274%					
R-squared (adjusted for d.f.) = 98.7032%					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Value**	**P-Value**
A:Asphalt	0.135	1	0.135	45.04	0.0005
B:Water	1.69602	1	1.69602	565.86	0.0000
Total error	0.0179833	6	0.002997		

Outputs of ANOVA table for results of Relative Moisture Retained in Sample shows that two effects have P-value less than 0.05, which shows they are significantly different from zero at the 95.0% confidence level. These two effects are effects of asphalt emulsion residue content (Ai), and added water content (Ej). Estimated F-value for effect of asphalt emulsion residue and added water content are 45.04 and 565.86 respectively.

As it can be seen from ANOVA table the effect of added water content is well beyond of the effect of asphalt emulsion residue. Figure 6.14 shows the significant effect of asphalt emulsion and added water content on results of Relative Moisture Retained in Sample. This figure clearly shows that how much the effect of added water content is well beyond of the red line (critical F-value), and how much this effect is greater than the effect of asphalt emulsion residue on results of relative moisture retained in loaded wheel test samples.

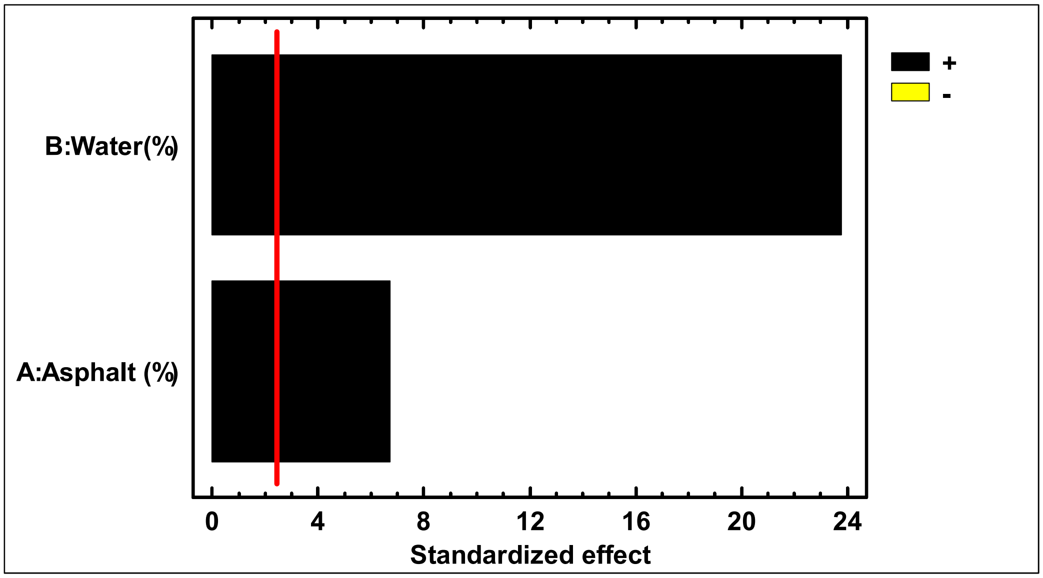

Figure 6.14 Standardized Pareto chart for Results of Relative Moisture Retained in Sample (The red line represent the estimated critical F value)

Figure 6.15 and 6.16 show the main effect plot and estimated response for results of Relative Moisture Retained in Sample. The results showed that the relative percent retained moisture after 24 hours curing, expressed as percent by weight of the initial available moisture (initial added moisture + water portion of asphalt emulsion) ranges between 1.11% and 2.5%. Also, for a specific amount of asphalt residue, the relative percent retained moisture after 24 hours curing increased as added water content increased. Figure 6.16, shows clearly shows that the effect of added water content is much greater than the effect of asphalt emulsion residue on results of relative moisture retained in LWT samples. In section 6.2, it was shown that, for a specific amount of asphalt residue, when amount of added water content increased, sample adhere more sand and result of loaded wheel Test significantly increased. Primary reason for inconsistency of loaded wheel test (Sand Adhesion) results is increasing in moisture retained in sample by adding more water. It seems that the galvanized steel materials used in fabricating specimen mounting plates in loaded wheel test prevent moisture evaporation from mixture during cure process of specimen. Retained moisture in loaded wheel Test specimens range from 1.2 to 2.5% of total mixture weight, while this amount for Wet Track abrasion Test specimens range from 0.8 to 1.4% (See section 6.4.2), which uses saturated roofing felt materials.

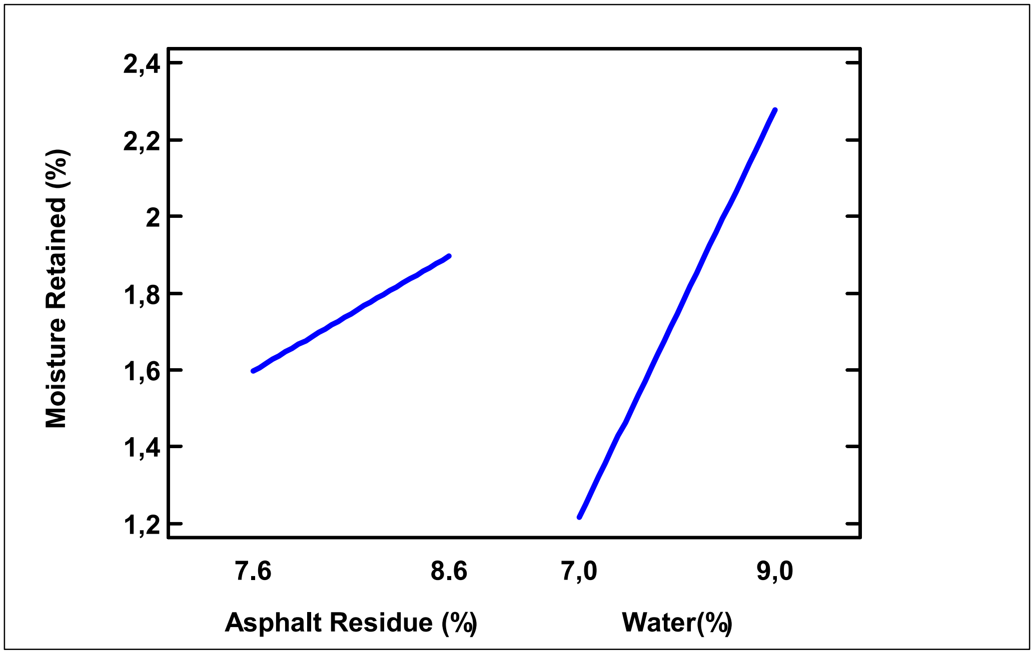

Figure 6.15 Effects of Asphalt Emulsion Residue and Water on Results of Relative Moisture Retained (Main Effect Plot)

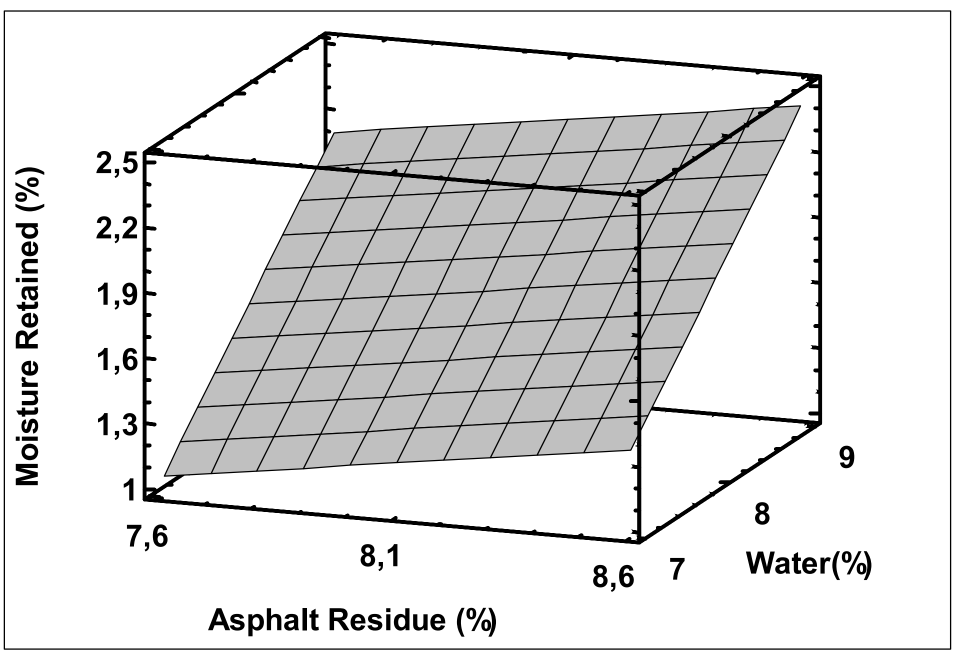

Figure 6.16 Effects of Asphalt Emulsion Residue and Water on Results of Relative Moisture Retained (Estimates Response)

6.4.2 Relative Moisture Retained in the samples of Wet Track Abrasion Test

Summary of test results to determine relative moisture retained in samples are presented in table 6.9. Three replications were made for each asphalt emulsion residue-water combination.

Table 6.9 Summary of test results of Moisture Retained in Wet Abrasion Sample

Asphalt Residue Content (%)	**Added Water Content** (%)	**Moisture Retained in Wet Track Abrasion Samples**			
		Mean Moisture (kg-cm)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
7.6	**7**	1.337	0.087	6.51	3
8.1	**7**	0.917	0.015	1.64	3
8.6	**7**	1.237	0.021	1.70	3
7.6	**8**	0.993	0.031	3.12	3
8.1	**8**	0.883	0.006	0.68	3
8.6	**8**	1.077	0.012	1.11	3
7.6	**9**	1.417	0.025	1.76	3
8.1	**9**	1.243	0.031	2.49	3
8.6	**9**	1.410	0.017	1.21	3

Figure 6.17 is the graph that shows relative moisture retained in samples of water track abrasion test versus asphalt emulsion residue at 7, 8, and 9% added water content. Samples prepared with 8% added water content show lower relative moisture content. Also, relative moisture retained in sample was lower for mixtures with 8.1% asphalt emulsion residue that those with 7.6 and 8.6%. Thus, it can be concluded that selecting appropriate amount of asphalt emulsion residue can lead to decrease of relative moisture retained in micro-surfacing mixtures. Figure 6.17 also shows that the added water content can be selected so that the relative moisture retained in sample decrease. As it can be seen from this figure, when the added water content increases from 7 to 8%, the relative moisture retained in sample decrease. By increasing of added water contents from 8 to 9%, the amount of relative moisture retained in the sample increases.

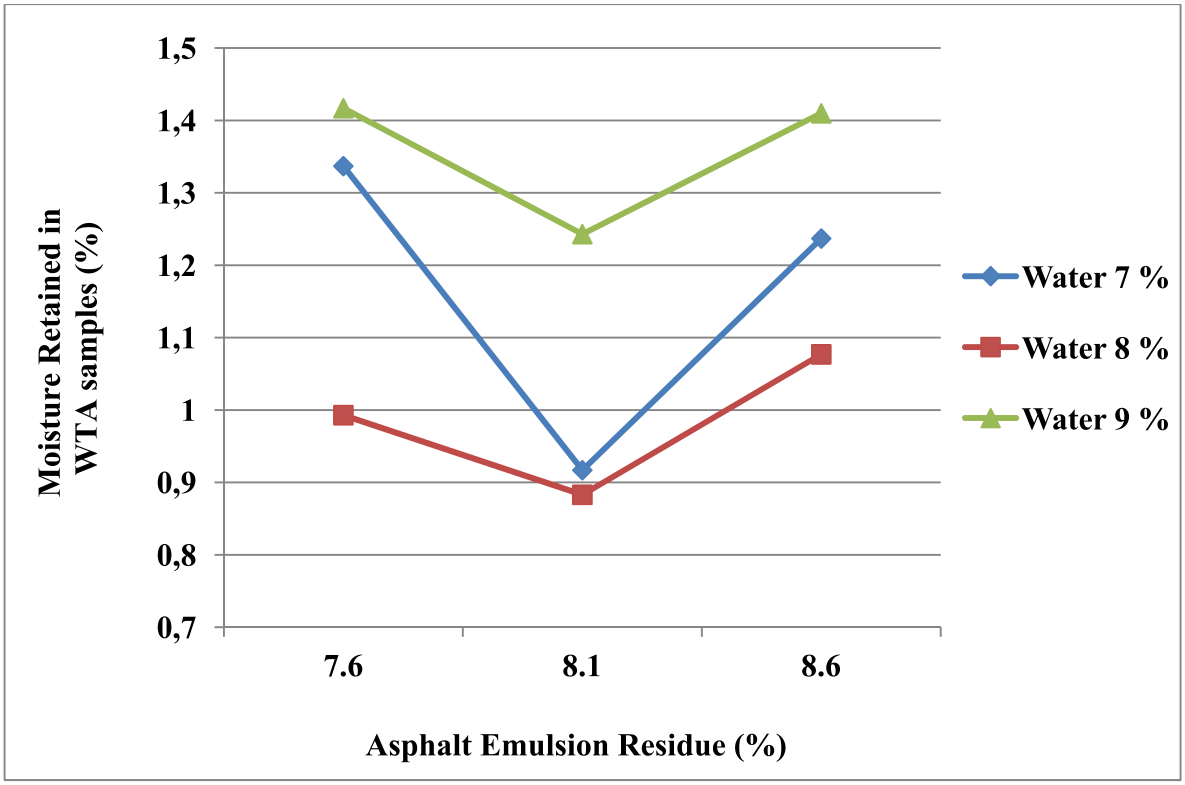

Figure 6.17 Relative moisture retained (in wet track abrasion samples) values against asphalt emulsion residue with 7, 8, 9, and% added water

The ANOVA model for this experiment is:

$$Y_{ijk} = \mu + A_i + Ej + (A_i)^2 + (E_j)^2 + \varepsilon_{ijk} \quad (6.5)$$

Where Y_{ijk} = Moisture (%), μ = mean moisture (%), A_i = effect of i^{th} asphalt emulsion residue content, E_j = effect of j^{th} water content, $(A_i)^2$ = effect of squared amount of asphalt emulsion residue, $(E_j)^2$ = effect of squared amount of added water, and ε_{ijk} = random error for the i^{th} asphalt emulsion residue content and j^{th} added water content, and k^{th} replicate.

Final ANOVA model for this experiment is:

Relative Moisture Retained (%) =
$85.4137 - 16.3088 \times A_i - 4.60007 \times E_j + 0.99977 (A_i)^2 + 0.293333 \times (E_j)^2$

Table 6.10 shows ANOVA table for this study. As it can be seen from this table, R-Squared is 89.339%. The R-squared statistics indicates that this model as fitted explains 89.339% of the variability, which is relatively a high R-square.

Table 6.10 ANOVA Output of Analysis of Variance Moisture Retained in WTAT Samples

Analysis of Variance for Moisture Retained in the sample					
Dependent Variable: Moisture					
R-squared = 89.339%					
R-squared (adjusted for d.f.) = 78.678%					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Value**	**P-Value**
A:Asphalt	0.00201667	1	0.00201667	0.20	0.6756
B:Water	0.0450667	1	0.0450667	4.54	0.1001
AA	0.113606	1	0.113606	11.44	0.0277
BB	0.172089	1	0.172089	17.33	0.0141
Total error	0.372489	4	0.00992778		

Outputs of ANOVA table for results of Relative Moisture Retained in Sample show that two effects has P-value less than 0.05, this indicates that these two effects are significantly different from zero at the 95.0% confidence level. These effects are effects of water content square $(Ej)^2$, and asphalt emulsion content square $(Aj)^2$. As it can be seen from this table, the estimated F-value for effects of square amount of asphalt emulsion residue $(Aj)^2$, and added water content $(Ej)^2$ are 11.44 and 17.33 that are greater than critical F-value represented by red line in figure 6.18. However, the F-value for the effect of asphalt emulsion residue and added water content are 0.2 and 4.54 that are less than critical F-value. Thus, it can be concluded that square amount of asphalt emulsion residue and added water content have significantly affected the results of relative moisture retained in wet track abrasion test samples. Figure 6.18 shows the significant effect of square amount of asphalt emulsion rsidue and added water contents. This figure also shows that how the square amount of effect of asphalt emulsion residue and added water content are much greater than the effect of asphalt emulsion residue and added water content on results this experiment.

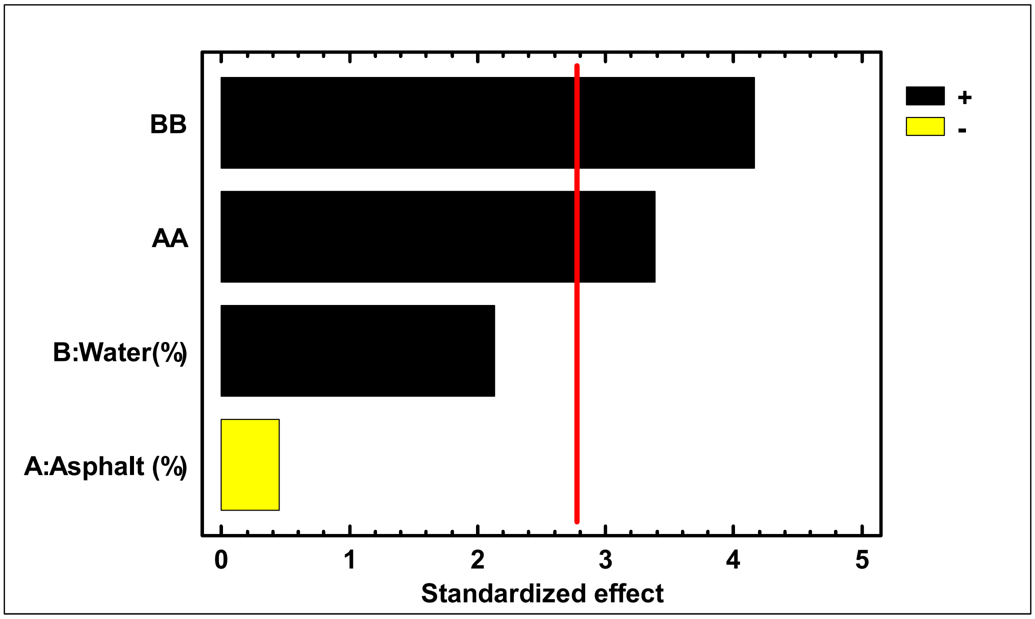

Figure 6.18 Standardized pareto chart for results of relative moisture retained in WTAT samples (The red line represent the estimated critical F value)

Figure 6.19 and 6.20 show the main effect plot and estimated response for results of Relative Moisture Retained in Sample. From figure 6.20, it also can be seen that the effect of added water content is a little more than the effect of asphalt emulsion residue. The results showed that the relative percent retained moisture after 24 hours curing, expressed as percent by weight of the initial available moisture (initial added moisture + water portion of asphalt emulsion), ranges from 0.88 to 1.42% of total mixture weight. Also, for a specific amount of asphalt residue, the relative percent retained moisture after 24 hours curing decrease to a specific amount and then increase by adding more water. Thus, it can be concluded that there is specific amount water at which the moisture retained in sample can be minimized. Moisture retained in sample after 24-hours curing time is water trapped in the coated aggregates and may cause moisture damage. Previous researches have not focus on reducing moisture trapped in coated aggregates because it seems to be difficult to take out whole amount of retained moisture which generally ranges from 0.88 to 1.42% of total mixture weight. However, it seems to be possible to minimize trapped water in coated aggregates. Thus selection of optimum water content is dependent on moisture retained in coated aggregates.

