Development of a Quality Control Test Procedure for Characterizing Fracture Properties of Asphalt Mixtures

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LONG BEACH
DEPARTMENT OF CIVIL ENGINEERING AND CONSTRUCTION ENGINEERING MANAGMENT

Project No. 10-24

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June 2011

METRANS Transportation Center
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Disclosure

This project was funded in its entirety under a contract with the California Department of Transportation.

Acknowledgments

The authors would like to thank the United States Department of Transportation, the California Department of Transportation, and METRANS for their interest and provision of grant support to make this project possible. We would also like to thank Brian C. Kramer of Twining Laboratories, Dr. Elie Y. Hajj of Western Regional Superpave Center, Edgard Hitti of Paramount Petroleum, and Dr. Carl Monismith of the University of California Berkley for their invaluable technical and operational support in the project.

ABSTRACT

The main objective of this study is to investigate the use of the semi-circular bend (SCB) test as a quality assurance/quality control (QA/QC) measure for field construction. Comparison of fracture properties from the SCB test and fatigue beam test (FBT) was conducted. The SCB J_c values for PG64-10 and PG58-22 mixtures on dry and wet conditions were determined. An FBT was performed on PG64-10 and PG58-28 mixtures in dry and wet conditions. The SCB J_c and FBT N_f indicated better fracture properties for the dry mixtures compared to wet mixtures. In general, the SCB J_c and the FBT N_f had similar ranking of both mixtures at dry and wet conditions. The FBT N_f had higher variability, %CV (16.5 – 48.9%), compared to SCB J_c, %CV (0 – 33.2%). The SCB test has great potential as a QA/QC test of fracture properties of asphalt mixtures.

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INTRODUCTION

Fatigue life resistance of asphalt concrete (AC) is defined as AC's ability to resist repeated traffic loading without significant cracking or failure [1]. Fatigue cracking is a primary distress in asphalt concrete due to repetitive stresses and strains caused by both traffic loading and environmental factors such as temperature differences. The fatigue resistance of AC is investigated by a number of fatigue testing.

Roque et al [2] proposed the dissipated creep strain energy (DCSE) limit as one of the most important factors that control crack performance and hence durability of AC mixtures. Roque studied 22 field mixtures that have been in service for more than 10 years in the State of Florida. In order to determine this parameter, two laboratory tests were conducted on the same specimen. These tests were the indirect tensile resilient modulus test (ITMr) and the indirect tensile strength (ITS) test. Both tests were conducted at 10 °C on specimens with 150 mm diameter and 50 mm thickness. From the ITS test, failure strain (ε_f), tensile strength (S_t) and fracture energy (FE) can be determined.

The indirect tensile strength test is the most traditional test method used to evaluate the fracture properties of AC mixture in laboratory, and has been used in some cracking characteristics study as well [3,4]. During the ITS test, the specimen is loaded until failure and the load and deformation is continuously recorded, and then the indirect tensile strength and the corresponding strain can be computed.

Wagoner et al. [5] introduced the disk-shaped compact tension (DCT) test for AC material. The test uses specimens modified from the ASTM E399 standard for compact tension testing of metals. The fracture energy of the asphalt specimens can be calculated from this test.

Zhou et al. [6] presented the Texas overlay test (OT). The researchers at Texas Transportation Institute developed this test to assess the fatigue cracking prediction. The device tests AC specimens that are glued to two steel plates, with half of its length resting on each plate. One of the steel plates is fixed and the other moves horizontally to simulate the opening and closing of the crack under overlays. The AC mixture specimen has a standard dimension of 150 mm length by 75 mm width by 38 mm height. The test specimen can be fabricated from a superpave gyratory compactor (SGC) or from field cores.

The Strategic Highway Research Program (SHRP) Project A-003A included the development of a flexural beam test for measuring fatigue of AC mixtures and an analysis system based on multilayer elastic theory to estimate in-situ performance, Deacon et al. [7].