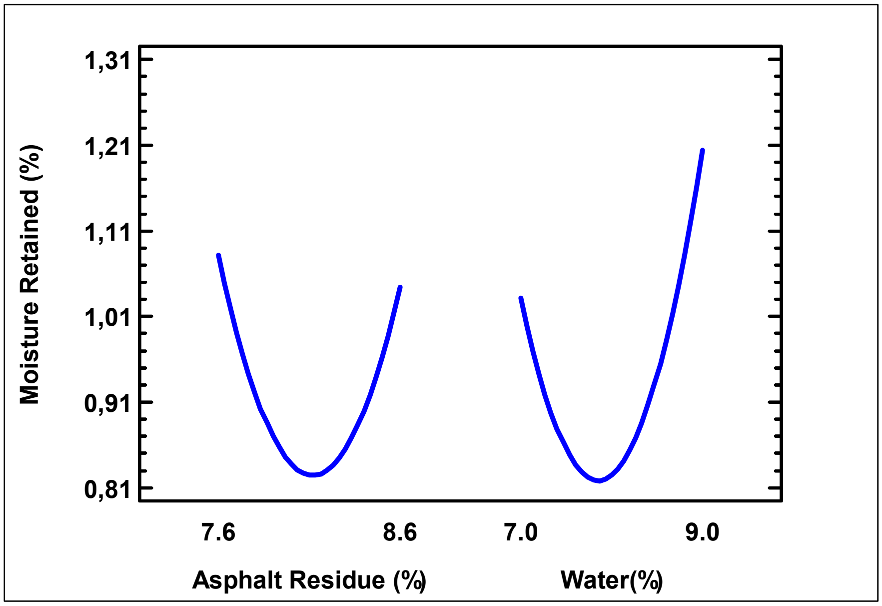

Figure 6.19 Effect of Asphalt Emulsion Residue and Water on Results of Relative Moisture Retained in WTAT Samples (Main Effect Plot)

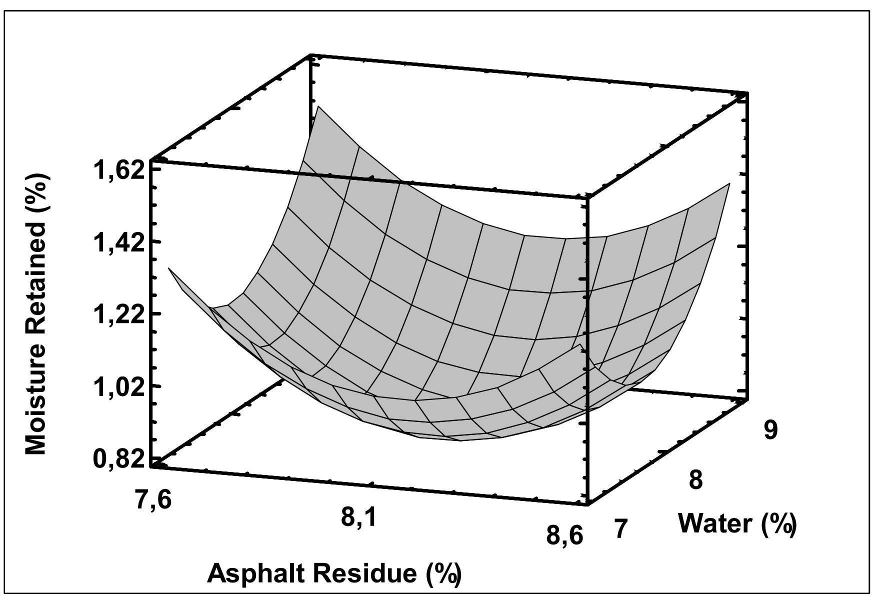

Figure 6.20 Effect of Asphalt Emulsion Residue and Water on Results of Relative Moisture Retained in WTAT Samples (Estimated Response)

6.5 Modified Cohesion Test Results Analysis

The analysis of variance (ANOVA) was performed to find the significant factors that affect Set and Traffic time behavior of Micro-surfacing mixtures. In this section, results from the Modified Cohesion Test (30 min and 60 min) are presented to discuss the effects of variations in asphalt emulsion and added water content on the test results of specific micro-surfacing for emulations.

6.5.1 Test Results Analysis for Cohesion at 30 minutes

1) Effect of Asphalt Emulsion Residue and Added Water Content

Summary of test results and torque measured by modified cohesion tester at 30 minutes for each asphalt emulsion residue-water combination are presented in table 6.11. Three asphalt emulsion residue content (7.6, 8.1, and 8.6%) and four added water content are the independent variables to estimate the percent excess asphalt of specific micro-surfacing formulations. Five replications were made for each asphalt emulsion-water combination. Mixing Time Tests (ISSA TB 113) were already conducted for each asphalt emulsion residue-water combination, and those combinations resulted mixing time less than 2 minutes were removed from input data of modified cohesion test results analysis.

Based on ISSA mix design guideline and specifications for Micro-surfacing, asphalt emulsion and water content should be selected so that the mixture set in more than 2 minutes. The result show that optimum water content for mixture is dependent of cohesion of mixture at 30 minutes and 60 minutes. Thus, set and traffic time of mixture should be considered in selection of optimum added water content for Micro-surfacing mixtures.

Table 6.11 Summary of test results of Modified Cohesion Test at 30 min, mixtures prepared without Portland cement

Asphalt Residue Content (%)	**Added Water Content** (%)	**Modified Cohesion Test (Cohesion at 30 min)**			
		Mean Torque (kg-cm)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
7.6	**8**	12.9	0.2	1.55	5
8.1	**8**	15.6	0.5	3.21	5
8.6	**8**	16.6	0.5	3.01	5
7.6	**9**	12.7	0.4	3.15	5
8.1	**9**	18.8	0.4	2.13	5
8.6	**9**	15.8	0.4	2.53	5
7.6	**10**	11.4	0.9	7.89	5
8.1	**10**	16.0	0.4	2.50	5
8.6	**10**	14.4	0.4	2.78	5

Figure 6.21 is a plot of raw data for wet cohesion values at 30 minutes versus asphalt emulsion residue at 8, 9, and 10% added water content.

As different water contents are added to 8.1% asphalt emulsion residue mixture, there is an increase of cohesion for mixture with 9% added water content.

For mixture with 8.6% asphalt emulsion residue, maximum cohesion was observed at 8% added water content.

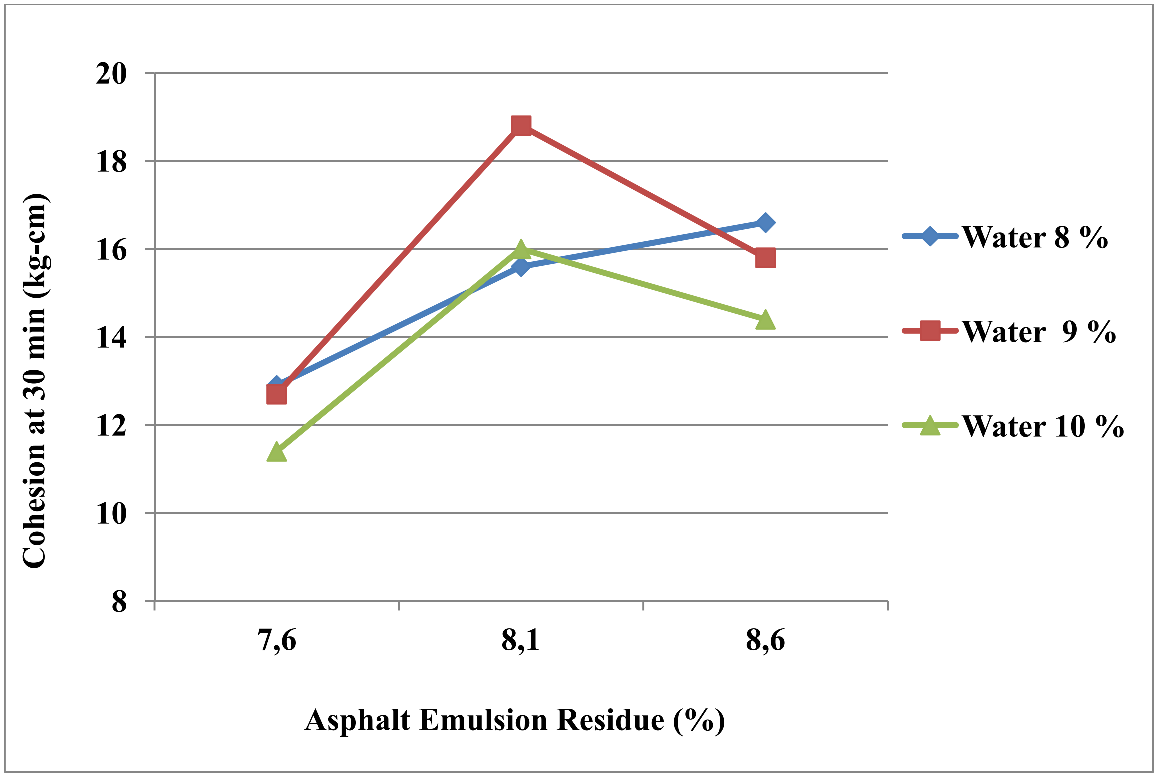

Figure 6.21 30-minute wet cohesion torque values against different asphalt emulsion residue with 8, 9, and 10% water, mixtures prepared without Portland cement

The ANOVA model for this experiment is:

$$Y_{ijk} = \mu + A_i + E_j + (A_i)^2 + (E_j)^2 + \varepsilon_{ijk} \qquad (6.6)$$

Where Y_{ijk} = Cohesion at 30 minutes (kg-cm), μ = mean Cohesion (kg-cm), A_i = effect of i^{th} asphalt emulsion residue content, E_j = effect of j^{th} water content, $(A_i)^2$ = effect of squared amount of asphalt emulsion residue, $(E_j)^2$ = effect of squared amount of added water, and ε_{ijk} = random error for the i^{th} asphalt emulsion residue content and j^{th} added water content, and k^{th} replicate.

Final ANOVA model for this experiment is:

Cohesion at 30 min (kg-cm) =
$-868.44 + 190.988 \times Ai + 21.9167 \times E_j - 11.5358 \times (Ai)^2 - 1.25 \times (E_j)^2$

As it can be seen from ANOVA table (Table 6.12), R-Squared is 88.3333%. The R-squared statistics indicates that this model as fitted explains 88.3333% of the variability.

Table 6.12 ANOVA Table, Output of Modified Cohesion Test at 30 (minutes), mixtures prepared without Portland cement

Analysis of Variance for Modified Cohesion Test					
Dependent Variable: Cohesion at 30 mints					
R-squared = 88.3333%					
R-squared (adjusted for d.f.) = 76.6667%					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Value**	**P-Value**
A:Asphalt	15.0417	1	15.0417	12.89	0.0229
B:Water	2.04167	1	2.04167	1.75	0.2564
AA	15.125	1	15.125	12.96	0.0227
BB	3.125	1	3.125	2.68	0.1770
Total error	4.66667	4	1.16667		

Output of ANOVA table for results of Modified cohesion Test at 30 minutes show, that two effects have P-value less than 0.05, indicating that they are significantly different from zero at the 95% confidence level. These two effects are effect of asphalt emulsion (Ai). and effect of square asphalt emulsion residue content. $(Ai)^2$.

The R-square for this experiment is 88.3333%. which shows model as fitted explains 89.339% of the variability. Figure 6.22 shows the significant effect of asphalt emulsion and added water content on result of Loaded wheel test.

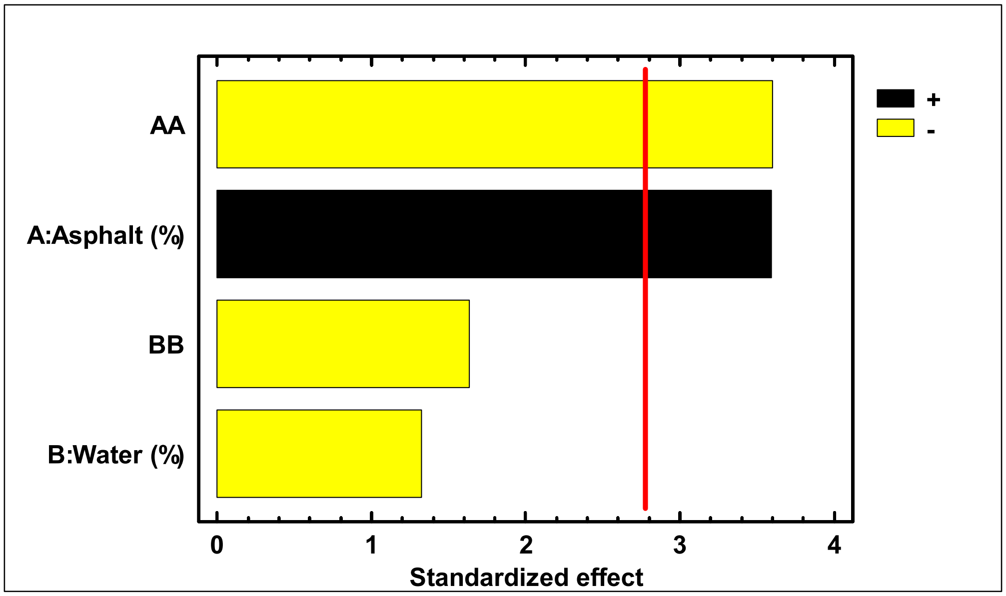

Figure 6.22 Standardized pareto chart for Modified Cohesion
at 30 minutes, mixtures prepared without Portland cement
(The red line represents the estimated critical F value)

Estimated R-square for effect of asphalt emulsion residue content and its square amount are respectively 12.89 and 12.96, which shows that these two factors almost equally affect the 30-min cohesion of mixtures at the to each other. As it can be seen from figure 6.22, estimated F-value of these two effects are more than estimated critical F-value, which shows their significant effect on 30-min cohesion of micro-surfacing mixtures. It also should be noted that the effect of added water content did not significantly change the 30-min cohesion of mixture. The reason is because the cohesion of mixtures prepared using 7.6, 8.1, and 8.6% asphalt emulsion residue behaved differently when the water changed. As the water increased, the cohesion of mixtures prepared using 7, 6 and 8.6% asphalt emulsion residue decreased. However, for mixture prepared with 8.1% asphalt emulsion residue, as the water increased, there observed an optimum amount of 30-min cohesion. This results are only valid in the range of added water and added asphalt emulsion used in this experiment. If the modified cohesion test at 30 minutes is conducted on mixtures prepare using other ranges of asphalt emulsion residue and added water, the reults may different and the 30-min cohesion of mixture with different amount of asphalt emulsion behaves in the same trend when the water increse. In this case, water may significantly affect the test results of modified cohesion test at 30 minutes.

Figure 6.23 and 6.24 show the main effect plot and estimated response for 30-min cohesion test results. As it can be seen from these figures, as asphalt emulsion residue increse from 7.6 to 8.1% for asphalt residue, cohesion of mixture increses significantly.

But, if the asphalt residue increse from 8.1 to 8.6%. cohesion of mixture decreases. Modified cohesion test results at 30 minutes shows that there was a specific asphalt emulsion residue content at which when the added water content increased, there observed an optimum amount of 30-min and 60-min cohesion, which is the maximum cohesion of the mixture. However, for other asphalt emulsion residue content used in this study, as the water increased, the 30-min and 60-min cohesion of mixture decreased. For the aggregate gredation using in modified cohesion experiment, this asphalt emulsion residue content is equal to 8.1%. For the mixture with 8.1% asphalt residue and 8% water, mean cohesion of mixture at 30 minutes with 5 replications is 16 kg-cm. As added water content increases to 9%. mean cohesion of mixture increases to 18 kg-cm. If added water content increses to 10%. mean cohesion of mixture at 30 minutes decrese to 16 kg-cm. Thus, it can be concluded that the optimum water content is dependent of mixture cohesion. For asphalt residue of 7.6%, maximum cohesion was occurred in 8% adding water and by incresing water content to 9 and 10%. cohesion of mixture decresed.

However, maximum cohesion at 7.6% asphalt residue was less than the maximum cohesion at asphalt-water combination equal to 8.1–9%. Same behaviour was observed for 8.6% asphalt residue. Maximum cohesion was occurred at 8% adde water content and after that by incresing water content, cohesion decreses. In fact, mixture at asphalt-water combinatione of 8.1–9% shows its maximum cohesion at 30 and 60 minutes. However, there is another asphalt-water combination at which mixture reach to the cohesion very close to its maximum amount. This asphalt-water combination is 8.6–8 %.

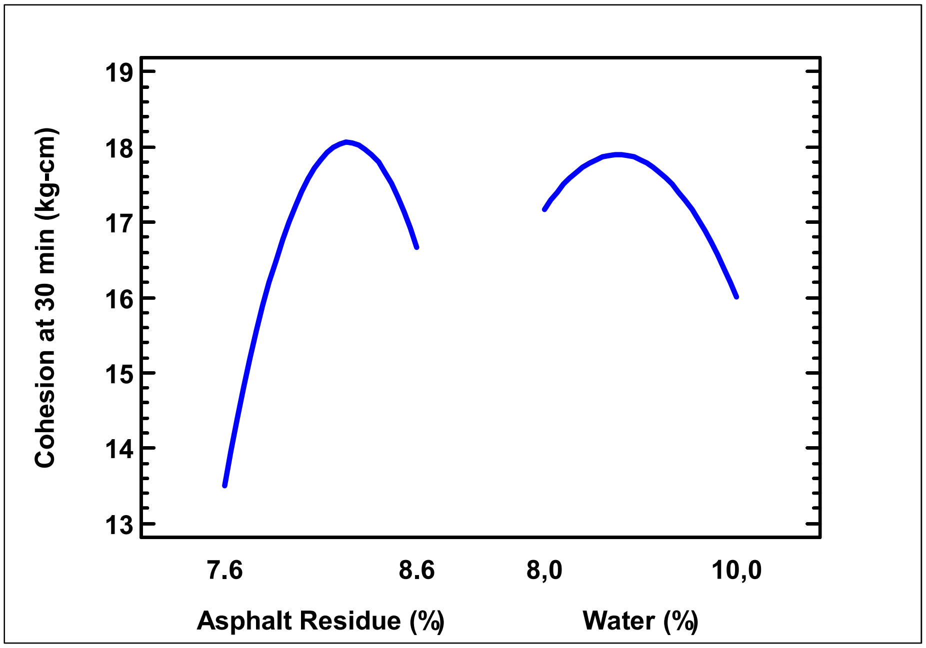

Figure 6.23 Effect of Asphalt Emulsion Residue and Water on Results of Modified Cohesion Test at 30 minutes, mixtures prepared without Portland cement (Main Effect Plot)

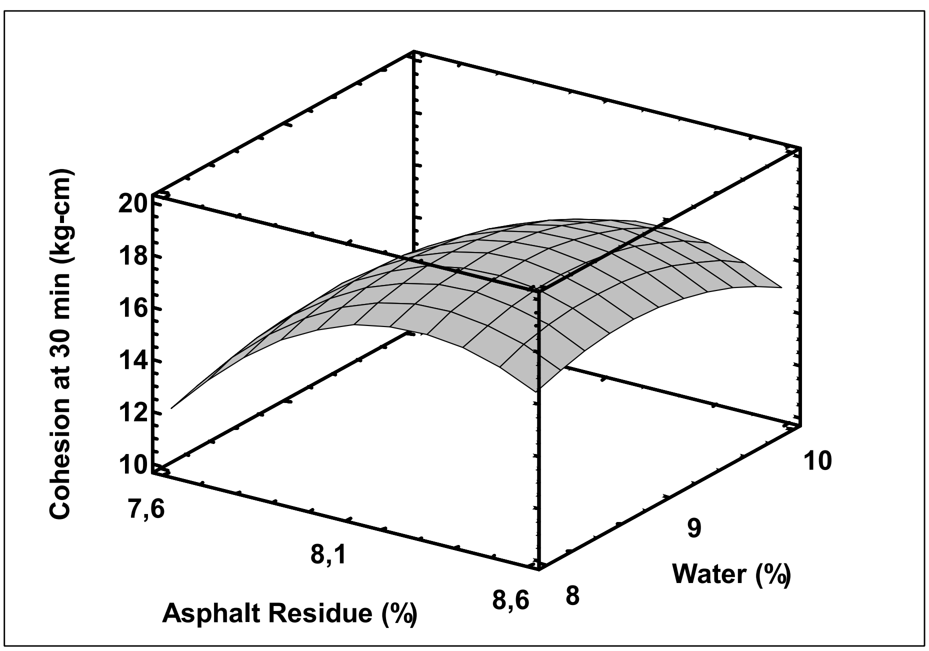

Figure 6.24 Effect of Asphalt Emulsion Residue and Water on Results of Modified Cohesion Test at 30 minutes, mixtures prepared without Portland cement (Estimates Response)

2) Effect of Portland cement (P.C.)

Effect of Portland cement on the set and traffic characteristics of Micro-surfacing mixtures was also evaluated in this part of the study. One% of Portland cement (1% by weight of the dry aggregate) was used. The Portland cement (P.C.) was added to the wet aggregate and mixed immediately before adding the asphalt emulsion. Three asphalt emulsion residue content (7.6, 8.1, and 8.6%) were chosen. Mixing Time Test (ISSA TB 113) was already conducted for different asphalt emulsion residue-water combination, and those combinations resulted mixing time more than 2 minutes were selected for further testing. Five replications were made for each asphalt emulsion-water combination. Table 6.13 shows summary of test results.

Table 6.13 Summary of test results of Modified Cohesion Test at 30 min, mixtures prepared with 1% Portland cement

Asphalt Residue Content (%)	**Added Water Content** (%)	**Modified Cohesion Test (Cohesion at 30 min)**			
		Mean Torque (kg-cm)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
7.6	**9**	13.2	0.4	3.03	5
8.1	**9**	15.7	0.4	2.55	5
8.6	**9**	16.7	0.7	4.19	5
7.6	**10**	12.6	0.5	3.97	5
8.1	**10**	18.8	0.3	1.60	5
8.6	**10**	15.7	0.4	2.55	5
7.6	**11**	11.4	0.4	3.51	5
8.1	**11**	15.7	0.4	2.55	5
8.6	**11**	14.4	0.4	2.78	5

Figure 6.25 is a plot of raw data for wet cohesion values at 30 minutes versus asphalt emulsion residue at 8, 9, and 10% added water content. The same trend as mixtures without cement additives was observed. The only different was about amount of water at which mixtures show the maximum cohesion value. As different water contents are added to 8.1% asphalt emulsion residue mixture, there is an increase of cohesion for mixture with 10%

added water content. For mixture with 8.6% asphalt emulsion residue, maximum cohesion was observed at 9% added water content.

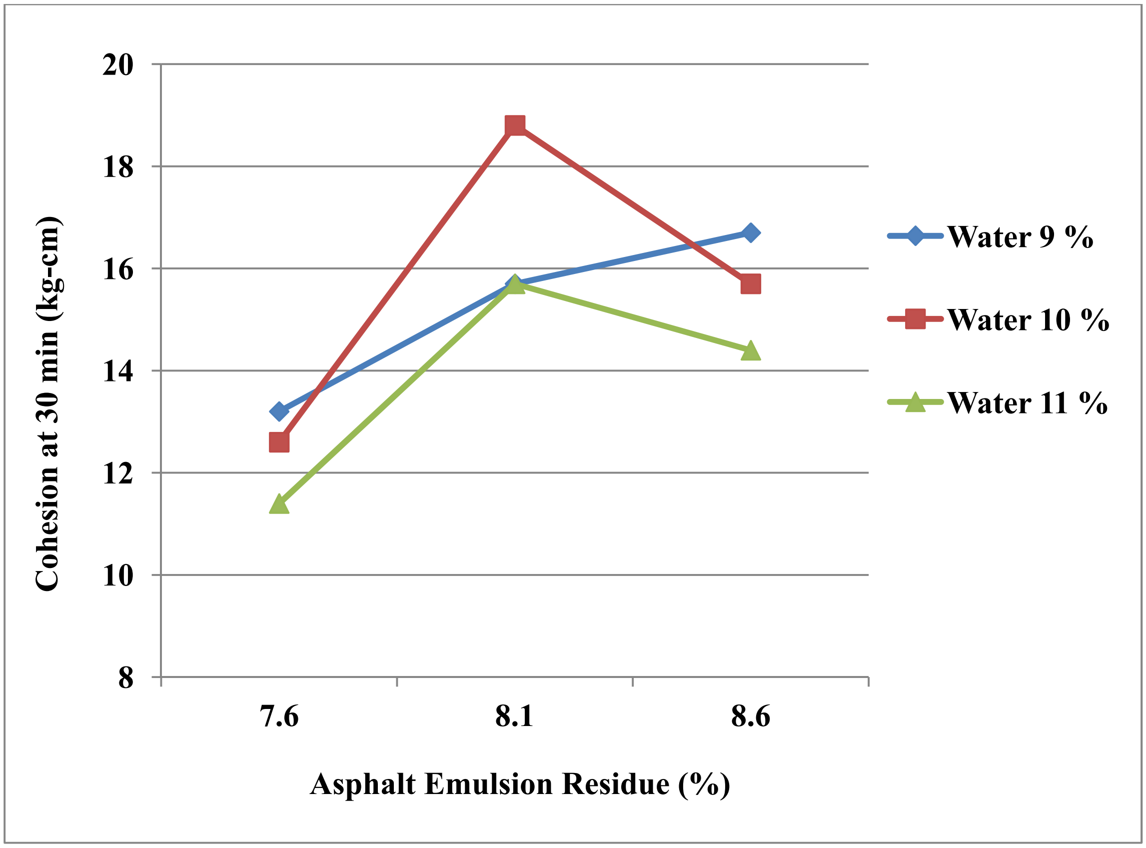

Figure 6.25 30-minute wet cohesion torque values against different asphalt emulsion residue with 9, 10, and 11% water, mixtures prepared with 1% Portland cement

Figure 6.26 shows a comparison between test results of mixture with 8.1% asphalt residue, and prepared without Portland cement additive and prepared with 1% Portland cement additive. As it can be seen from this figure, for both mixtures, there is a specific asphalt residue content at which by increasing of added water content to a particular amount, cohesion of mixture increases to its maximum amount and after that by more increasing of added water content, cohesion of mixture decreases.

However, the only difference is in amount of optimum added water that is 9% for mixture prepared without portland cement, and 10% for mixture prepared with 1% portland cement.

Thus adding 1% portland cement to the mixture increases optimum water content of mixture up to 1%.

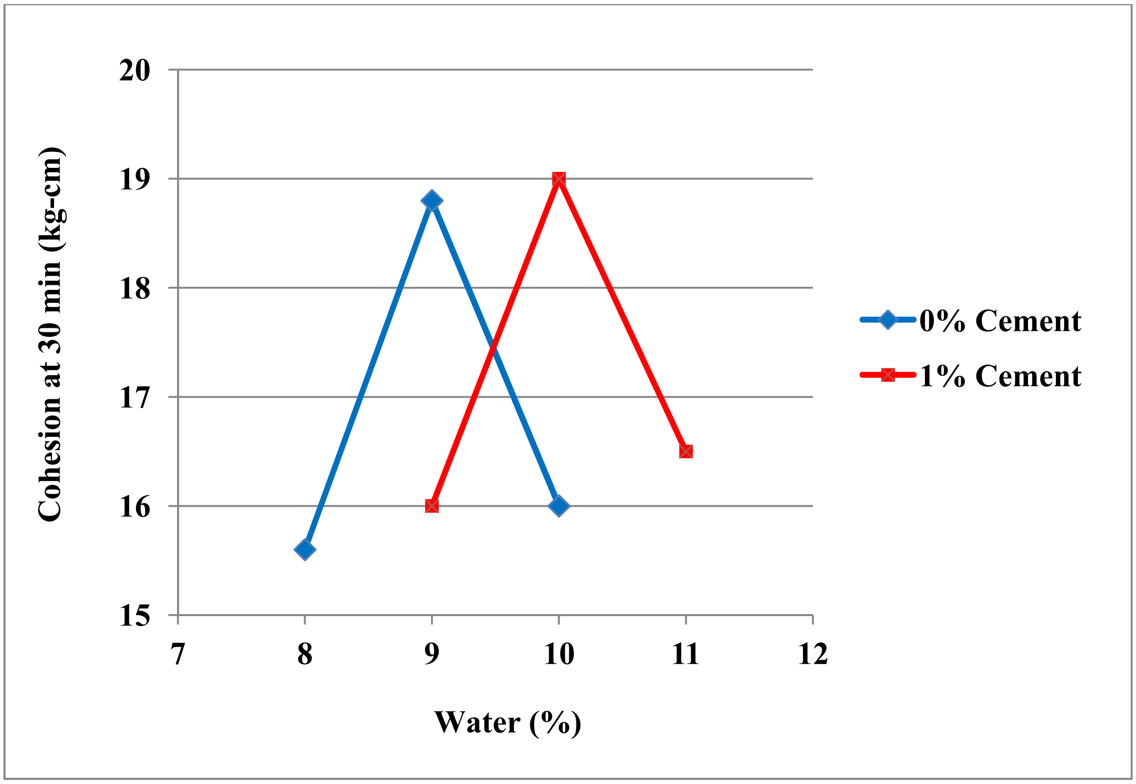

Figure 6.26 Comparison between 30-min cohesion values of mixture prepared with and without Portland cement at 8.1% asphalt emulsion residue

Figure 6.27 and 6.28 show comparisons between test results of mixture with 7.6% and 8.6% asphalt residue, and prepared without Portland cement additive and prepared with 1% Portland cement additive. As it can be seen from both these figures, the amount of optimum water content increased up to 1% for mixture with 1% Portland cement additives comparing with the mixture without Portland cement additives. For the mixture prepare using 7.6% asphalt emulsion residue and without Portland cement, the maximum 30-min cohesion was observed at 8% added water content, however, for mixtures prepared with 1% Portland cement, maximum 30-min cohesion was observed at 9% added water content. Similar to mixtures with 7.6% asphalt emulsion residue, for mixtures with 8.6% asphalt emulsion residue, when using 1% Portland cement, the mixture required 1% more added water content in order to reach its maximum 30-min cohesion.

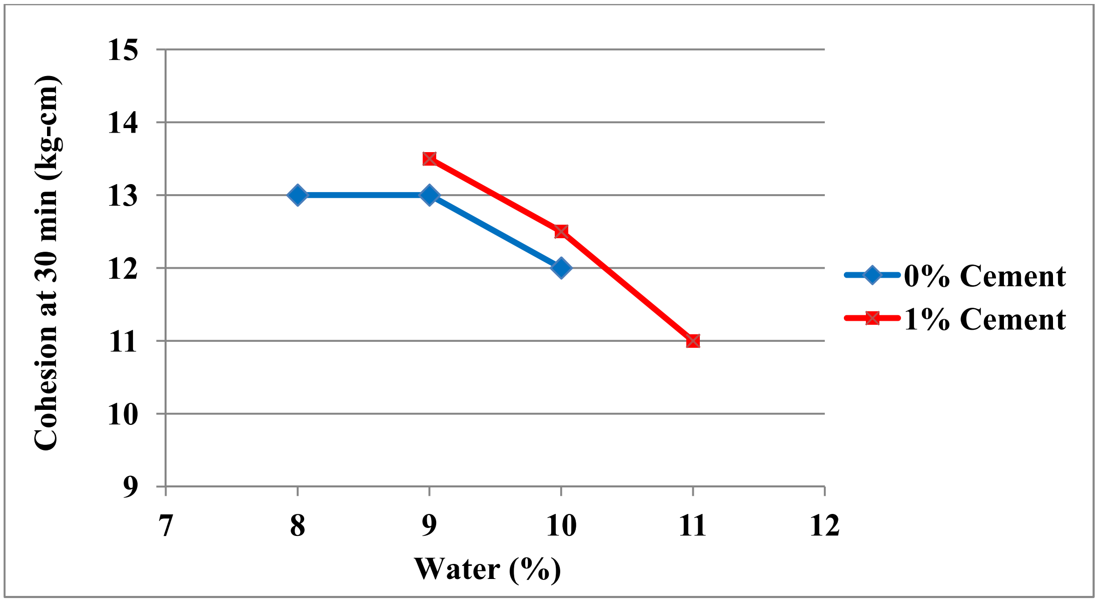

Figure 6.27 Comparison between 30-min cohesion values of mixture prepared with and without Portland cement at 7.6% asphalt emulsion residue

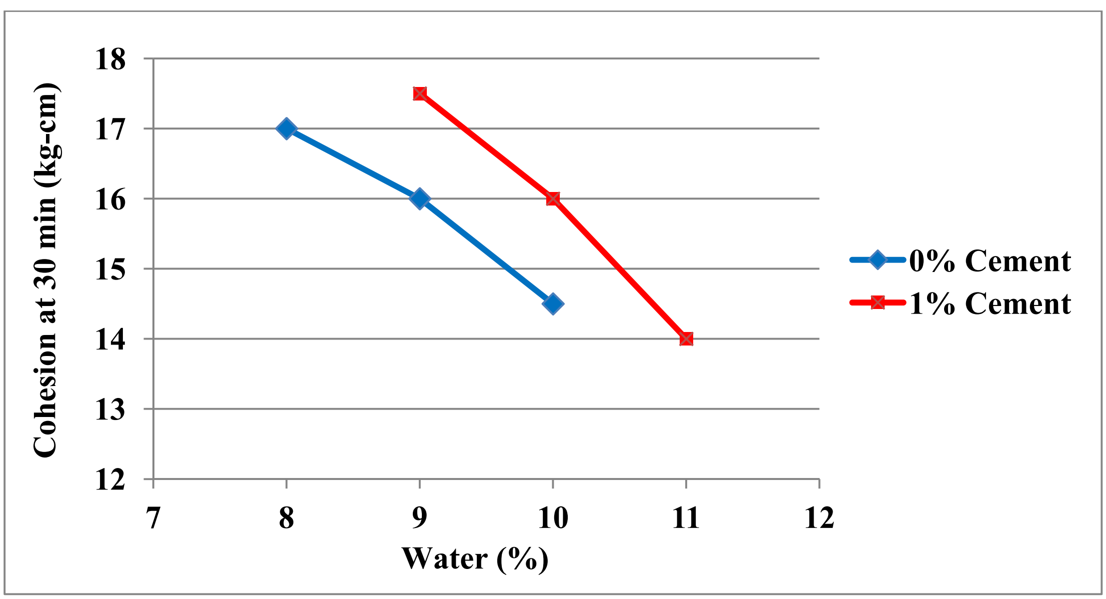

Figure 6.28 Comparison between 30-min cohesion values of mixture prepared with and without Portland cement at 8.6% asphalt emulsion residue

6.5.2 Test Results Analysis for Cohesion at 60 minutes:

1) Effect of Asphalt Emulsion Residue and Added Water Content

Summary of test results and torque measured by modified cohesion tester at 60 minutes for each asphalt emulsion residue-water combination are presented in table 6.14. Three asphalt emulsion residue content (7.6, 8.1, and 8.6%) and four added water content (are the independent variables to estimate the percent excess asphalt of specific micro-surfacing formulations. Five replications were made for each asphalt emulsion-water combination.

Table 6.14 Summary of test results for Modified Cohesion Test at 60 minutes, mixture prepared without Portland cement

Asphalt Residue Content (%)	**Added Water Content** (%)	**Modified Cohesion Test (Cohesion at 60 min)**			
		Mean Torque (kg-cm)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
7.6	**8**	15.7	0.4	2.55	5
8.1	**8**	18.1	0.7	3.87	5
8.6	**8**	18.7	0.4	2.14	5
7.6	**9**	15.8	0.4	2.53	5
8.1	**9**	21.3	0.8	3.76	5
8.6	**9**	18.6	0.5	2.69	5
7.6	**10**	14.8	0.6	4.05	5
8.1	**10**	19.0	0.6	3.16	5
8.6	**10**	17.3	0.3	1.73	5

Figure 6.29 is a plot of raw data for wet cohesion values at 60 minutes versus asphalt emulsion residue at 8, 9, and 10% added water content. The same trend as for mixtures prepared without Portland cement was observed. As different water contents are added to 8.1% asphalt emulsion residue mixture, there is an increase of cohesion for mixture with 9% added water content. For mixture with 8.6% asphalt emulsion residue, maximum cohesion was observed at 8% added water content.

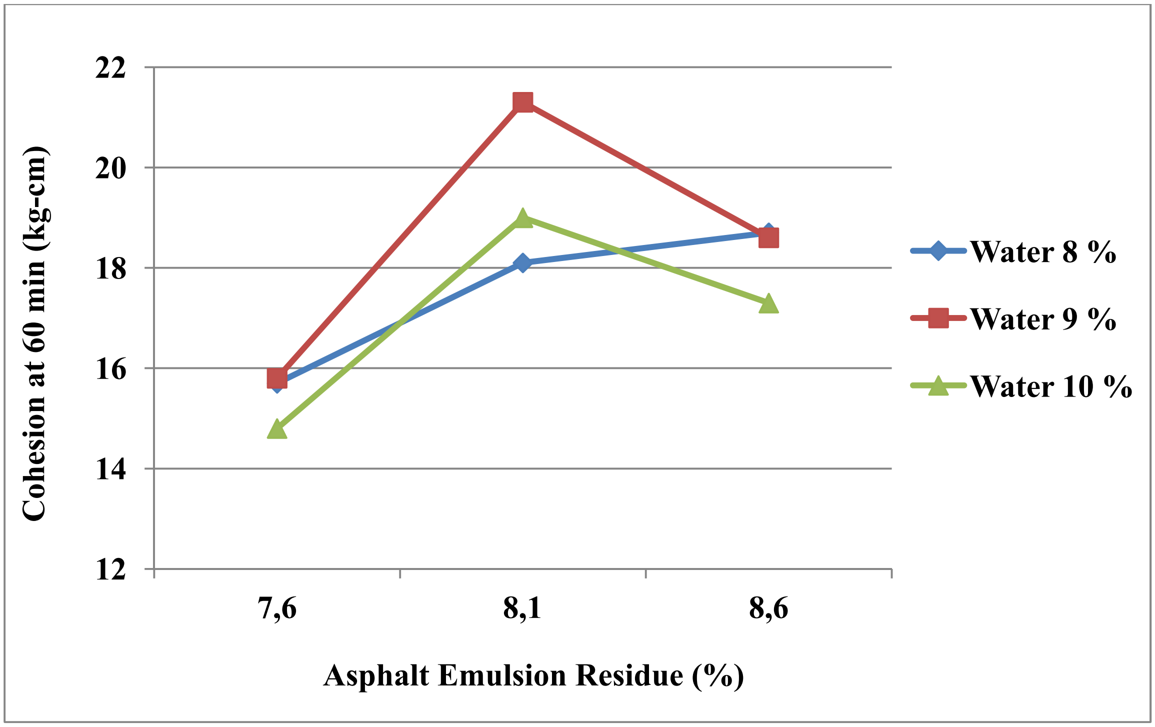

Figure 6.29 60-minute wet cohesion torque values against different asphalt emulsion residue with 8. 9, and 10% water, mixtures prepared without Portland cement

The ANOVA model for this experiment is:

$$Y_{ijk} = \mu + A_i + E_j + (AE)_{ij} + (Ai)^2 + (E_j)^2 + \varepsilon_{ijk} \quad (6.7)$$

Where Y_{ijk} = Cohesion at 60 minutes (kg-cm), μ = mean Cohesion (kg-cm), A_i = effect of i^{th} asphalt emulsion residue content, E_j = effect of j^{th} water content, $(A_i)^2$ = effect of squared amount of asphalt emulsion residue, $(E_j)^2$ = effect of squared amount of added water, AE_{ij} = effect of interaction between i^{th} asphalt emulsion residue content and j^{th} added water content, and ε_{ijk} = random error for the i^{th} asphalt emulsion residue content and j^{th} added water content, and k^{th} replicate.

Final ANOVA model for this experiment is:

Cohesion at 60 min (kg-cm) =
$-925.352 + 202.025\times A_i + 25.25\times E_j - 12.235\times (A_i)^2 - 12.235\times (AE)_{ij} - 1.4167\times (E_j)^2$

As it can be seen from ANOVA table (Table 6.15), R-Squared is 85.1852%.

Table 6.15 ANOVA Table, Output of Modified Cohesion Test Results at 60 minutes, mixtures prepared without cement

Analysis of Variance for Modified Cohesion Test					
Dependent Variable: Cohesion at 60 mints					
R-squared = 88.6598%					
R-squared (adjusted for d.f.) = 77.3196%					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Value**	**P-Value**
A:Asphalt	12.0417	1	12.0417	11.26	0.0284
B:Water	0.375	1	0.375	0.35	0.5856
AA	17.0139	1	17.0139	15.91	0.0163
BB	4.01389	4	4.01389	3.75	0.1248
Total error	4.27778	8	1.06944		

Output of ANOVA table for results of Modified cohesion Test at 60 minutes show that there are two effect having P-value less than 0.05, indicating that they are significantly different from zero at the 95.0% confidence level. These two effects are effect of asphalt emulsion (Ai), and effect of square asphalt emulsion residue content. $(Ai)^2$. Estmated F-value for effect of asphalt emulsion residue and its square maount are 11.26 and 15.91, which shows that the effect of square amount of asphalt emulsion residue is greater thatn the effect of asphalt emulsion itself. Figure 6.30 shows the significant effect of asphalt emulsion and added water content on result modified cohesion test at 60 minutes. As it can be seen from this figure, the effects of asphalt emulsion residue and its square amount has F-value beyond estimated critical F-value. Similar to modified cohesion test results at 30 minutes, as the water incresed. 60-min cohesion of mixture behaved differently for mixture prepared with 7.6, 8.1, and 8.6 asphalt emulsion residue. The 60-min cohesion of mixtures prepared using 8.1% asphalt emulsion residue behaved differently when the water changed. The presence of optimum 60-min cohesion was observed for mixture with 8.1% asphalt emulsion residue.

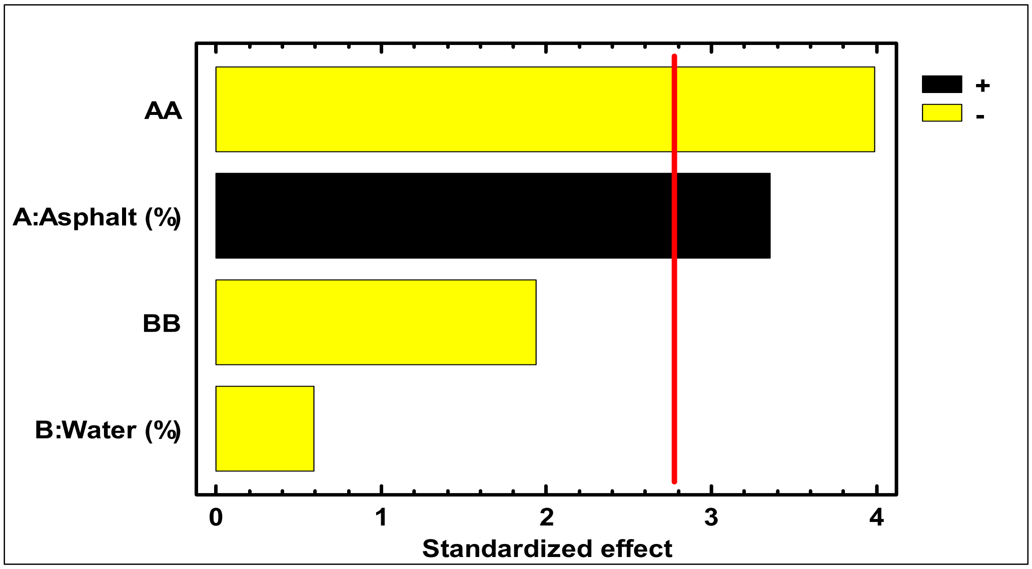

Figure 6.30 Standardized pareto chart for Modified Cohesion at
60 minutes, mixtures prepared without Portland cement

Figure 6.31 and 6.32 show the main effect plot and estimated response for modified cohesion test results. From this two figures it can be seen that, for mixtures prepared using 8.1% asphalt emulsion residue, modified cohesion test results at 60 minutes reach to its optimum amount. This optimum amount is maximum amount of cohesion at 60 minutes. In the mixtures prepared with 7.6% and 8.6% asphalt emulsion residue, as the water increased the 60-min cohesion of mixture decreased. The 60-min cohesion of mixtures with 7.6% asphalt emulsion residue ranged from 14.8-15.7 kg-cm. For mixtures with 8.6% asphalt emulsion residue, the 60-min cohesion ranged from 17.3-18.7. The maximum 60-min cohesion of micro-surfacing mixtures prepared in this study was observed at 8.1% asphalt emulsion residue, which ranged from 18.1-21.3 kg-cm. The interesting point is that using excees asphalt emulsion in micro-surfaicng mixtures can be lead to cohesion loss. Therefore, there is a need to select optimum asphalt emulsion residue with regard to long-term properties of micro-surfacing mixtures. Section 7.3 describes that how test method for measurement of stability and resistance to compaction, vertical and lateral displacement of multilayered fine aggregate cold mixes (ISSA TB 147- Method A) was used to determine optimum asphalt emulsion.