In California, the Asphalt Research Program performed a five-year study on the fatigue performance of AC mixtures, Harvey et al. [1]. The fatigue beam test (FBT) developed during these studies well predicted the asphalt mixture fatigue performance. However, the relatively long testing period and the high variability in the test results make the FBT impractical for quality assurance/quality control testing. Therefore, a quality control test that is simple to perform yet well correlated to the fatigue beam test is needed to support the frequently required quality assurance/quality control testing.

Therefore the semi-circular bend (SCB) test is being selected in this study for further evaluation because it is simple to perform (it can be conducted using regular stabilometer that is used in the mix design), inexpensive (one compacted specimen makes four SCB specimens), and simple to analyze (the output parameter is indicative of the dissipated energy during the crack propagation).

The SCB test is still unknown to most AC technologists in the US even though "it was introduced to the asphalt community in US by Europeans and South African researchers" in the late 1990s and early 2000s. Originally, the SCB was used in rock mechanics to characterize the fracture resistance of rock materials [8]. Lim et al. used the SCB for determining the characteristics of a water-saturated synthetic mudstone. It was found that the SCB test can provide reliable results that are comparable to other methods used to compute the Mode I fracture property. The SCB test was employed to determine Mode I fracture for mudstone [9]. Chong and his group proposed use of a semi-circular core specimen with a single-edge notch subjected to three point loading [10]. Recently, the SCB test has been introduced to the study of pavement material, and many research projects have applied this method to investigate the fracture property of different AC mixtures [11, 12, 13, and 14]. The SCB test can be a potential test to further explore the material fracture properties.

The SCB test has many advantages over other tests in characterizing AC mixtures. The main advantage is that different notch depths can be made easily on the semi-circular test specimen. The notch is made by a special saw blade of 3.0 mm thickness [8]. The SCB test can be performed and many specimens can be made with one core. Moreover, SCB test specimens can be prepared directly from cylindrical samples obtained from standard cores prepared in the superpave gyratory compactor (SGC) or taken from field.

SCB test results are analyzed using the elastic–plastic fracture mechanics concept of critical strain energy release rate, which is referred to as critical value of J-integral (J_c). Some studies have shown that the J_c value is sensitive to a number of variables such as type of binder, type of aggregate size and method of compaction [15]. All of these factors are significant to fracture properties of AC mixtures. This study aimed at investigating the use of the semi-circular bend (SCB) test as a quality assurance/quality control (QA/QC) measure for field construction.

OBJECTIVES

The main objective of this study is to investigate the use of the SCB test as a quality assurance/quality control (QA/QC) measure for field construction. In particular, the objectives include the following:

– Compare the fracture properties of AC mixtures using the SCB test to those of the FBT.
– Evaluate the impact of moisture damage on the fracture and fatigue properties as determined by SCB and FBT.

SCOPE

Two binder types, PG64-10 and PG58-22, were used in this study. The job mix formulas for each mix type considered were identical except for the binder type. The asphalt binder met California specifications. Granite was the predominate aggregate used in the AC mixture types considered.

There was one day of production for the SCB and FBT mixtures. Viscosity and dynamic shear rheometer, aging, and bending beam rheometer measurements were used to determine the rheological properties of both binder types. The AC mixture fracture properties were determined using the SCB and FBT tests. Both mixtures were compacted to a target air void of (5 ± 1%) in beams and core specimens. Cores for SCB testing and beams for FBT were sawed from the same slab that was fabricated to ensure consistency among specimens. This will reduce the variability of the results due to changes in the specimens. The specimens were tested in both dry and wet conditions to evaluate the impact of moisture-induced damage on the measured properties.

METHODOLOGY

Material Properties and Mixture Design

Asphalt Cement Binder

PG64-10 and PG58-22 were the two binder types considered in this study since they are commonly used in California, meeting the AASHTO M320 specifications. Binders were supplied by Blue Diamond Materials.

Aggregates

The aggregates used in both binder course mixtures were produced at the Lehigh Hanson Irwindale, California plant (SMARA No. 91-19-0025) and are derived from alluvium of the San Gabriel Mountains as deposited in the San Gabriel River basin. A petrographic examination performed in accordance with ASTM C295 indicates the aggregate materials are composed of igneous, metamorphic, and sedimentary rocks and minerals. These materials are principally granitic in origin with minor amounts of schist, diorite, gabbro and basalt.