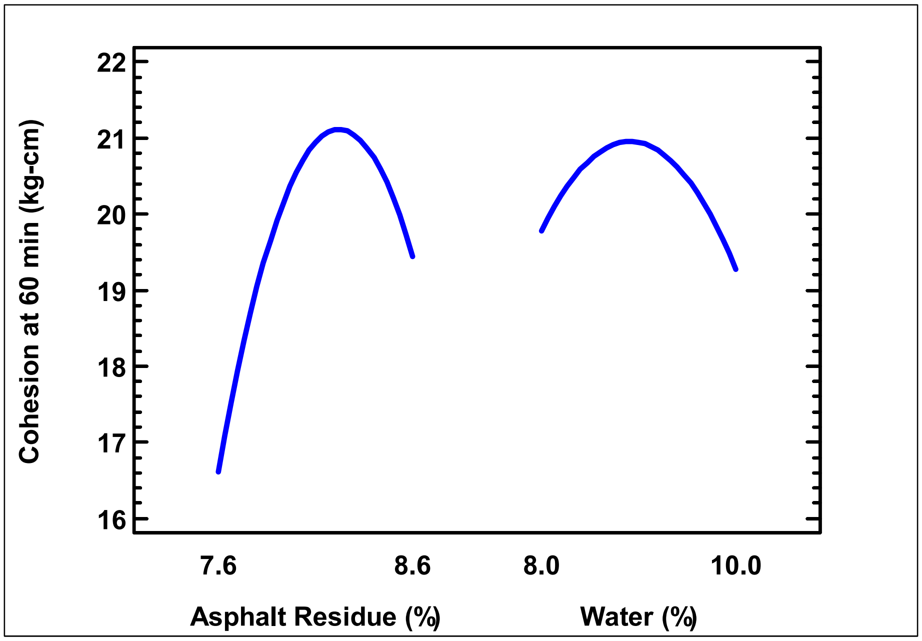

Figure 6.31 Effects of Asphalt Emulsion Residue and Water on Results of Modified Cohesion Test at 60 minutes, mixtures prepared without Portland cement (Main Effect Plot)

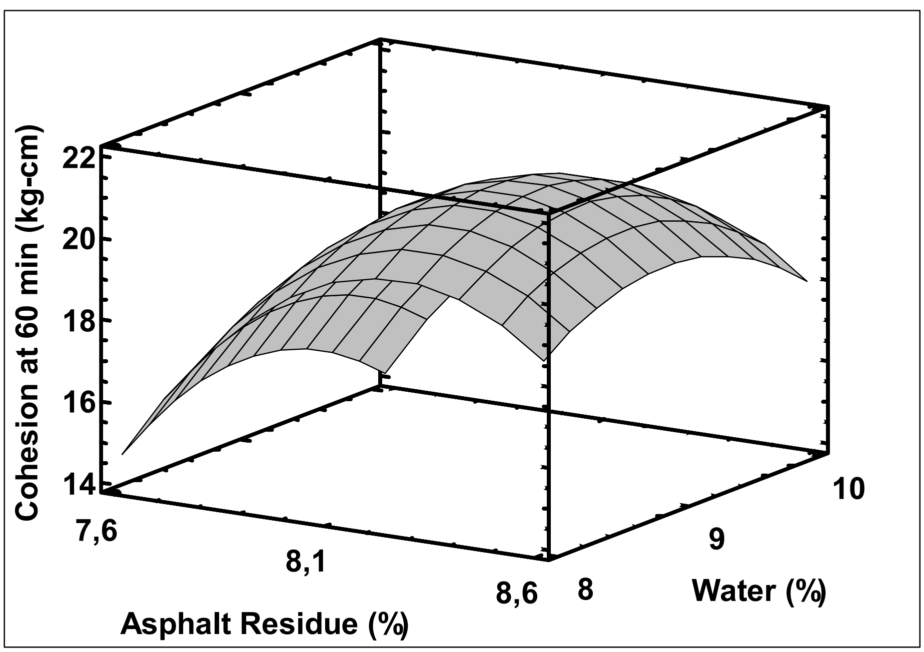

Figure 6.32 Effects of Asphalt Emulsion Residue and Water on Results of Modified Cohesion Test at 60 minutes, mixtures prepared without Portland cement (Estimates Response)

2) 6.5.2.2. Effect of Portland cement (P.C.)

Effect of Portland cement on the set and traffic characteristics of Micro-surfacing mixtures was also evaluated in this part of the study. One% of Portland cement (1% by weight of the dry aggregate) was used. The Portland cement (P.C.) was added to the wet aggregate and mixed immediately before adding the asphalt emulsion. Three asphalt emulsion residue content (7.6, 8.1, and 8.6%) were chosen. Mixing Time Test (ISSA TB 113) was already conducted for different asphalt emulsion residue-water combinations, and those combinations resulted mixing time more than 2 minutes were selected for further testing. Five replications were made for each asphalt emulsion-water combination. Table 6.16 shows summary of test results.

Table 6.16 Summary of test results for Modified Cohesion Test at 60 minutes, mixtures prepared with 1% Portland cement

Asphalt Residue Content (%)	**Added Water Content** (%)	**Modified Cohesion Test (Cohesion at 60 min)**			
		Mean Torque (kg-cm)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
7.6	**9**	16.1	0.2	0.05	5
8.1	**9**	18.1	0.2	0.05	5
8.6	**9**	18.7	0.4	0.2	5
7.6	**10**	15.9	0.5	0.3	5
8.1	**10**	20.7	0.4	0.2	5
8.6	**10**	18.6	0.4	0.3	5
7.6	**11**	15.7	0.3	0.075	5
8.1	**11**	18.3	0.3	0.1	5
8.6	**11**	17.1	0.2	0.05	5

Figure 6.33 is a plot of raw data for wet cohesion values at 60 minutes versus asphalt emulsion residue at 8, 9, and 10% added water content. The same trend as mixtures without Portland cement was observed. The only different was about the amount water at which mixture show its maximum cohesion. As different water contents are added to 8.1% asphalt emulsion residue mixture, there is an increase of cohesion for mixture with 10% added water

content. For mixture with 8.6% asphalt emulsion residue, maximum cohesion was observed at 9% added water content.

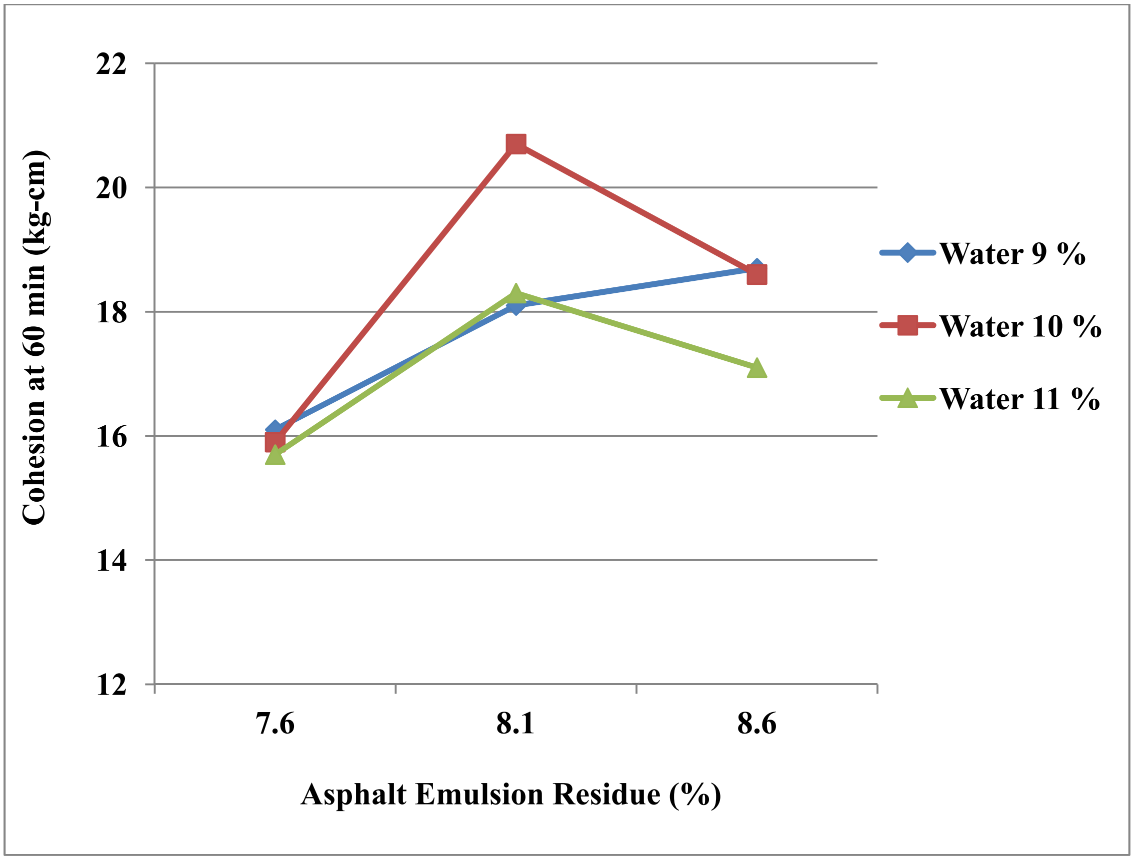

Figure 6.33 60-minute wet cohesion torque values against different asphalt emulsion residue with 9, 10, and 11% water, mixtures prepared with 1% Portland cement

6.6 Mixing Time Test Results Analysis

Summary of test results of mixing time torque measured for each asphalt emulsion residue-water combination are presented in table 6.17. Three asphalt emulsion residues content (7.6, 8.1, and 8.6%) and four added water contents are the independent variables to estimate the percent excess asphalt of specific micro-surfacing formulations. Three replications were made for each asphalt emulsion-water combination.

Table 6.17 Summary of test results for Mixing Time

Asphalt Residue Content (%)	Added Water Content (%)	Mixing Time Test (sec)			
		Mixing Time (sec)	Standard Deviation	Coefficient of Variance	Replication (N)
7.6	**8**	124.50	6.36	5.11	2
8.1	**8**	134.00	5.66	4.22	2
8.6	**8**	142.50	2.12	1.49	2
7.6	**9**	137.50	3.54	2.57	2
8.1	**9**	183.50	4.95	2.70	2
8.6	**9**	206.00	5.66	2.75	2
7.6	**10**	192.00	9.90	5.16	2
8.1	**10**	211.50	13.44	6.35	2
8.6	**10**	292.50	10.61	3.63	2

Figure 6.34 is a plot of raw data for mixing time values versus asphalt emulsion residue at 8, 9, and 10% added water content.

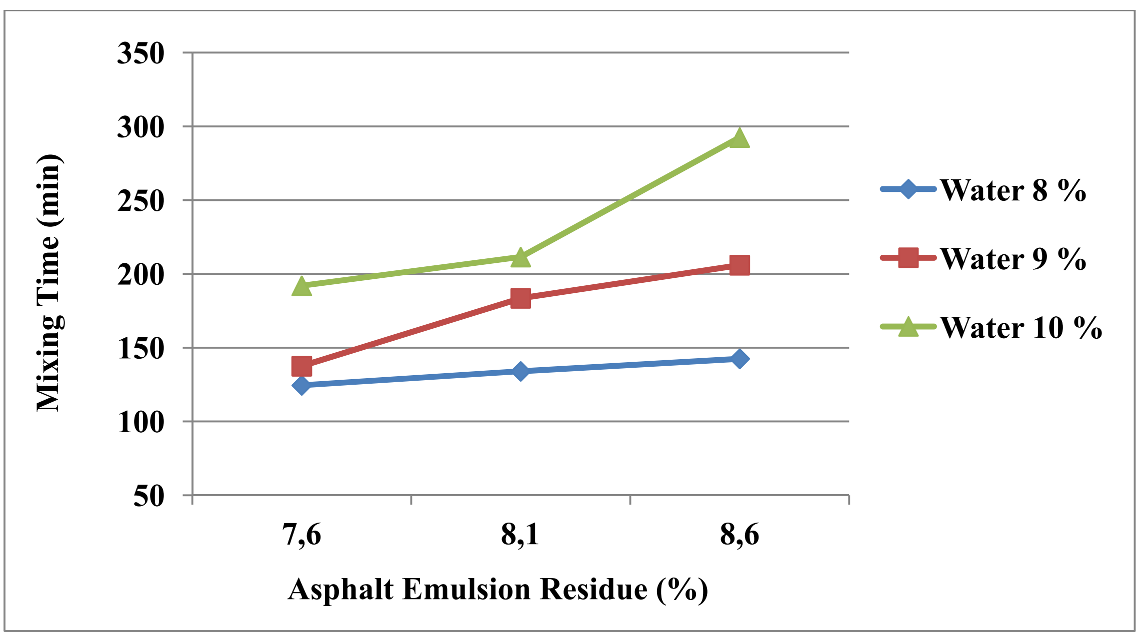

Figure 6.34 Plot of raw data for mixing time values versus asphalt emulsion residue at 8, 9, and 10% added water content

The ANOVA model for this experiment is:

$$Yijk = \mu + A_i + Ej + (AE)\,ij + \varepsilon ijk \tag{6.8}$$

Where Yijk = Mixing Time (sec), μ = mean mixing time (sec), A_i = effect of ith asphalt emulsion residue content, Ej = effect of j^{th} added water content, AE_{ij} = effect of interaction between i^{th} asphalt emulsion residue content and j^{th} added water content, and ε_{ijk} = random error for the i^{th} asphalt emulsion residue content and j^{th} added water content, and k^{th} replicate.

Final ANOVA model for this experiment is:

Mixing Time (sec) = $3383.69 - 476.346\times A_i - 279.0\times Ej + 40.4506\times (AE)_{ij}$

Output of ANOVA table for results of Mixing Time Test show that. there are three effects having P-value less than 0.05 (Table 6.18).

Table 6.18 ANOVA, Output of Mixing Time Test (min)

Analysis of Variance for Mixing Time Test (sec)					
Dependent Variable: Mixing Time					
R-squared = 98.4783%					
Source	**Sum of Squares**	**Df**	**Mean Square**	**F-Value**	**P-Value**
A:Asphalt	5890.67	1	5890.67	84.52	0.0003
B:Water	15100.2	1	15100.2	216.66	0.0000
AB	1560.25	1	1560.25	22.39	0.0052
Total error	348.472	5	69.6944		

These effects are effects of asphalt emulsion residue. added water contents and effect of their interaction. As it can be seen from ANOVA table, estimated F-value for effect of added water content is 216.66, whixh is well beyond of the estimated F-value for effect of asphalt emulsion residue. This shows that. the effect of added water content in incresing the mixing time of micro-surfacing mixtures is much more than the effect of asphalt emulsion residue. Figure 6.35 shows the significant effect of asphalt emulsion and added water content on result of Loaded wheel test. This figure shows how the effect of water is much more than the effect of asphalt emulsion residue to increase mixing time of micro-surfacing mixtures.

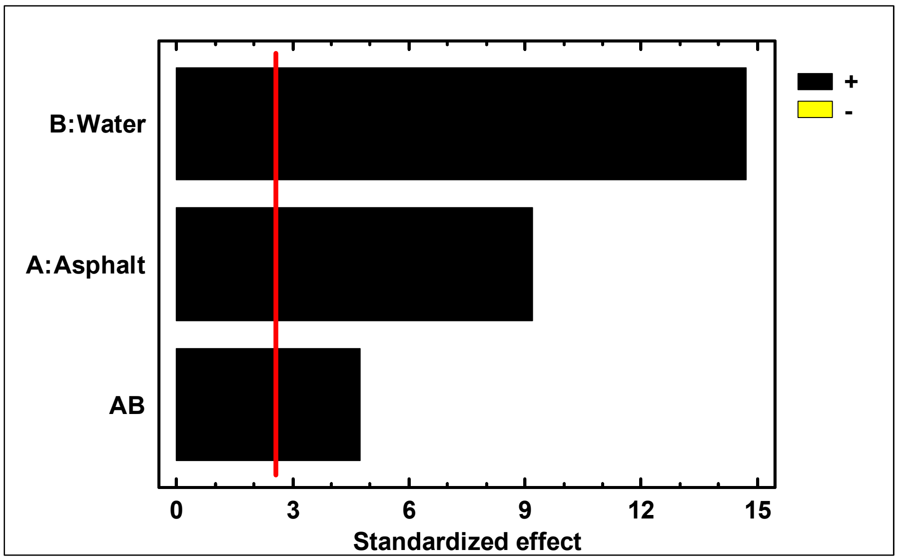

Figure 6.35 Standardized Pareto chart for Mixing Time Test (min)

Figure 6.36 shows main effect plot for modified cohesion test results. Mixing Time test reasults show that effect of water is more significant than asphalt residue effect. The result of mixing time range from 120 to 245 second. Based on ISSA mix design guide line for Micro-surfacing, mixing time of mixture must be more than 120 second (2 minutes). It was observed that, added water content equal to 7% does not provide enough mixing time, and water content equal to 10% was lead to free flow in mixture.

As it was explained in sections 3.5.4.1 and 3.5.4.2. cohesion of mixture with 7.6, 8.1, and 8.6% asphalt residue, was decreased at 10% added water content. The reason for decreasing of cohesion of mixture at 10% adding water for asphalt residue is because free flow occurred in the mixture. For all the mixtures with 8 and 9% added water content minimum of 120 seconds mixing time with a uniform mixture was observed.

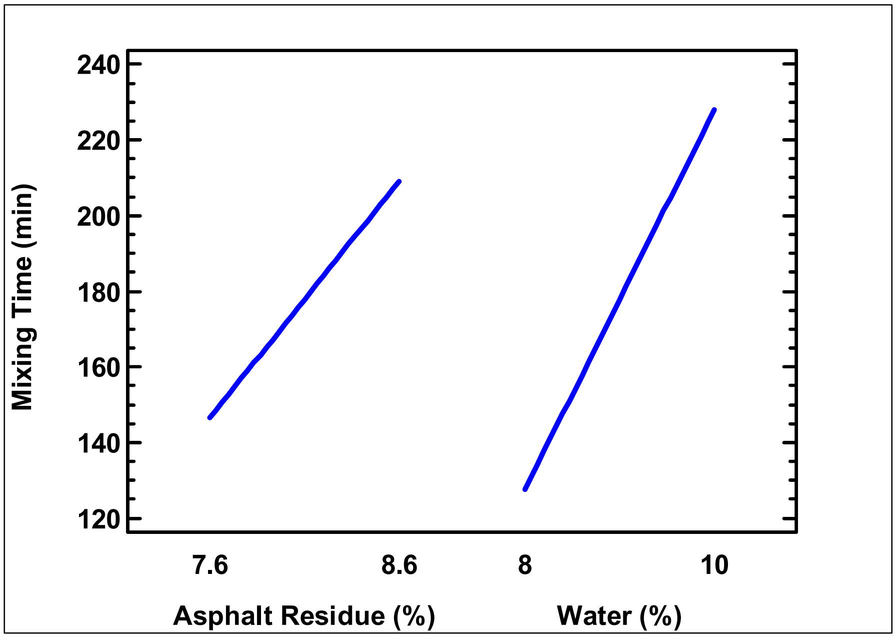

Figure 6.36 Effects of Asphalt Emulsion Residue and
Water on Results of Mixing Time Test (Main Effect Plot)

6.7 Results Summary

As it was just showed, the impact of the amount of asphalt residue and the amount of added water to micro-surfacing are quite important. A summary of the results presented in the previous sections is shown in table 6.19. Asphalt emulsion residue and added water content have a significatnt effect on the results of loaded wheel test, wet track abrasion test, mixing time test, and moisture retained in loadded wheel test. As for modified cohesion test (30-min and 60-min), asphalt emulsion residue and its square amount has a significant effect. For the moisture retained in wet track abrasion test samples, square amount of asphalt emulsion residue and added water content have a significant effect. It is important to note that those results are valid only for the different materials used in this study. If one uses another type of emulsion which reacts differently with another type of aggregates, the results may vary. The results are also only valid in the range of added water and asphalt emulsion used in this study. On the other hand, the different values that were used are commonly used amount and are the quantities that give overall optimum results.

Table 6.19 Results summary for all tests done on micro-surfacing shown in this chapter

Test	Significant effect of Added Water (W)	Significant effect of Asphalt Residue (A)	Trend
Loaded wheel test	yes	yes	W ↑ : adhered sand ↑
			A ↑: adhered sand ↑
Wet track abrasion (1 hour soaked)	no	yes	W ↑: aggregates loss ↓
			A ↑: aggregates loss ↓
Wet track abrasion (6-day soaked)	yes	yes	W ↑: aggregates loss ↓
			A ↑: aggregates loss ↓
Mixing time	yes	yes	W ↑: mixing time ↑
			A ↑: mixing time ↑
Relative moisture retained (LWT samples)	yes	yes	W ↑ : moisture↑
			A ↑: moisture↑
Relative moisture retained (WTAT samples)	yes[1]	yes[2]	W ↑ : Presence of an optimum moisture content
			A ↑ : Presence of an optimum moisture content
Modified cohesion at 30 minutes (with or without cement)	no	yes[3]	W ↑ : cohesion ↓ (at 7.6 & 8.6 asphalt residue)
			W ↑: Presence of an optimum cohesion content (at 8.1 asphalt residue)
			A ↑ : Presence of an optimum cohesion
Modified cohesion at 60 minutes (with or without cement)	no	yes[4]	W ↑ : cohesion ↓ (at 7.6 & 8.6 asphalt residue)
			W ↑ : Presence of an optimum cohesion (at 8.1 asphalt residue)
			A ↑ : Presence of an optimum cohesion

[1] Significant effect of square amount of water
[2] Significant effect of square amount of asphalt emulsion residue
[3] Significant effect of asphalt emulsion and its square amount
[4] Significant effect of asphalt emulsion and its square amount

Another interesting fact that can be seen from the previous sections is the variability of the results. As shown in table 6.20, the coefficient of variation between replicates for each tests goes from 0.7% up to 29%. This shows that test like the modified cohesion test has a good repeatability. but that the wet track abrasion test has a lot more variations in the test results (Table 6.20).

Table 6.20 Max and min coefficients of variation between replicates for each test

Test	**Coefficient of variation (%)**	
	Minimum	**Maximum**
Loaded wheel test	1.7	3.6
Wet track abrasion – 1 hour soaked	2.2	29.0
Wet track abrasion – 6 days soaked	2.8	22.3
Relative moisture retained in LWT samples	0.7	2.8
Relative moisture retained in WTAT samples	0.7	6.5
Modified cohesion at 30 minutes (with or without cement)	1.6	7.9
Modified cohesion at 60 minutes (with or without cement)	1.7	3.9
Mixing time	1.5	6.4

CHAPITRE 7

MODIFICATION TO ISSA A-143 DESIGN PROCEDURE FOR MICRO-SURFACING

7.1 Introduction

A Study of ISSA mix design tests for micro-surfacing was conducted to select optimum mix design procedure. The amount of asphalt emulsion residue and added water content in the mixture greatly influences the magnitude of the test response for all the tests investigated in this report. Mix design procedure for micro-surfacing suggested by ISSA to select optimum asphalt emulsion is based on loaded wheel test and wet track abrasion tests. In this method, the optimum asphalt emulsion is selected by evaluating the abrasion loss in the wet track abrasion tests versus pick up from the loaded wheel tester. Based on statistical analysis of detailed laboratory findings in this research, consistency for the loaded wheel test and wet track abrasion test is poor. The amount of water in the mixture had a profound influence on the sand adhered in sample of loaded wheel test, and aggregate loss in samples of wet track abrasion tests. However, the consistency for modified cohesion test is good, and the test can be used to select the optimum water content. The test should be performed at all asphalt emulsion/cement combinations used in the mixing test. The optimum water content for each of asphalt emulsion/cement combinations is selected at 30 minutes and 60 minutes cohesion. Those asphalt emulsion/cement/water combinations that show maximum cohesion at 30 and 60 minutes are selected for further testing following the mixing test to ensure minimum 120 seconds of mixing time at 25ºC (77ºF) for each of emulsion/cement/water combinations. As the main application of type III micro-surfacing is filling ruts in areas with heavy traffic, optimum asphalt emulsion content is selected for maximum rutting resistance.

7.2 Modification to Outline Guide Design Procedure for Micro-surfacing

Following is preliminary design considerations and suggested job mix formula procedures for micro-surfacing (see figure 7.1 and 7.2):

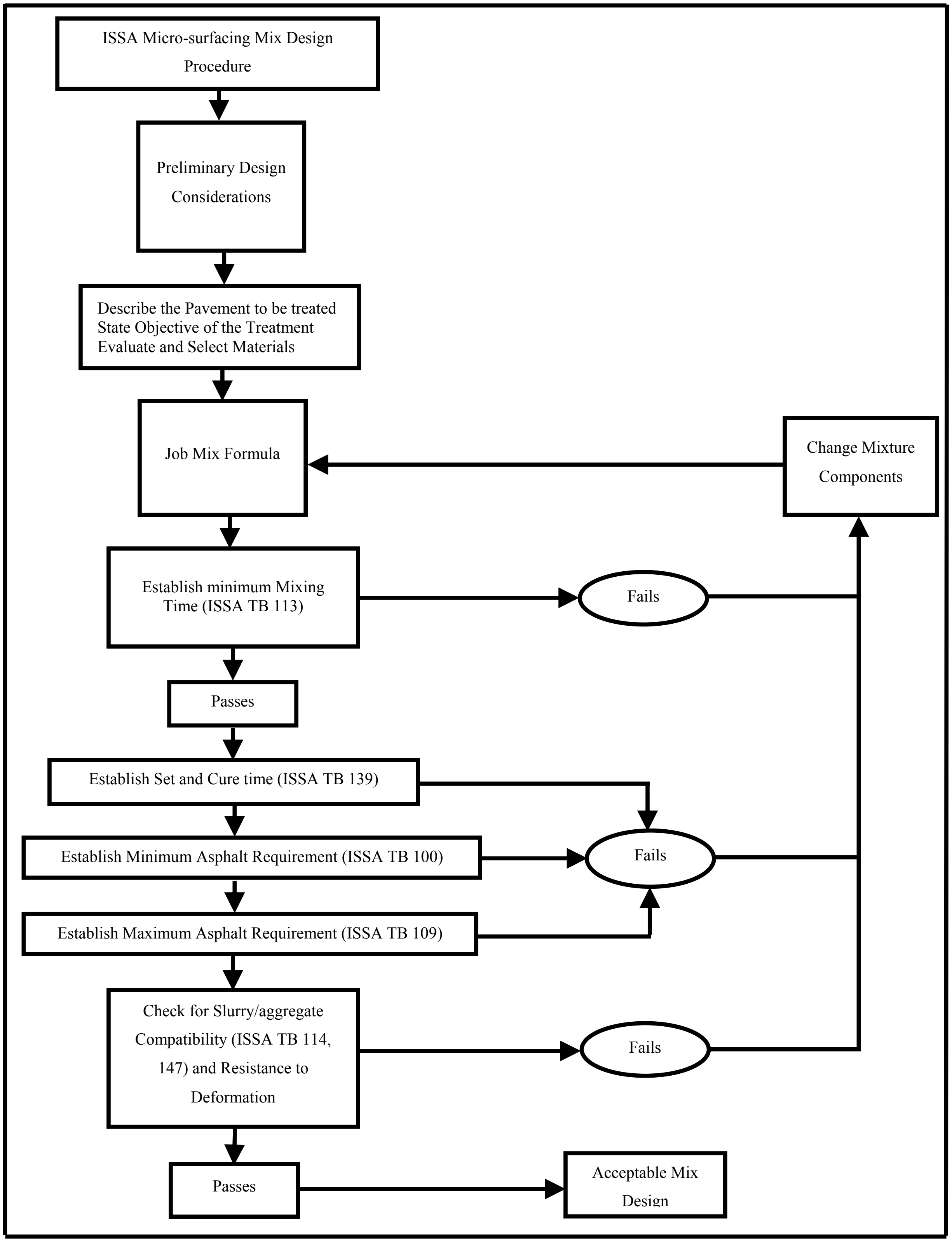

Figure 7.1 Flowchart of ISSA mix design procedure for micro-surfacing

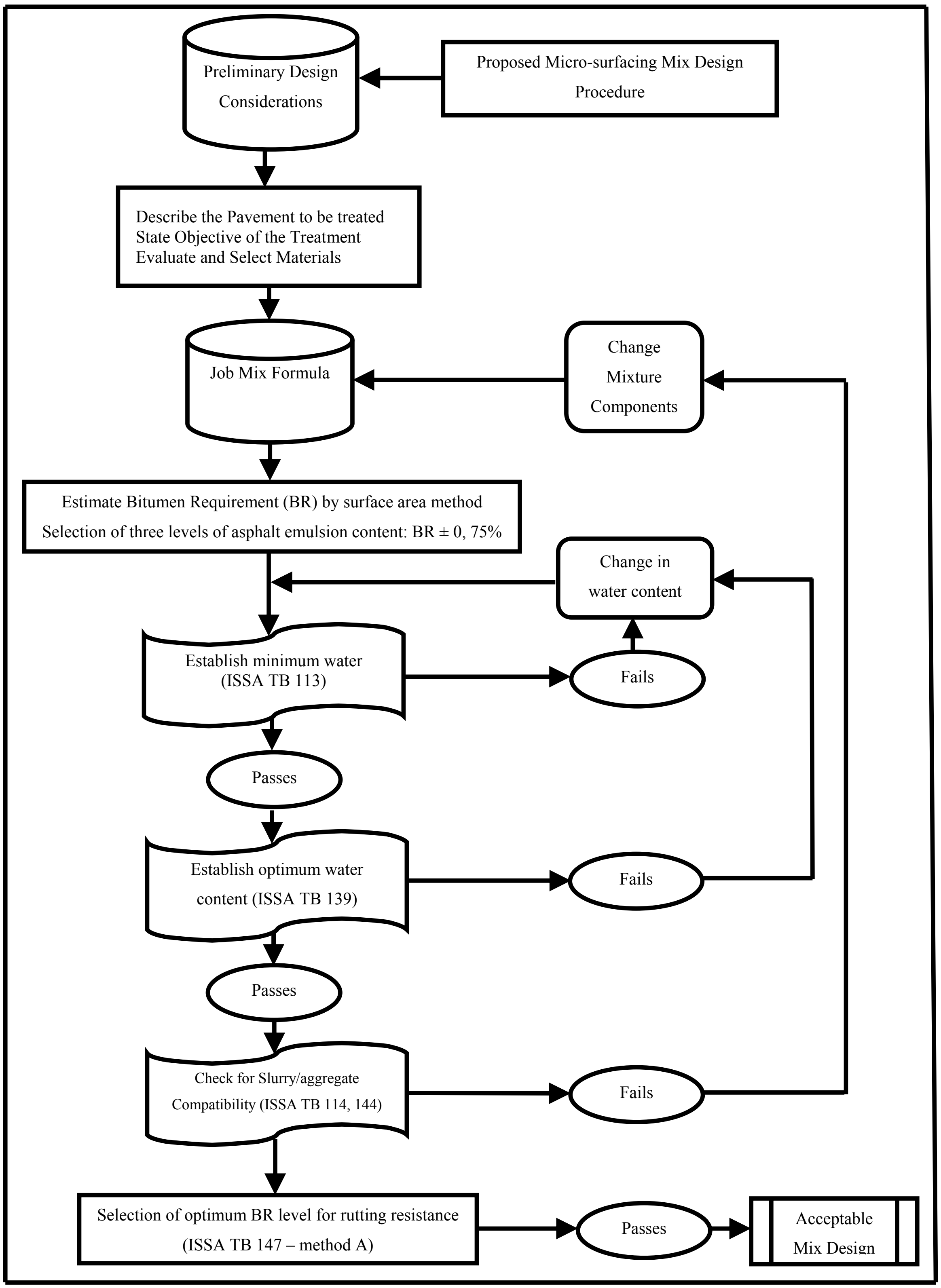

Figure 7.2 Flowchart of proposed mix design procedure for micro-surfacing

7.2.1 Preliminary design considerations

i. Describe the pavement to be treated: This includes providing information about surface condition, and climate conditions.

ii. State objective of surface treatment: This mix design procedure is suggested for maximum rutting resistance in areas with heavy traffic.

iii. Evaluate and select materials: The aggregate has to conform to grade III gradation suggested by ISSA mix design procedure. Mineral filler, and asphalt emulsion have to conform to specifications suggested by ISSA mix design procedure for micro-surfacing.

7.2.2 Job Mix Formula Procedures

i. Estimate Bitumen Requirement by surface area method for 8µm coating: Bitumen requirement can also be selected based on designer experience. For type III micro-surfacing. 12.5% asphalt emulsion (expressed by total weight of aggregates) is suggested.

ii. Selection of three levels of asphalt emulsion content: These three levels of asphalt emulsion are bitumen requirement determined by surface area method ± 0.75%.

iii. Estimate minimum water content: Filler/additives content is selected and added to aggregates. Mixing time test (ISSA TB 113) is run for each of mixtures with three different levels of asphalt emulsion to determine minimum added water content at which mixture can be mixed at room temperature (77ºF or 25ºC) for at least 120 seconds.

iv. Conduct compatibility tests: Determination of aggregate filler-bitumen compatibility for each of three asphalt emulsion/filler/water combinations by Schulze-Breuer procedure or wet stripping tests.

v. Selection of optimum water content: The optimum water content for each of asphalt emulsion/filler combinations is selected at maximum 30 min and 60 min cohesion.

vi. Selection of optimum asphalt emulsion: Test method for measurement of stability and resistance to compaction, vertical and lateral displacement of multilayered fine aggregate cold mixes (ISSA TB 147- Method A) is conducted for those asphalt emulsion/filler/water combinations having greater amount of 30-min and 60-min cohesion. Optimum emulsion content for rutting resistance can be determined at the minimum vertical and lateral displacements after 1000 cycle compactions of 56.7 kg load.

7.3 Validate Modified Design Procedure for Three Types of Aggregates

Raycar, Graham Pitt, and rive-sud aggregates obtained from Quebec. Canada, were used in this part of study. Aggregate sizes range from 0-5 mm. Mid-range type III aggregate gradation was selected, and 1% of Portland cement was used in all mixture specimens. Based on job mix formula procedure suggested for micro-surfacing in section 7.2.2, mixture proportions were selected. Three levels of asphalt emulsion were bitumen requirement ± 0.75%. These three levels were 11.75, 12.5, and 13.25% (expressed by total weight of aggregates) asphalt emulsion. As CQS-1HP asphalt emulsion included 65% asphalt residue, these three levels of asphalt emulsion include 7.6, 8.1, and 8.6% asphalt emulsion residue respectively. 1% cement was added to aggregates. and mixing time test (ISSA TB 113) was run for each of mixtures to determine the minimum added water content at which a mixture can be mixed at room temperature (25ºC or 77ºF) for at least 120 seconds. Table 7.1 shows a summary of test results of mixing time measured for all specimens. As it can be seen from this table, Raycar aggregates required minimum of 9% water for each of 7.6, 8.1, and 8.6% asphalt residue content at which mixture can be mixed at room temperature (77ºF or 25ºC) for at least 120 seconds. The minimum added water content for Graham Pitt and rive-sud aggregates were 4 and 11% respectively.

Table 7.1 Mixing Time test results, Raycar, Graham Pitt and rive-sud aggregates

Aggregate	Asphalt Residue Content (%)	Added Water Content (%)	Mixing Time Test (sec)			
			Mixing Time (sec)	Standard Deviation	Coefficient of Variance	Replication (N)
Ray Car	**7.6**	**9**	127.50	2.10	1.65	2
	8.1	**9**	133.50	2.10	1.57	2
	8.6	**9**	145.50	4.90	3.37	2
Graham Pitt	**7.6**	**4**	125.50	3.50	2.79	2
	8.1	**4**	134.50	2.10	1.56	2
	8.6	**4**	150.50	2.10	1.40	2
Rive Sud	**7.6**	**11**	131.00	2.80	2.14	2
	8.1	**11**	140.50	0.70	0.50	2
	8.6	**11**	152.00	4.20	2.76	2

Determination of aggregate filler-bitumen compatibility for each of three asphalt emulsion/filler/water combinations having mixing time greater than 120 seconds was conducted by wet stripping tests.

Table 7.2 shows a summary of wet stripping test results for all specimens. This test is designed to help designer to select a compatible slurry system with a given aggregate. Wet stripping test results for raycar aggregates ranged from 95.5-97.5%. Graham Pitt ranged from 92.5-94%, and for rive-sud aggregates ranged from 90.5-93.5%.

As it can be seen from table 7.2, all three levels of asphalt emulsion with 1% cement at minimum required water result in mixing time more than 120 seconds were compatible with raycar, Graham Pitt, and rive-sud aggregates, however, raycar aggregates were more compatible with three selected asphalt emulsion/water formulations.

Table 7.2 Wet Stripping test results, Raycar, Graham Pitt and rive-sud aggregtes

Aggregate	**Asphalt Residue Content** (%)	**Added Water Content** (%)	**Wet Stripping Test (%)**			
			Coated Areas (%)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
Ray Car	**7.6**	**9**	95.50	0.7	0.73	2
	8.1	**9**	96.75	0.4	0.41	2
	8.6	**9**	97.50	0.7	0.72	2
Graham Pitt	**7.6**	**4**	92.50	0.7	0.76	2
	8.1	**4**	93.00	0.7	0.75	2
	8.6	**4**	94.00	1.4	1.49	2
Rive Sud	**7.6**	**11**	90.50	0.7	0.77	2
	8.1	**11**	92.00	1.4	1.52	2
	8.6	**11**	93.50	0.7	0.75	2

The optimum water content for each of asphalt emulsion/filler combinations were selected at maximum 30 min and 60 min cohesion. Table 7.3 and 7.4 show summary of test results of 30-min and 60-min modified cohesion test measured for raycar, Graham Pitt, and rive-sud aggregates with 7.6, 8.1, and 8.6% asphalt emulsion residue at optimum added water content, and 1% of cement additives. As it can be seen from these two tables, 30-min cohesion of mixtures prepared using Raycar, Graham Pitt, and rive-sud aggregates. ranged from 12.8 to 13.2 kg-cm at 7.6% asphalt emulsion residue and optimum added water content. However. cohesion of these mixtures at 8.1 and 8.6% asphalt emulsion residue and optimum added water content respectively ranged from 18-18.8 and 16.4 to 16.8 kg-cm. Thus. it can be concluded that for all three types of aggregates, mixtures with 8.1 and 8.6% asphalt emulsion residue had greater amount of 30-min and 60-min cohesion than mixtures with 7.6% asphalt emulsion residue. Therefore, optimum binder content should be selected between 8.1 and 8.6% asphalt emulsion residue for all three types of aggregates. Figure 7.3 and 7.4 tabulate test results of 30-min and 60-min cohesion test for raycar, Graham Pitt and rive-sud aggregates.