Mixture Design

The Hveem mix design procedure was used to determine the optimum asphalt content of the AC mixtures. The final aggregate structure for the AC mixtures was determined using the petrographic examination. The maximum density was 2.492 g/cm^3 (155.6 lb/ft^3) for both mixtures. The maximum specific gravities were 2.474 and 2,473 for the PG58-22 and PG64-10 mixtures, respectively. The optimum asphalt binder content was incorporated at 4.3% by total weight as required by the mix design. The RAP binder content was 5%. Table 1 presents the job mix formula (JMF), mixture properties, and gradation analysis for the AC binder course mixtures that are used in this study.

Table 1, JMF, mix properties, and gradation analysis

Maximum Density =2.492 g/cm^3		
Rap Binder Content = 5%		
Sieve	**Combined**	**Min--Max**
37 mm (1 ½”)	100	100-100
25 mm (1”)	100	100-100
19 mm (¾”)	100	100-100
12.5 mm (½”)	97	95-100
9 mm (3/8”)	82	72-88
No. 4	55	46-60
No. 8	40	28-42
No. 16	30	-
No. 30	21	15-27
No. 50	13	10-20
No. 100	7	-
No. 200	3.9	2-7

Slab Compaction

Vibratory steel wheel rollers were used to compact the fabricated AC mixture specimens to required density. A conventional steel wheel rolling protocol was followed, i.e. breakdown, intermediate, and then finished roller. The established rolling pattern was maintained for both mixes evaluated as can be seen in figure 1. The average AC plant temperature was 165°C (330°F) for both mix types evaluated. The initial compaction temperature for both mixtures was approximately 150°C (300°F). A frame was prepared to fabricate the slabs which were covered by a special red rosin paper as shown in figure 1. The asphalt was then placed on the frame as seen in figure 1b. The vibratory steel wheel roller compactor was used to compact the slabs. On the next day the sides of the frame were removed in order to obtain the desired specimens.

(a) (b)

(c) (d)

Figure 1 a) Slab mold fabrication b) Mixture spreading c) Compaction of the PG64-10 mixture and d) Compaction PG58-22 mixture

Fabrication of AC Mixture Test Specimens

Specimens were prepared according to the specific requirements of each test. Cylindrical 150 mm (6 in.) diameter specimens were cored for the SCB test and rectangular beams were sawn for the FBT at 50 mm thickness x 63 mm width x 380 mm length (2.0- thickness x 2.5- width x 15 in. length) as shown in figure 2.

(a) (b)

Figure 2. a) Coring SCB specimens and b) Sawing FBT specimens.

Fundamental Material Characterization

Asphalt binders were tested and characterized by performance grading tests including rotational viscometer, dynamic shear rheometer, bending beam rheometer, rolling thin film oven, and pressure aging vessel. The AC mixture fracture properties were characterized using the SCB test and the FBT.

The following sections outline the test methodology used for fundamental material characterizations of the evaluated asphalt binders and mixtures.

Asphalt Binder Rheology

Asphalt binders were tested and characterized according to AASHTO R29, "Grading or Verifying the Performance Grade (PG) of an Asphalt Binder." The following standard asphalt test methods were performed:

- AASHTO T 316, "Standard Test Method for Viscosity Determination of Asphalt Binder Using Rotational Viscometer"
- AASHTO T 48, "Standard Test Method for Flash and Fire Points by Cleveland Cup"
- AASHTO T 44, "Standard Method of Test for Solubility of Bituminous"
- AASHTO T 240, "Standard Method of Test for Effect of Heat and Air on a Moving Film of Asphalt Force Binder (Rolling Thin-Film Oven Test"