Table 7.3 30-min cohesion test results, Raycar, Graham Pitt and rive-sud aggregates

Aggregate	Asphalt Residue Content (%)	Added Water Content (%)	Cohesion at 30 min (kg-cm)			
			Cohesion at 30 min (kg-cm)	Standard Deviation	Coefficient of Variance	Replication (N)
Ray Car	**7.6**	**9**	13.2	0.40	3.03	5
	8.1	**10**	18.8	0.30	1.60	5
	8.6	**9**	16.7	0.70	4.19	5
Graham Pitt	**7.6**	**4**	13.1	0.40	3.05	5
	8.1	**5**	18.0	0.60	3.33	5
	8.6	**4**	16.8	0.80	4.76	5
Rive-Sud	**7.6**	**11**	12.8	0.80	6.25	5
	8.1	**12**	18.1	0.40	2.21	5
	8.6	**11**	16.4	0.50	3.05	5

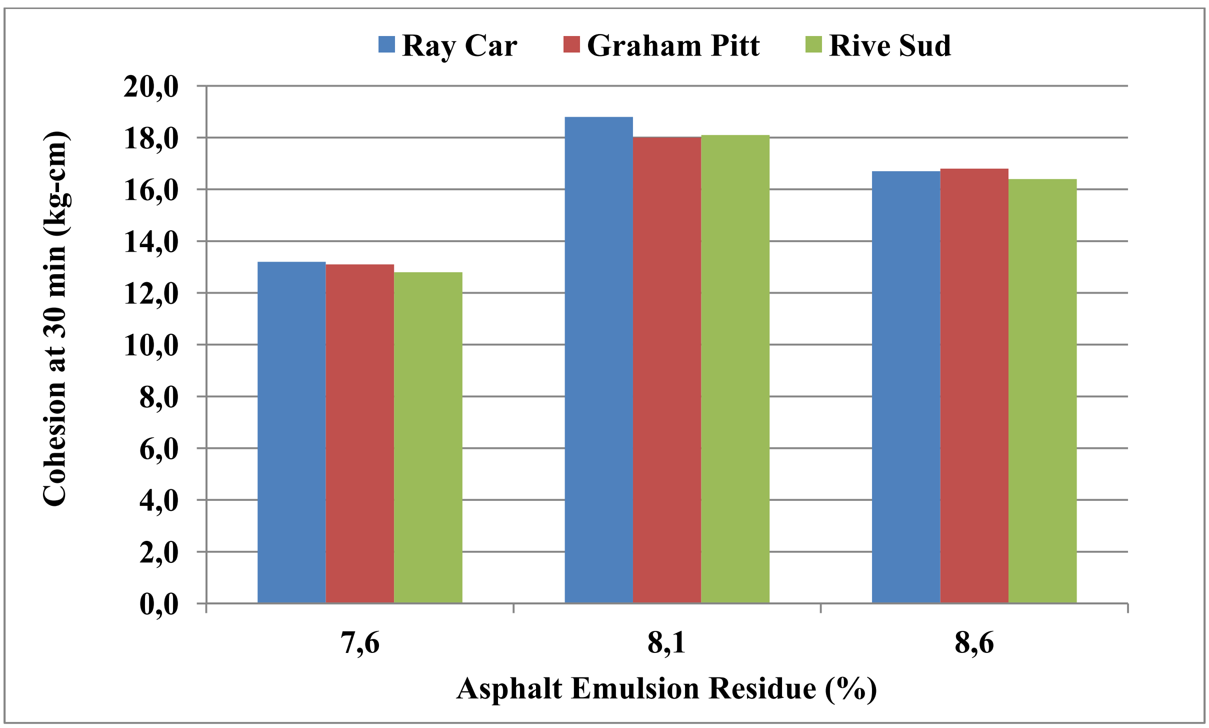

Figure 7.3 Comparison of 30-min cohesion test results, Ray car, Graham Pitt and Rive sud aggregates

Table 7.4 60-min cohesion test results, Ray car, Graham Pitt and Rive sud aggregates

Aggregate	Asphalt Residue Content (%)	Added Water Content (%)	Cohesion at 60 min (kg-cm)			
			Cohesion at 60 min (kg-cm)	Standard Deviation	Coefficient of Variance	Replication (N)
Ray Car	7.6	9	16.1	0.20	1.24	5
	8.1	10	20.7	0.40	1.93	5
	8.6	9	18.7	0.40	2.14	5
Graham Pitt	7.6	4	15.7	0.40	2.55	5
	8.1	5	20.3	0.80	3.94	5
	8.6	4	17.7	0.40	2.26	5
Rive Sud	7.6	11	15.9	0.50	3.14	5
	8.1	12	20.5	0.50	2.44	5
	8.6	11	17.6	0.50	2.84	5

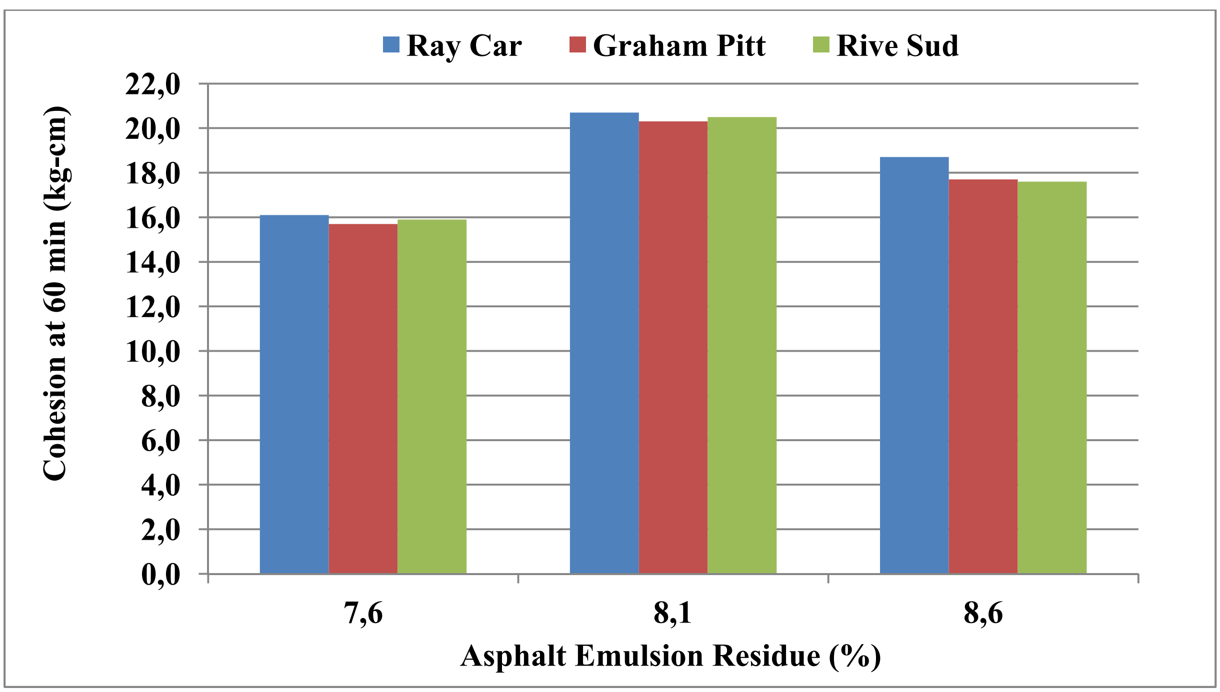

Figure 7.4 Comparison of 60-min cohesion test result,
Raycar, Graham Pitt and rive-sud aggregates

Test method for measurement of stability and resistance to compaction, vertical and lateral displacement of multilayered fine aggregate cold mixes (ISSA TB 147- Method A) were run for mixtures with 8.1 and 8.6% asphalt emulsion residue to select optimum binder. Tables 7.5 and 7.6 show summary of test results of lateral and vertical displacements measured at mid-length of specimens prepared with raycar, Graham Pitt, and rive-sud aggregates with 8.1 and 8.6% asphalt emulsion residue at optimum water content, and 1% cement.

Table 7.5 Lateral displacement results, Ray car, Graham Pitt and Rive sud aggregates

Aggregate	**Asphalt Residue Content** (%)	**Number of Cycles of 56.7 kg Load**	**Lateral Displacement of Multilayered Fine Aggregate Cold Mixes (ISSA TB 147)**			
			Lateral Deformation (mm)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
Ray Car	**8.1**	**1000**	2.33	0.15	6.44	3
		2000	4.73	0.21	4.44	3
		3000	7.90	0.30	3.80	3
	8.6	**1000**	5.70	0.53	9.30	3
		2000	9.03	0.50	5.54	3
		3000	12.83	0.65	5.07	3
Graham Pitt	**8.1**	**1000**	3.40	0.26	7.65	3
		2000	6.80	0.20	2.94	3
		3000	10.57	0.40	3.78	3
	8.6	**1000**	6.53	0.35	5.36	3
		2000	10.00	0.62	6.20	3
		3000	13.47	0.25	1.86	3
Rive Sud	**8.1**	**1000**	4.57	0.40	8.75	3
		2000	8.47	0.57	6.73	3
		3000	12.80	0.36	2.81	3
	8.6	**1000**	7.87	0.35	4.45	3
		2000	11.57	0.31	2.68	3
		3000	14.97	0.50	3.34	3

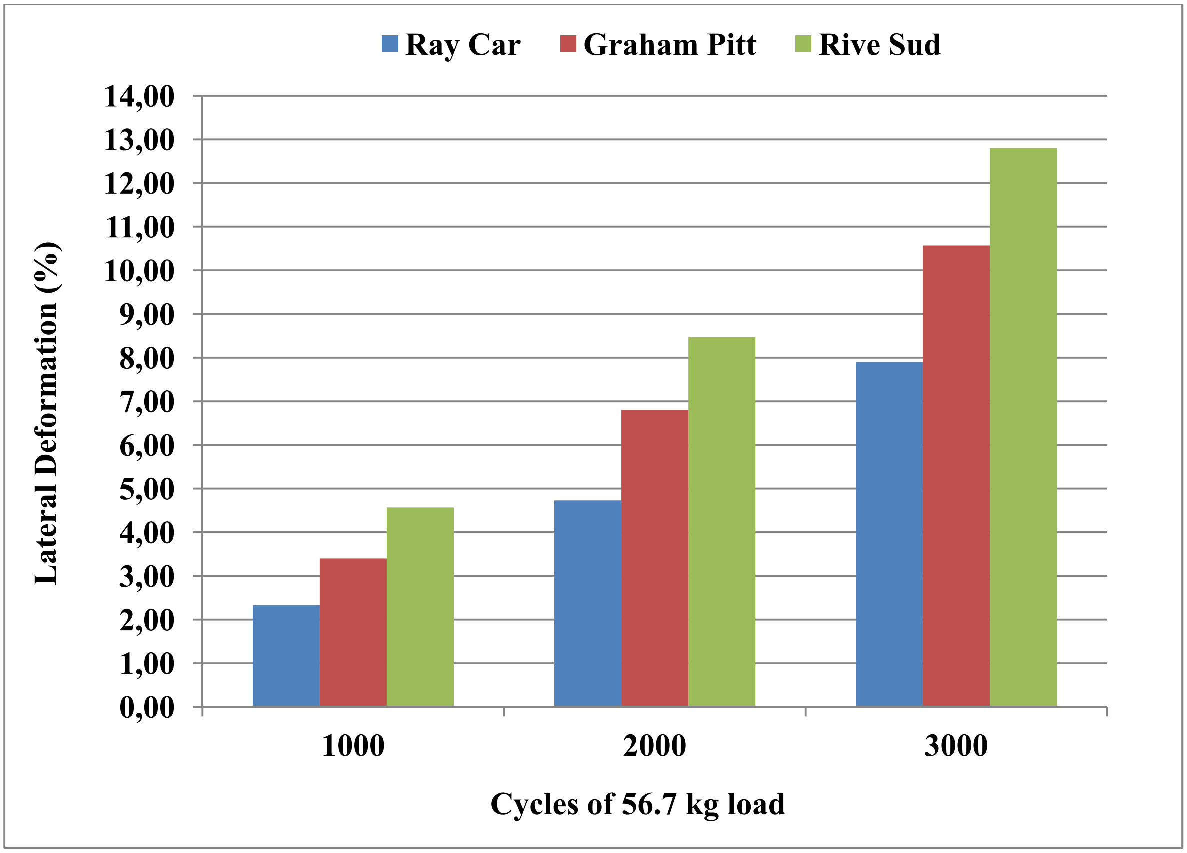

Figure 7.5 Comparison of lateral displacement test results, Ray car, and Graham Pitt and Rive sud aggregates with 8.1% asphalt emulsion, 1% cement, at optimum added water content

Figures 7.5 and 7.6 show lateral and vertical displacements at mid-length of specimens prepared with 8.1% asphalt emulsion residue. As it can be seen from these figures, mixtures prepared using raycar aggregates show relatively better rutting resistance as compared with the mixtures prepared with Graham Pitt and rive-sud aggregates. Samples made with rive-sud aggregates show least rutting resistance. It may be because raycar aggregates are more compatible with CQS-1HP asphalt emulsion, while, rive-sud aggregates that contained lime stone filler were less compatible with CQS-1HP asphalt emulsion. Based on ISSA mix design procedure for micro-surfacing, for design to be accepted, lateral and vertical displacements at mid-length of specimen, after 1000 cycles of 56.7 kg load, must be less than 5% and 10% of original width and length at mid-length of specimen respectively. Lateral and vertical displacements at mid length of specimens prepared using Ray car aggregates were respectively equal to 5% and 10% of original width and thickness at mid-length of specimen as the number of cycles of 56.7 kg load approached to 3000 cycles. However, for Graham Pitt and rive-sud, lateral displacement were less than 5% and 10% of original width and thickness at mid-length of specimen as the number of cycles of 56.7 kg load approached to 2000 cycles.

Table 7.6 Vertical displacement results, Ray car, Graham Pitt and Rive sud aggregates

Aggregate	**Asphalt Residue Content** (%)	**Number of Cycles of 56.7 kg Load**	**Vertical Displacement of Multilayered Fine Aggregate Cold Mixes (ISSA TB 147)**			
			Vertical Deformation (mm)	**Standard Deviation**	**Coefficient of Variance**	**Replication** (N)
Ray Car	**8.1**	**1000**	6.80	0.56	8.24	3
		2000	10.17	0.70	6.88	3
		3000	14.80	0.26	1.76	3
	8.6	**1000**	13.60	0.56	4.12	3
		2000	17.63	0.49	2.78	3
		3000	20.80	0.30	1.44	3
Graham Pitt	**8.1**	**1000**	8.50	0.50	5.88	3
		2000	12.53	0.25	2.00	3
		3000	16.60	0.36	2.17	3
	8.6	**1000**	14.30	1.15	8.04	3
		2000	19.13	0.57	2.98	3
		3000	23.33	0.38	1.63	3
Rive Sud	**8.1**	**1000**	14.47	0.15	1.04	3
		2000	19.67	0.40	2.03	3
		3000	25.40	1.82	7.17	3
	8.6	**1000**	15.90	0.30	1.89	3
		2000	21.80	0.56	2.57	3
		3000	26.10	0.20	0.77	3

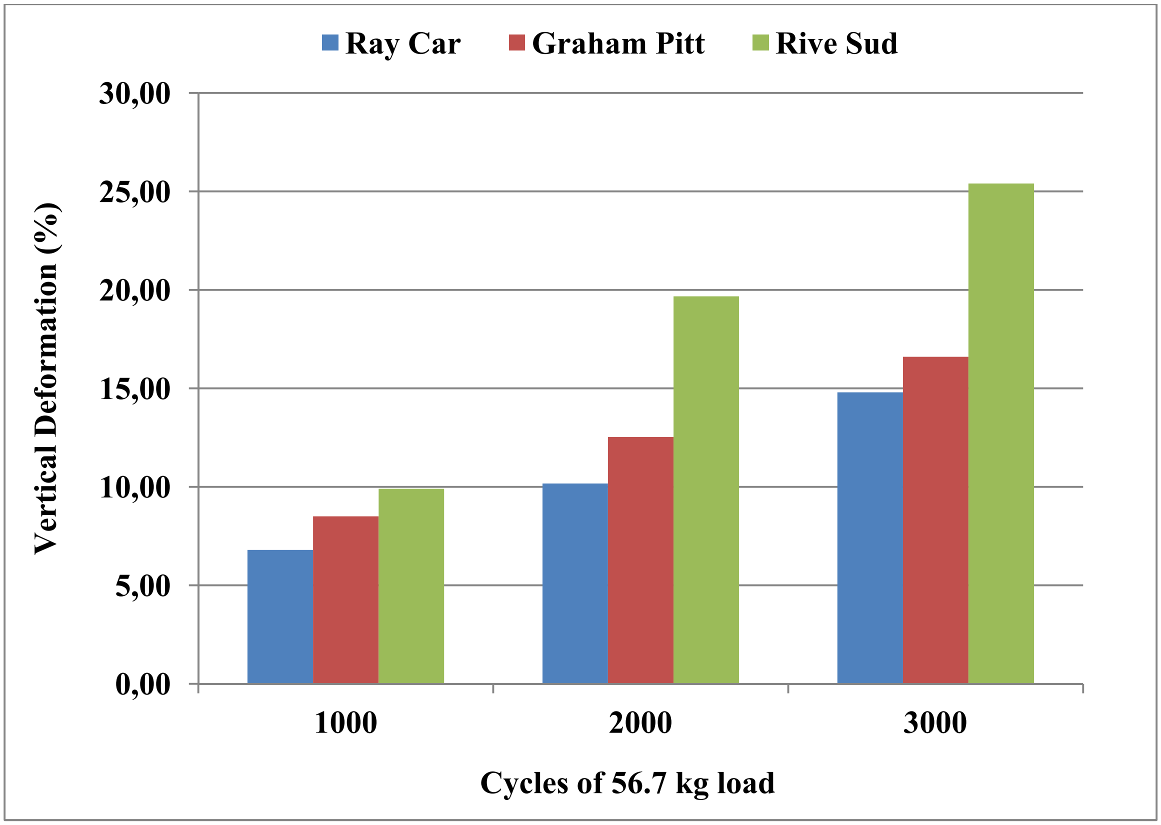

Figure 7.6 Comparison of vertical displacement test results, Raycar, and Graham Pitt and rive-sud aggregates with 8.1% asphalt emulsion, 1% cement, at optimum added water content

Figure 7.7 to 7.12 show lateral and vertical displacements at mid-length of specimens prepared using 8.1% and 8.6% asphalt emulsion residue. As it can be seen from these figures, lateral and vertical displacements of samples prepared with 8.1% asphalt emulsion residue were respectively less than 5% and 10% of original width and thickness at mid-length of specimens made by raycar, Graham Pitt, and rive-sud aggregates.

For samples prepared with 8.6% asphalt emulsion residue, lateral and vertical displacements, after 1000 cycle compactions of 56.7 kg load, were beyond limits specified with ISSA TB 147 mix design test (Method A).

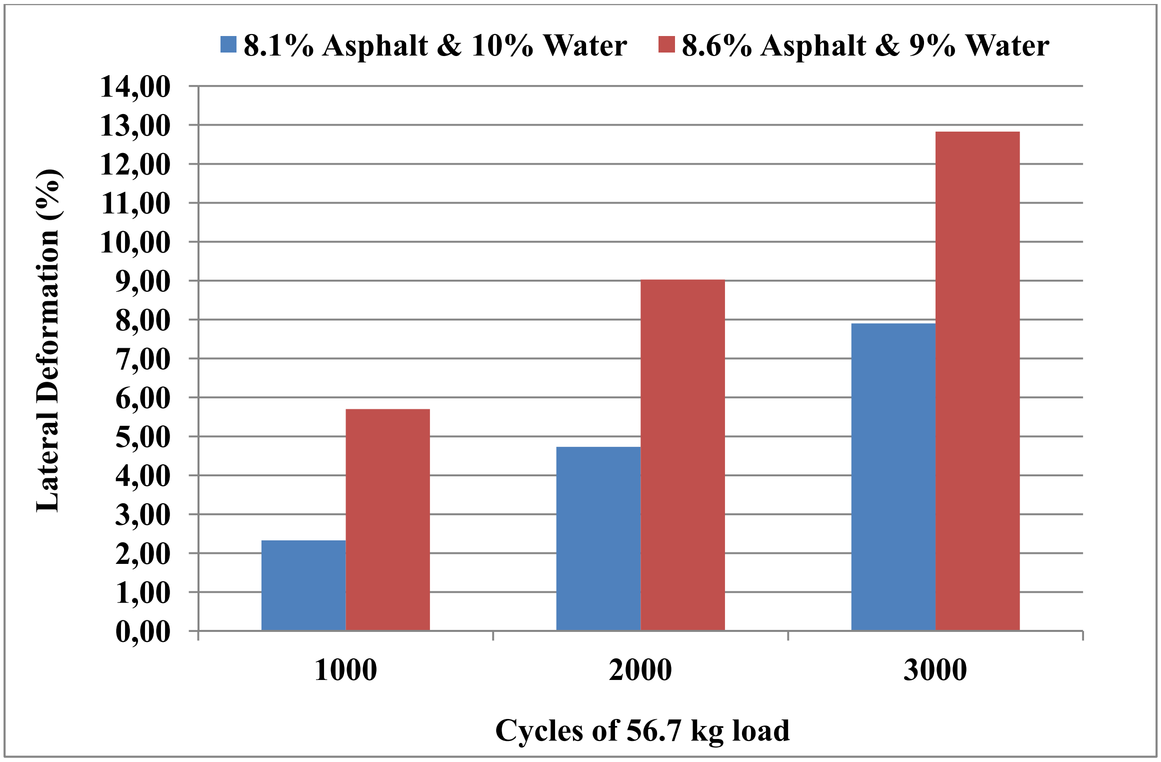

Figure 7.7 Lateral displacement test results, Ray car aggregates

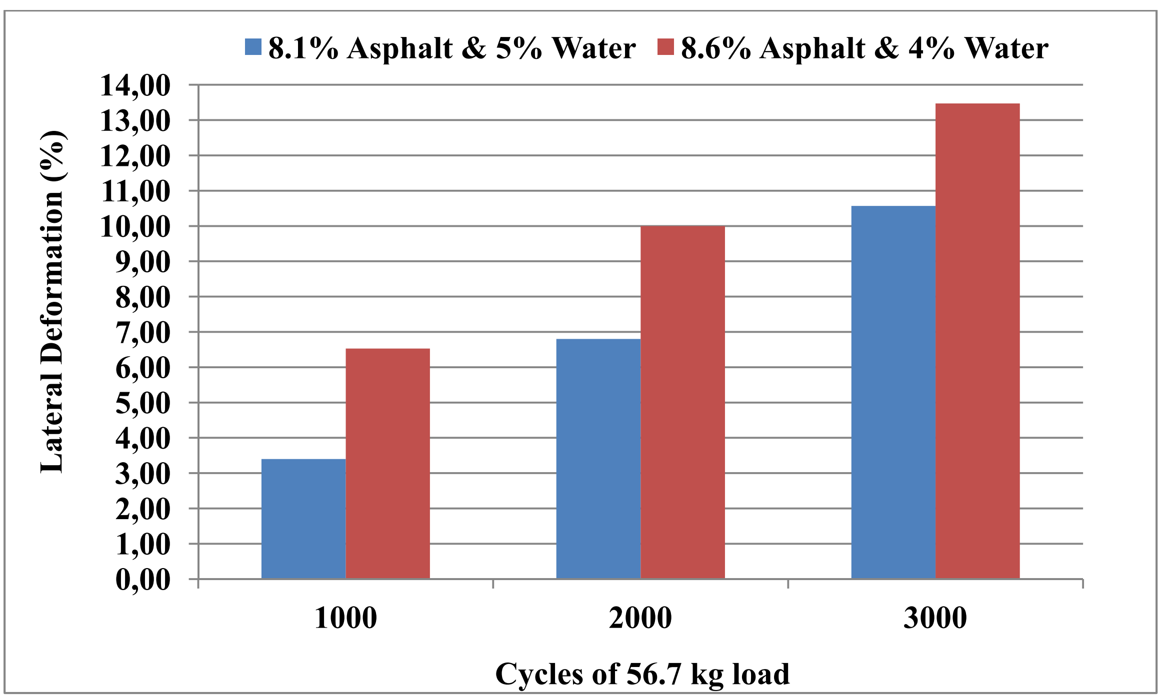

Figure 7.8 Lateral displacement test results, Graham Pitt aggregates

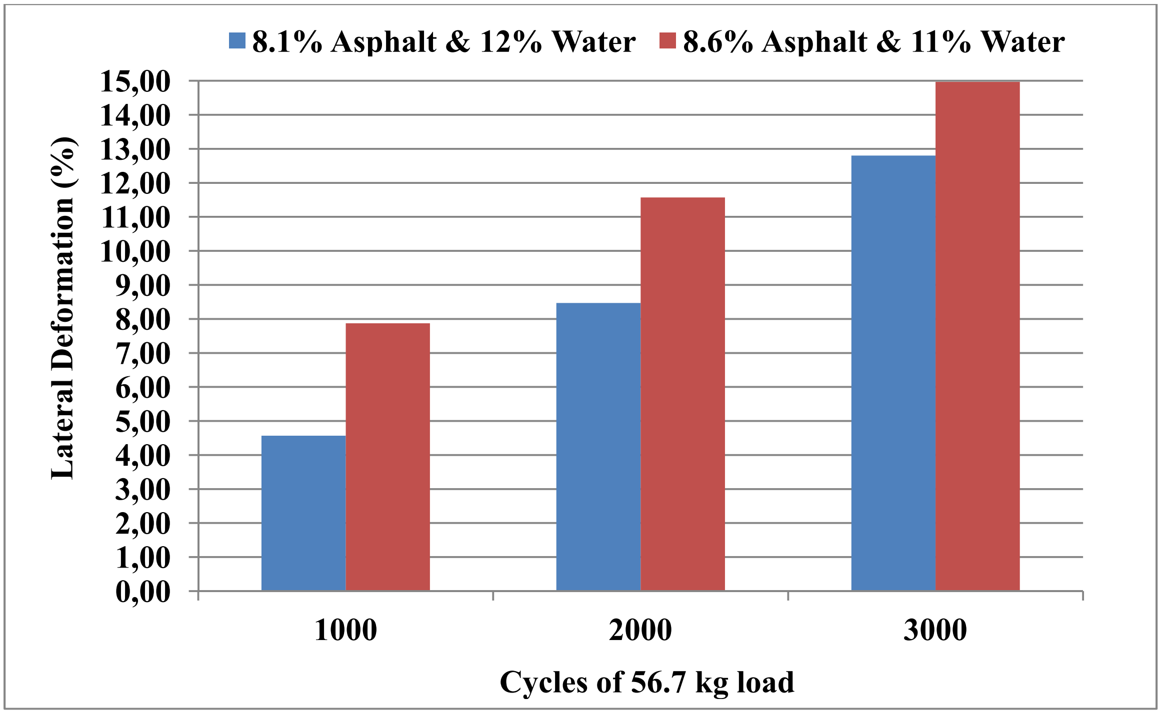

Figure 7.9 Lateral displacement test results, Rive sud aggregates

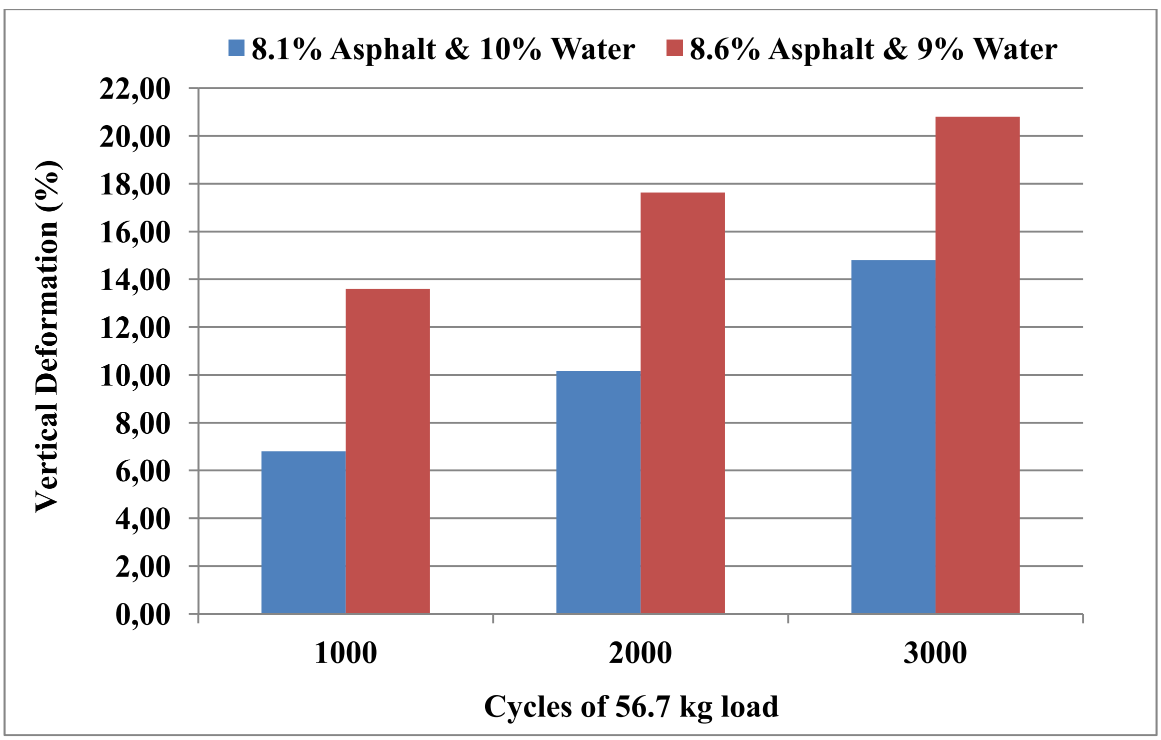

Figure 7.10 Vertical displacement test results, Ray car aggregates

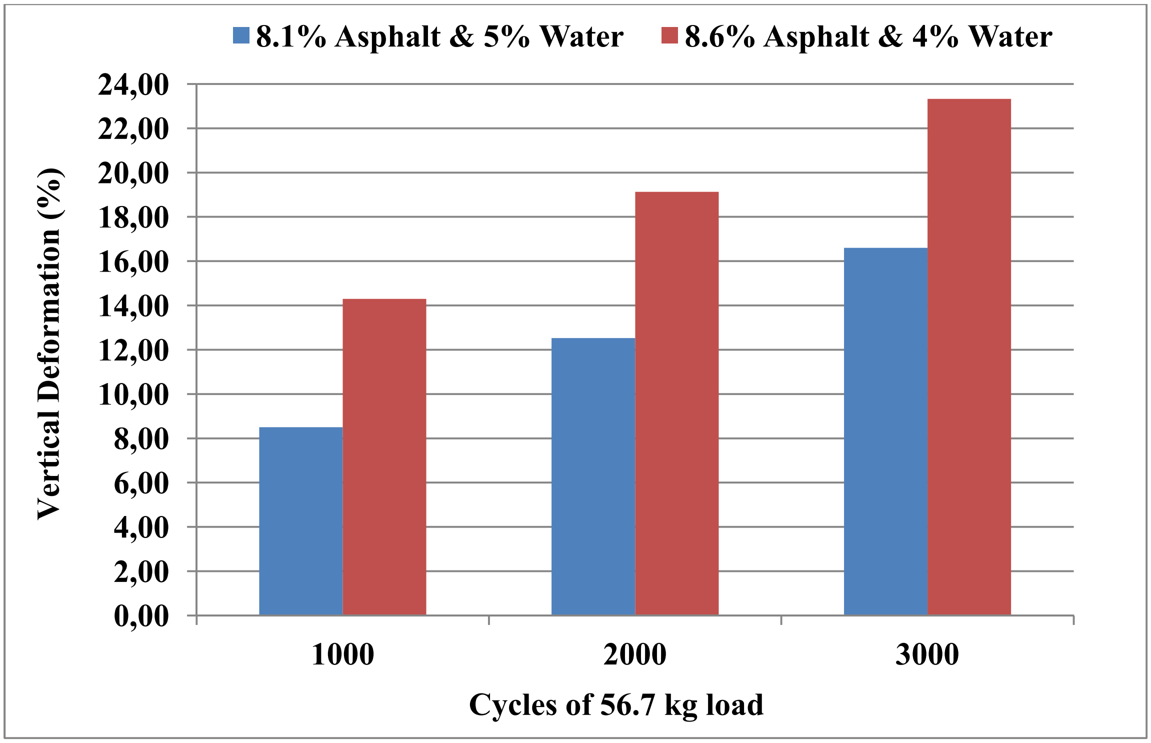

Figure 7.11 Vertical displacement test results, Graham Pitt aggregates

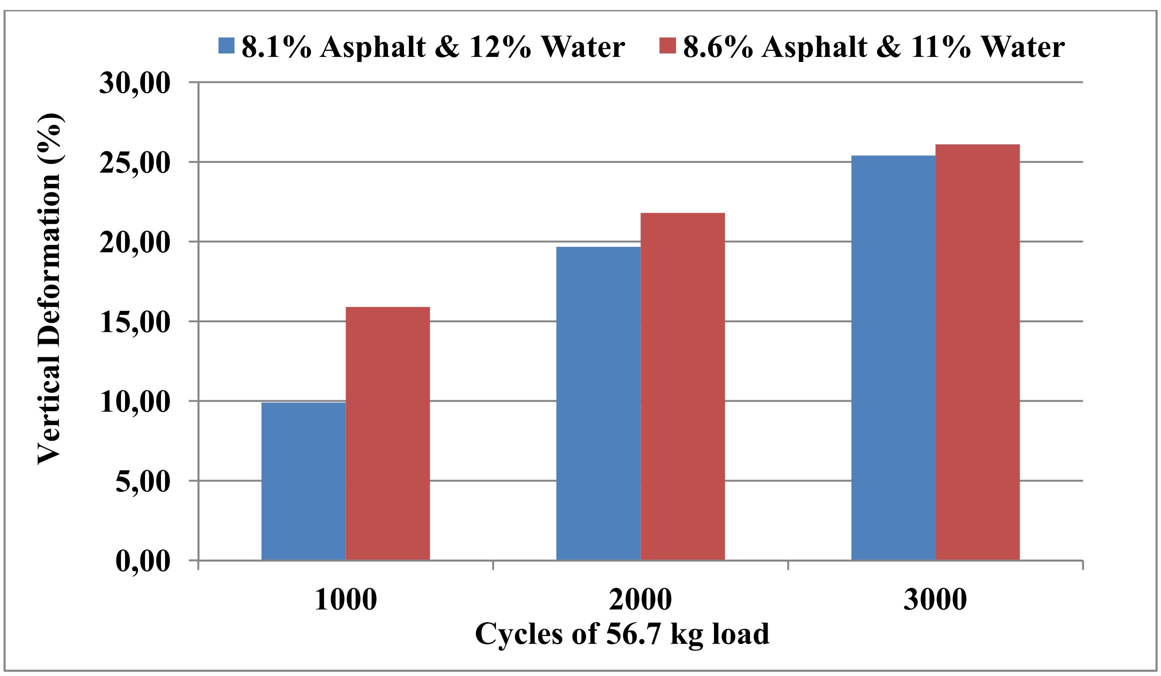

Figure 7.12 Vertical displacement test results, Rive sud aggregates

Finally, optimum emulsion content for rutting resistance can be determined at the minimum vertical and lateral displacements after 1000 cycle compactions of 56.7 kg load. Therefore, 8.1% asphalt emulsion residue was selected as optimum asphalt emulsion residue content for maximum rutting resistance.

CONCLUSION

The overall goal of this part of study was to improve the performance of micro-surfacing mixtures through the development of a rational mix design procedure, guidelines, and specifications. This was achieved thru a two parts experimental program. In the first part, the influence of different parameters was studied and the sensitivity of different tests was evaluated. Then, in the second part, modifications to ISSA mix design procedure for selecting optimum mix design proportions were suggested. Based on statistical analysis of the findings, the following conclusions are submitted:

1. Total amount of water in micro-surfacing mixtures appears to have a profound influence on the results of loaded wheel test and we track abrasion tests (1-hour and 6-day soaked samples). The effect of added water content on 6-day wet track abrasion test results was much greater than the effect of asphalt emulsion residue. At the same amount of asphalt emulsion in mixtures, as the added water content increased, the amount of sand adhered in loaded wheel test increases and the amount of aggregate loss in wet track abrasion test also increases. Selecting the optimum asphalt emulsion content by evaluating the abrasion loss in the wet track abrasion test versus pick up from the loaded wheel tester, is not precise enough.

2. The use of galvanized steel as specimen mounting plates in loaded wheel test do not allow water to evaporate through the curing process of mixture. Study of relative moisture retained in loaded wheel test samples after 24-hours curing show that as the asphalt emulsion and added water content increased, the retained moisture in samples was also increased and subsequently the amount of sand adhered in loaded wheel test increased. Results of relative moisture retained in wet track abrasion test after 24-hours curing evident that as the asphalt emulsion and added water content increases, there observed an optimum amount of relative moisture retained in WTAT samples.

3. Selection of optimum asphalt emulsion should be based on results obtained from test method for measurement of stability and resistance to compaction, vertical and lateral displacement of multilayered fine aggregate cold mixes (ISSA TB 147- Method A). Optimum emulsion content for rutting resistance can be determined at the minimum vertical and lateral displacements after 1000 cycle compactions of 56.7 kg load.

4. Selection of optimum water content for micro-surfacing mixtures should be based on results obtained from modified cohesion test (ISSA TB 139). The optimum water content for different asphalt emulsion/filler combinations should be selected at maximum 30 min and 60 min cohesion of mixture.

5. Regardless of the type of aggregates or filler that is used in preparing micro-surfacing mixtures, there is a specific asphalt emulsion residue content at which if the added water content increases, there will observe an optimum amount of 30-min and 60-min cohesion, which is the maximum cohesion of mixture. However, for other asphalt emulsion residue content, as the water increases, the 30-min and 60-min cohesion of mixture decreases. This specific asphalt emulsion residue content seems to be the optimum emulsion content for mixture. There is other asphalt emulsion content at which 30-min and 60-min cohesion of mixture are also maximized. Optimum asphalt emulsion residue for mixture is selected based on maximum rutting resistance of the mixtures.

6. Mixtures prepared using Ray car aggregate, that is more compatible with CQS-1HP asphalt emulsion rather than other aggregates types used in study, showed relatively better rutting resistance. Therefore, it can be concluded that compatibility between aggregates and asphalt emulsion does play an important role in micro-surfacing mixture design procedure and evaluation.

7. The 30-min and 60-min cohesion of micro-surfacing mixtures despite the types of aggregates used is maximized at a specific asphalt emulsion residue. It was observed that the 30-min and 60-min cohesion of micro-surfacing mixtures is not being affected by

types of aggregates used in preparing mixture. Adding a little more or less asphalt emulsion than the optimum amount can be lead to cohesion loss.

RECOMMENDATIONS

1. The use of Mixing Time test (ISSA TB 113) to establish minimum added water content for micro-surfacing mixtures is recommended.

2. Modified Cohesion test (ISSA TB 139) is a precise test, and its use to determine optimum added water content is recommended.

3. Selecting optimum asphalt emulsion content for micro-surfacing mixtures by evaluating the abrasion loss in the wet track abrasion test versus pick up from the loaded wheel tester (Similar to ISSA TB 111 mix design procedure for Slurry Seal) is not a precise method. Determining optimum asphalt emulsion content for micro-surfacing mixtures by this method should be discontinued.

4. The use of Wet Track Abrasion test 1-hour and 6-day soak samples (ISS TB 100) to determine minimum asphalt emulsion content for micro-surfacing mixtures is not recommended, mostly because, the added water content have a profound influence on the results of both 1-hour and 6-day soak wet track abrasion tests. Moreover, 1-hour soak wet track abrasion yields unexpected test results, which shows that it is not a precise test.

5. The use of Loaded Wheel test (ISS TB 109) to establish maximum asphalt emulsion content for micro-surfacing mixtures should be discontinued. Since the results of loaded wheel test are not only influenced by the amount of asphalt emulsion in the mixture, but also, affected by the amount of added water content in micro-surfacing mixtures.

6. When a series of micro-surfacing mixtures are prepared that contain a wide range of asphalt emulsion content, the use of test method for measurement of resistance to compaction (method A- ISSA TB 147) is recommended to determine optimum asphalt emulsion content for rutting resistance at the minimum vertical and lateral displacements.

7. Further studies need to be conducted with field experiments to determine the actual behavior of micro-surfacing mixtures prepared using the same types and proportions of asphalt emulsion and aggregates used in this study.

8. Characteristics of the bonding area between asphalt emulsion and aggregates in micro-surfacing mixtures required to be studied to investigate the relative compatibility between aggregate filler of specific gradation and emulsified asphalt residue.

ANNEX I

Loaded Wheel Test Data (ISSA TB 109)

The Annexes contains results for each test replicate. There were twelve asphalt residue-water combinations for loaded wheel test and wet track abrasion test, and nine asphalt residue-water combinations for modified cohesion test, mixing time test, and study of relative moisture retained in sample. The material variant within each material combination is the quantity of asphalt cement and added water content. At the bottom of each table, the mean, standard deviations, and variance are given.

Table-A I-1 Loaded Wheel Test results for samples prepared using Ray Car aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 7% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m²)
1	632.1	636.1	295.24
2	633.3	637.5	310
3	631.1	635.1	295.24
Mean	632.17	636.23	300.16
Std	1.10	1.21	8.52
var	1.21	1.45	72.62

Table-A I-2 Loaded Wheel Test results for samples prepared using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue with 7% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m²)
1	633.5	638.5	369.05
2	632.2	637.1	361.67
3	625.8	631	383.81
Mean	630.50	635.53	371.51
Std	4.12	3.99	11.27
var	16.99	15.90	127.08

Table-A I-3 Loaded Wheel Test results for samples prepared using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue with 7% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m²)
1	640.9	647.7	501.91
2	635.1	641.7	487.14
3	632.2	639	501.91
Mean	636.07	642.80	496.99
Std	4.43	4.45	8.53
var	19.62	19.83	72.72

Table-A I-4 Loaded Wheel Test results for samples prepared using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 8% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m²)
1	625.6	630.6	369.05
2	629.1	634.2	376.43
3	632.1	636.9	354.29
Mean	628.93	633.90	366.59
Std	3.25	3.16	11.27
var	10.58	9.99	127.08

Table-A I-5 Loaded Wheel Test results for samples prepared using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue with 8% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m²)
1	635	641.9	509.29
2	631.9	638.4	479.76
3	640.7	647.5	501.91
Mean	635.87	642.60	496.99
Std	4.46	4.59	15.37
var	19.92	21.07	236.18

Table-A I-6 Loaded Wheel Test results for samples prepared using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue with 8% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m^2)
1	625.7	632.8	524.05
2	635.2	642.2	516.67
3	617.9	624.7	501.91
Mean	626.27	633.23	514.21
Std	8.66	8.76	11.27
var	75.06	76.70	127.08

Table-A I-7 Loaded Wheel Test results for samples prepared using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 9% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m^2)
1	627.5	631.7	310
2	637.5	641.5	295.24
3	616.5	620.6	302.62
Mean	627.17	631.27	302.62
Std	10.50	10.46	7.38
var	110.33	109.34	54.46

Table-A I-8 Loaded Wheel Test results for samples prepared using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue with 9% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m^2)
1	624.7	631.5	501.91
2	630	636.7	494.52
3	616.5	623	479.76
Mean	623.73	630.40	492.06
Std	6.80	6.92	11.28
var	46.26	47.83	127.18

Table-A I-9 Loaded Wheel Test results for samples prepared using Ray Car aggregate and 8.6% CQS-1HP Asphalt emulsion residue with 9% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m²)
1	640.7	646.8	450.24
2	645.9	651.9	442.86
3	633.9	639.7	428.1
Mean	640.17	646.13	440.40
Std	6.02	6.13	11.27
var	36.21	37.54	127.08

Table-A I-10 Loaded Wheel Test results for samples prepared using Ray Car aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 10% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m²)
1	635.3	642.2	509.29
2	642.2	648.9	494.52
3	620	626.6	487.14
Mean	632.50	639.23	496.98
Std	11.36	11.44	11.28
var	129.09	130.92	127.21

Table-A I-11 Loaded Wheel Test results for samples prepared using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue with 10% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m²)
1	653.1	659.6	479.76
2	634.8	640.9	450.24
3	650.7	657.2	479.76
Mean	646.20	652.57	469.92
Std	9.95	10.17	17.04
var	98.91	103.52	290.48

Table-A I-12 Loaded Wheel Test results for samples prepared using Ray Car aggregate and 8.6% CQS-1HP Asphalt emulsion residue with 10% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Excess Asphalt (g/m^2)
1	653.9	661.9	590.48
2	630.8	638.4	560.95
3	640.1	648.1	590.48
Mean	641.60	649.47	580.64
Std	11.62	11.81	17.05
var	135.09	139.46	290.67

ANNEX II

Wet Track Abrasion Test Data (ISSA TB 100)

Table-A II-1 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 7% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m²)
1	637.3	634.6	88.83
2	610.5	607.9	85.54
3	670.5	667.8	88.83
Mean	639.43	636.77	87.73
Std	30.06	30.01	1.90
var	903.41	900.52	3.61

Table-A II-2 Wet Track Abrasion 6-Day soak test results for mixtures prepare using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 7% water and without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m²)
1	677.4	673.5	128.31
2	630.5	626.8	121.73
3	660	655.9	134.89
Mean	655.97	652.07	128.31
Std	23.71	23.58	6.58
var	562.10	556.24	43.30

Table-A II-3 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue**,** 7% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m²)
1	650	648.6	46.06
2	622	620.2	59.22
3	630.9	629.1	59.22
Mean	634.30	632.63	54.83
Std	14.31	14.53	7.60
var	204.67	211.00	57.73

Table-A II-4 Wet Track Abrasion 6-Day soak test results for mixtures prepare using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue, 7% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m²)
1	610.5	607	115.15
2	625.1	621.8	108.57
3	650.2	646.6	118.44
Mean	628.60	625.13	114.05
Std	20.08	20.01	5.03
var	403.21	400.37	25.26

Table-A II-5 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue**,** 7% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m²)
1	621.8	620	59.22
2	640.9	639.4	49.35
3	610.5	608.8	55.93
Mean	624.40	622.73	54.83
Std	15.37	15.48	5.03
var	236.11	239.69	25.26

Table-A II-6 Wet Track Abrasion 6-Day soak test results for mixtures prepare using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue**,** 7% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m^2)
1	614.6	611.2	111.86
2	622.2	618.8	111.86
3	650.3	647.2	101.99
Mean	629.03	625.73	108.57
Std	18.81	18.98	5.70
var	353.64	360.05	32.47

Table-A II-7 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue**,** 8% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m^2)
1	629.4	627.1	75.67
2	655.2	653.2	65.8
3	618.8	616.3	82.25
Mean	634.47	632.20	74.57
Std	18.72	18.97	8.28
var	350.49	359.91	68.55

Table-A II-8 Wet Track Abrasion 6-Day soak test results for mixtures prepare using Ray Car aggregate and 7.6% CQS-1HP Asphalt emulsion residue**,** 8% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m^2)
1	606	603.2	92.12
2	623.9	621.3	85.54
3	667.9	665	95.41
Mean	632.60	629.83	91.02
Std	31.85	31.77	5.03
var	1014.67	1009.42	25.26

Table-A II-9 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue**,** 8% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m²)
1	635.5	634.3	39.48
2	690.5	689.5	32.9
3	659.1	657.9	39.48
Mean	661.70	660.57	37.29
Std	27.59	27.70	3.80
var	761.32	767.09	14.43

Table-A II-10 Wet Track Abrasion 6-Day soak test results for mixtures prepare using raycar aggregate and 8.1% CQS-1HP emulsion residue**,** 8% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m²)
1	608.6	606.4	72.38
2	610.3	608.2	69.09
3	620.1	617.8	75.67
Mean	613.00	610.80	72.38
Std	6.21	6.13	3.29
var	38.53	37.56	10.82

Table-A II-11 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 8.6% CQS-1HP emulsion residue**,** 8% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m²)
1	631.5	629.9	52.64
2	620.9	619.2	55.93
3	680.2	678.7	49.35
Mean	644.20	642.60	52.64
Std	31.62	31.72	3.29
var	1000.09	1006.03	10.82

Table-A II-12 Wet Track Abrasion 6-Day soak test results for mixtures prepare using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue**,** 8% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m^2)
1	634.4	632.4	65.8
2	640.2	638.2	65.8
3	677.9	675.8	69.09
Mean	650.83	648.80	66.90
Std	23.62	23.56	1.90
var	557.86	555.16	3.61

Table-A II-13 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 7.6% CQS-1HP emulsion residue**,** 9% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m^2)
1	629.1	626.7	78.96
2	635.2	633	72.38
3	665.2	662.8	78.96
Mean	643.17	640.83	76.77
Std	19.32	19.28	3.80
var	373.40	371.82	14.43

Table-A II-14 Wet Track Abrasion 6-Day soak test results for mixtures prepare using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue**,** 9% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m^2)
1	609	607.4	52.64
2	612.5	610	82.25
3	630.3	628	75.67
Mean	617.27	615.13	70.19
Std	11.42	11.22	15.55
var	130.46	125.85	241.74

Table-A II-15 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 8.1% CQS-1HP emulsion residue**,** 9% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m²)
1	633.4	631.4	64.81
2	677.1	675	69.09
3	657.8	655.6	72.38
Mean	656.10	654.00	68.76
Std	21.90	21.84	3.80
var	479.59	477.16	14.41

Table-A II-16 Wet Track Abrasion 6-Day soak test results for mixtures prepare using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue**,** 9% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m²)
1	625.8	623.3	82.25
2	633.3	630.7	85.54
3	660.9	658.4	82.25
Mean	640.00	637.47	83.35
Std	18.48	18.50	1.90
var	341.67	342.34	3.61

Table-A II-17 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 8.6% CQS-1HP emulsion residue**,** 9% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m²)
1	634.2	633.3	29.61
2	641.9	641.3	19.74
3	620.5	619.4	36.19
Mean	632.20	631.33	28.51
Std	10.84	11.08	8.28
var	117.49	122.80	68.55

Table-A II-18 Wet Track Abrasion 6-Day soak test results for mixtures prepare using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue**,** 9% water,without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m^2)
1	630.8	629.5	42.77
2	612.3	611.1	39.48
3	650.6	649.5	36.19
Mean	631.23	630.03	39.48
Std	19.15	19.21	3.29
var	366.86	368.85	10.82

Table-A II-19 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 7.6% CQS-1HP emulsion residue**,** 10% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m^2)
1	622.4	620.8	52.64
2	633.8	632.1	55.93
3	642.2	640.6	52.64
Mean	632.80	631.17	53.74
Std	9.94	9.93	1.90
var	98.76	98.66	3.61

Table-A II-20 Wet Track Abrasion 6-Day soak test results for mixtures prepare using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue**,** 10% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m^2)
1	622.5	620.5	65.8
2	635.7	633.7	65.8
3	642.4	640.7	55.93
Mean	633.53	631.63	62.51
Std	10.13	10.26	5.70
var	102.52	105.21	32.47

Table-A II-21 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 8.1% CQS-1HP emulsion residue**,** 10% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m²)
1	642.9	641.4	49.35
2	666.3	665	42.77
3	684.4	682.9	49.35
Mean	664.53	663.10	47.16
Std	20.81	20.82	3.80
var	432.90	433.27	14.43

Table-A II-22 Wet Track Abrasion 6-Day soak test results for mixtures prepare using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue**,** 10% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m²)
1	630.8	629.2	52.64
2	625.5	624	49.35
3	678.8	677.6	39.48
Mean	645.03	643.60	47.16
Std	29.36	29.56	6.85
var	862.16	873.76	46.90

Table-A II-23 Wet Track Abrasion 1-Hour soak test results for mixtures prepare using raycar aggregate and 8.6% CQS-1HP emulsion residue**,** 10% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (1-Hour Soaked) (g/m²)
1	643.5	642.3	39.48
2	663.7	662.7	32.9
3	677.9	676.7	39.48
Mean	661.70	660.57	37.29
Std	17.29	17.30	3.80
var	298.84	299.25	14.43

Table-A II-24 Wet Track Abrasion 6-Day soak test results for mixtures prepare using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue**,** 10% water, without mineral filler.

Sample No	Original Weight (g)	Final Weight (g)	Wear Value (6-Day Soaked) (g/m²)
1	618	617	32.9
2	615.3	614.6	23.03
3	659.7	658.6	36.19
Mean	631.00	630.07	30.71
Std	24.89	24.74	6.85
var	619.59	612.05	46.90

ANNEX III

Relative Moisture Retained in Samples Test Data

Table-A III-1 Relative Moisture Retained in Loaded Wheel Test samples prepared using raycar aggregate and 7.6% CQS-1HP emulsion residue, 7% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	674.6	628.3	48.9	1.11
2	613.5	565	48.5	1.17
3	678.9	630.2	48.7	1.13
Mean	655.667	607.833	48.700	1.137
Std	36.581	37.107	0.200	0.031
var	1338.143	1376.923	0.040	0.001

Table-A III-2 Relative Moisture Retained in Wet Track Abrasion Test samples prepared using raycar agg and 7.6% CQS-1HP emulsion residue, 7% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	567.8	520.7	47.1	1.41
2	655.3	607.2	48.1	1.24
3	611.2	563.8	47.4	1.36
Mean	611.433	563.900	47.533	1.337
Std	43.750	43.250	0.513	0.087
var	1914.103	1870.570	0.263	0.008

Table-A III-3 Relative Moisture Retained in Loaded Wheel Test samples prepared using raycar agg and 8.1% CQS-1HP emulsion residue, 7% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	683.4	634.2	49.2	1.27
2	645.1	596.1	49	1.3
3	610.5	561.5	49	1.3
Mean	646.333	597.267	49.067	1.290
Std	36.466	36.364	0.115	0.017
var	1329.743	1322.343	0.013	0.000

Table-A III-4 Relative Moisture Retained in Wet Track Abrasion Test samples prepared using raycar agg and 8.1% CQS-1HP emulsion residue, 7% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	598.8	547.6	51.2	0.93
2	614.4	563	51.4	0.9
3	605.5	554.2	51.3	0.92
Mean	606.233	554.933	51.300	0.917
Std	7.826	7.726	0.100	0.015
var	61.243	59.693	0.010	0.000

Table-A III-5 Relative Moisture Retained in Loaded Wheel Test samples prepared using raycar agg and 8.6% CQS-1HP emulsion residue, 7% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	691	640.9	50.1	1.33
2	635.4	585.7	49.7	1.4
3	642.9	592.9	50	1.34
Mean	656.433	606.500	49.933	1.357
Std	30.170	30.008	0.208	0.038
var	910.203	900.480	0.043	0.001

Table-A III-6 Relative Moisture Retained in Wet Track Abrasion Test samples prepared using raycar agg and 8.6% CQS-1HP emulsion residue, 7% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	600.3	549.6	50.7	1.23
2	634.2	583.7	50.5	1.26
3	663.8	613.1	50.7	1.22
Mean	632.767	582.133	50.633	1.237
Std	31.774	31.779	0.115	0.021
var	1009.603	1009.903	0.013	0.000

Table-A III-7 Relative Moisture Retained in Loaded Wheel Test samples prepared using raycar agg and 7.6% CQS-1HP emulsion residue, 8% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	675.2	624	51.2	1.55
2	647.1	595.4	51.4	1.52
3	610.5	559.3	51.2	1.55
Mean	644.267	592.900	51.267	1.540
Std	32.443	32.422	0.115	0.017
var	1052.543	1051.210	0.013	0.000

Table-A III-8 Relative Moisture Retained in Wet Track Abrasion Test samples prepared using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 8% water and without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	613.3	558.8	54.5	1
2	684	629.6	54.4	1.02
3	652.9	598.2	54.7	0.96
Mean	650.067	595.533	54.533	0.993
Std	35.435	35.475	0.153	0.031
var	1255.643	1258.493	0.023	0.001

Table-A III-9 Relative Moisture Retained in Loaded Wheel Test samples prepared using raycar agg and 8.1% CQS-1HP emulsion residue, 8% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	683.8	632.2	51.6	1.69
2	664.3	612.8	51.5	1.71
3	663.2	611.6	51.6	1.69
Mean	670.433	618.867	51.567	1.697
Std	11.589	11.563	0.058	0.012
var	134.303	133.693	0.003	0.000

Table-A II-10 Relative Moisture Retained in Wet Track Abrasion Test samples prepared using raycar agg and 8.1% CQS-1HP emulsion residue, 8% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	617.5	561	56.5	0.88
2	611.9	555.5	56.4	0.89
3	644.4	587.9	56.5	0.88
Mean	624.600	568.133	56.467	0.883
Std	17.374	17.338	0.058	0.006
var	301.870	300.603	0.003	0.000

Table-A III-11 Relative Moisture Retained in Loaded Wheel Test samples prepared using raycar agg and 8.6% CQS-1HP emulsion residue, 8% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	667.4	625.7	51.8	1.87
2	615.2	563.4	51.8	1.87
3	645.2	593.1	52.1	1.81
Mean	642.600	594.067	51.900	1.850
Std	26.197	31.161	0.173	0.035
var	686.280	971.023	0.030	0.001

Table-A III-12 Relative Moisture Retained in Wet Track Abrasion Test samples prepared using raycar agg and 8.6% CQS-1HP emulsion residue, 8% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	613.2	556.6	56.6	1.07
2	619.9	563.3	56.6	1.07
3	668.9	612.4	56.5	1.09
Mean	634.000	577.433	56.567	1.077
Std	30.409	30.467	0.058	0.012
var	924.730	928.223	0.003	0.000

Table-A III-13 Relative Moisture Retained in Loaded Wheel Test samples prepared using raycar agg and 7.6% CQS-1HP emulsion residue, 9% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	623.9	571.35	52.55	2.14
2	633.7	581.3	52.4	2.17
3	688.1	635.4	52.7	2.12
Mean	648.567	596.017	52.550	2.143
Std	34.586	34.468	0.150	0.025
var	1196.173	1188.036	0.023	0.001

Table-A III-14 Relative Moisture Retained in Wet Track Abrasion Test samples prepared using raycar agg and 7.6% CQS-1HP emulsion residue, 9% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	610.5	553.6	56.9	1.42
2	664	607.2	56.8	1.44
3	625.9	568.8	57.1	1.39
Mean	633.467	576.533	56.933	1.417
Std	27.541	27.624	0.153	0.025
var	758.503	763.093	0.023	0.001

Table-A III-15 Relative Moisture Retained in Loaded Wheel Test samples prepared using raycar agg and 8.1% CQS-1HP emulsion residue, 9% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	670.3	617.2	53.1	2.26
2	612.8	559.8	53	2.28
3	651.7	598.8	52.9	2.29
Mean	644.933	591.933	53.000	2.277
Std	29.341	29.310	0.100	0.015
var	860.903	859.053	0.010	0.000

Table-A III-16 Relative Moisture Retained in Wet Track Abrasion Test samples prepared using raycar agg and 8.1% CQS-1HP emulsion residue, 9% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	634.5	575.3	59.2	1.25
2	652.9	593.4	59.5	1.21
3	611.4	552.3	59.1	1.27
Mean	632.933	573.667	59.267	1.243
Std	20.794	20.599	0.208	0.031
var	432.403	424.303	0.043	0.001

Table-A III-17 Relative Moisture Retained in Loaded Wheel Test samples prepared using raycar agg and 8.6% CQS-1HP emulsion residue, 9% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	633.8	581	52.8	2.5
2	663.9	611.4	52.5	2.55
3	610.4	557.7	52.7	2.52
Mean	636.033	583.367	52.667	2.523
Std	26.820	26.928	0.153	0.025
var	719.303	725.123	0.023	0.001

Table-A III-18 Relative Moisture Retained in Wet Track Abrasion Test samples prepared using raycar agg and 8.6% CQS-1HP emulsion residue, 9% water, without mineral filler.

Sample No	Original Weight before Cure (g)	Weight after 24-Hours Cure (g)	Moisture Loss (%)	Relative Moisture Retained (%)
1	621.9	562.5	59.4	1.42
2	642.9	583.3	59.6	1.39
3	648.2	588.8	59.4	1.42
Mean	637.667	578.200	59.467	1.410
Std	13.909	13.872	0.115	0.017
var	193.463	192.430	0.013	0.000

ANNEX IV

Modified Cohesion Test Data (ISSA TB 139)

Table-A IV-1 Modified Cohesion test results for mixture prepared using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 8% water and without mineral filler.

Sample No	Cohesion @ 30 min (kg-cm)	Cohesion @ 60 min (kg-cm)
1	13.0	16.0
2	13.0	16.0
3	13.0	15.5
4	13.0	15.0
5	12.5	16.0
Mean	12.9	15.7
Std	0.2	0.4
var	0.1	0.2

Table-A IV-2 Modified Cohesion test results for mixture prepared using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue with 8% water and without mineral filler.

Sample No	Cohesion @ 30 min (kg-cm)	Cohesion @ 60 min (kg-cm)
1	16.0	18.5
2	16.0	18.0
3	15.0	18.5
4	16.0	17.0
5	15.0	18.5
Mean	15.6	18.1
Std	0.5	0.7
var	0.3	0.4

Table-A IV-3 Modified Cohesion test results for mixture prepared using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue with 8% water and without mineral filler.

Sample No	Cohesion @ 30 min (kg-cm)	Cohesion @ 60 min (kg-cm)
1	17.0	18.0
2	17.0	19.0
3	17.0	19.0
4	16.0	19.0
5	16.0	18.5
Mean	16.6	18.7
Std	0.5	0.4
var	0.3	0.2

Table-A IV-4 Modified Cohesion test results for mixture prepared using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 9% water and without mineral filler.

Sample No	Cohesion @ 30 min (kg-cm)	Cohesion @ 60 min (kg-cm)
1	13.0	16.0
2	12.0	16.0
3	13.0	16.0
4	13.0	16.0
5	12.5	15.0
Mean	12.7	15.8
Std	0.4	0.4
var	0.2	0.2

Table-A IV-5 Modified Cohesion test results for mixture prepared using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue with 9% water and without mineral filler.

Sample No	Cohesion @ 30 min (kg-cm)	Cohesion @ 60 min (kg-cm)
1	19.0	21.0
2	18.0	20.0
3	19.0	22.0
4	19.0	22.0
5	19.0	21.5
Mean	18.8	21.3
Std	0.4	0.8
Var	0.2	0.7

Table-A IV-6 Modified Cohesion test results for mixture prepared using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue with 9% water and without mineral filler.

Sample No	Cohesion @ 30 min (kg-cm)	Cohesion @ 60 min (kg-cm)
1	16.0	18.0
2	16.0	18.0
3	16.0	19.0
4	16.0	19.0
5	15.0	19.0
Mean	15.8	18.6
Std	0.4	0.5
var	0.2	0.3

Table-A IV-7 Modified Cohesion test results for mixture prepared using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 10% water and without mineral filler.

Sample No	Cohesion @ 30 min (kg-cm)	Cohesion @ 60 min (kg-cm)
1	12.0	14.0
2	12.0	15.0
3	11.0	14.5
4	10.0	15.5
5	12.0	15.0
Mean	11.4	14.8
Std	0.9	0.6
Var	0.8	0.3

Table-A IV-8 Modified Cohesion test results for mixture prepared using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue with 10% water and without mineral filler.

Sample No	Cohesion @ 30 min (kg-cm)	Cohesion @ 60 min (kg-cm)
1	16.0	19.5
2	16.5	19.0
3	16.0	19.0
4	16.0	18.0
5	15.5	19.5
Mean	16.0	19.0
Std	0.4	0.6
var	0.1	0.4

Table-A IV-9 Modified Cohesion test results for mixture prepared using raycar aggregate. 8.6% CQS-1HP Asphalt emulsion residue with 10% water and without mineral filler.

Sample No	**Cohesion @ 30 min (kg-cm)**	**Cohesion @ 60 min (kg-cm)**
1	14.0	17.0
2	14.5	17.0
3	15.0	17.5
4	14.0	17.5
5	14.5	17.5
Mean	14.4	17.3
Std	0.4	0.3
var	0.2	0.1

ANNEX V

Mixing Time Test Data (ISSA TB 113)

Table-A V-1 Mixing Time test results for mixture prepare using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 8% water and without mineral filler.

Sample No	Mixing Time (Min)
1	120.00
2	129.00
Mean	124.50
Std	6.36
var	40.50

Table-A V-2 Mixing Time test results for mixture prepared using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue with 8% water and without mineral filler.

Sample No	Mixing Time (Min)
1	130.00
2	138.00
Mean	134.00
Std	5.66
var	32.00

Table-A V-3 Mixing Time test results for mixture prepared using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue with 8% water and without mineral filler.

Sample No	Mixing Time (Min)
1	141.00
2	144.00
Mean	142.50
Std	2.12
var	4.50

Table-A V-4 Mixing Time test results for mixture prepared using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 9% water and without mineral filler.

Sample No	Mixing Time (Min)
1	135.00
2	140.00
Mean	137.50
Std	3.54
var	12.50

Table-A V-5 Mixing Time test results for mixture prepared using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue with 9% water and without mineral filler.

Sample No	Mixing Time (Min)
1	180.00
2	187.00
Mean	183.50
Std	4.95
var	24.50

Table-A V-6 Mixing Time test results for mixture prepared using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue with 9% water and without mineral filler.

Sample No	Mixing Time (Min)
1	202.00
2	210.00
Mean	206.00
Std	5.66
var	32.00

Table-A V-7 Mixing Time test results for mixture prepared using raycar aggregate and 7.6% CQS-1HP Asphalt emulsion residue with 10% water and without mineral filler.

Sample No	Mixing Time (Min)
1	185.00
2	199.00
Mean	192.00
Std	9.90
var	98.00

Table-A V-8 Mixing Time test results for mixture prepared using raycar aggregate and 8.1% CQS-1HP Asphalt emulsion residue with 10% water and without mineral filler.

Sample No	Mixing Time (Min)
1	202.00
2	221.00
Mean	211.50
Std	13.44
var	180.50

Table-A V-9 Mixing Time test results for mixture prepared using raycar aggregate and 8.6% CQS-1HP Asphalt emulsion residue with 10% water and without mineral filler.

Sample No	Mixing Time (Min)
1	285.00
2	300.00
Mean	292.50
Std	10.61
var	112.50

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