- AASHTO T 315, "Standard Method of Test for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)"
- AASHTO T 51, "Standard Test Method for Ductility of Asphalt Materials"
- AASHTO T 313 "Standard Test Method for Determining the Flexural Creep Stiffness of Asphalt Binder Using the Binding Beam Rheometer (BBR)"
- AASHTO T 228 "Standard Test Method for Specific Gravity of Semi-Solid Asphalt Materials"

Beam Specimens Preparation and Conditioning

The bulk-specific gravity, width, and height of each beam were first measured and recorded. Each beam was then dried at room temperature (around 30 °C) in a forced-draft oven or in a concrete conditioning room to constant mass which is defined as the mass at which further drying does not alter the mass by more than 0.05 percent at two-hour drying intervals. Beams were placed on a rigid and flat surface during drying to avoid any bending of the specimens. A nut used for supporting the linear variable differential transducer (LVDT) was bonded to the beam using epoxy resin. The mass of the beam with the nut was recorded.

Moisture conditioning:

The moisture conditioning procedure outlined in Jones et al. [16] was followed to prepare the wet specimens:

1. The specimen was placed in the vacuum container supported above the container bottom by a spacer. The container was filled with water so that the specimen was totally submerged in the water and a vacuum of 635 mm (25 in.) of mercury was applied. After 30 minutes the vacuum was stopped and the sample was removed and the saturated surface dry mass according to AASHTO T-166 was determined. The volume of absorbed water and the degree of saturation was determined. A saturation level of 70-80% was targeted for various specimens.
2. The vacuum-saturated specimen was then placed in a water bath at a pre-set temperature of 60 ºC. The specimen was supported on a rigid, flat (steel or wood) plate to prevent deformation of the specimen during conditioning. The top surface of the specimen was about 25 mm below the water surface.
3. After 24 hours, the water bath was drained and refilled with cold tap water. The water bath temperature was set to 20 ºC. It took two hours for the water bath to reach an equilibrium temperature.
4. The specimen was then removed from the water bath, and the saturated surface dry mass was determined.
5. The specimen was then wrapped with Parafilm to ensure no water leakage.
6. The bonded nut (for the beam) was checked. When loose, it was removed and re-bonded with epoxy resin.
7. A layer of scotch tape was applied to the areas where the specimen contacts the clamps of the fatigue machine. This would prevent adhesion between the Parafilm and the clamps.
8. The fatigue test of the conditioned beam was started within 24 hours.

Testing Factorial

Both SCB and FBT specimens had a measured air voids of (5 ± 1%). Specimens that had air voids out of this range were discarded. Tables 2 and 3 present the test factorial for the SCB and FBT, respectively. A description of each test is provided below.

Table 2 SCB test factorial

Condition	Mix	Specimen Name	
		Before Cutting	After Cutting
Dry	PG64-10	(1-10 SCB [1])	(1-10 SCB [1]) A
			(1-10 SCB [1]) B
		(2-10 SCB [1])	(2-10 SCB [1]) A
			(2-10 SCB [1]) B
		(2-10 SCB [2])	(2-10 SCB [2]) A
			(2-10 SCB [2]) B
	PG58-22	(5-22-SCB [2])	(5-22 SCB [2]) A
			(5-22 SCB [2]) B
		(6-22 SCB [1])	(6-22 SCB [1]) A
			(6-22 SCB [1]) B
		(6-22 SCB [2])	(6-22 SCB [2]) A
			(6-22 SCB [2]) B
Wet	PG64-10	(3-10 SCB [1])	(3-10 SCB [1]) A
			(3-10 SCB [1]) B
		(4-10 SCB[1])	(4-10 SCB[1]) A
			(4-10 SCB[1]) B
		(4-10 SCB[2])	(4-10 SCB[2]) A
			(4-10 SCB[2]) B
	PG58-22	(Extra 22 SCB [1])	(Extra 22 SCB [1]) A
			(Extra 22 SCB [1]) B
		(Extra 22 SCB [3])	(Extra 22 SCB [3]) A
			(Extra 22 SCB [3]) B
		(Extra 22 SCB [4])	(Extra 22 SCB [4]) A
			(Extra 22 SCB [4]) B

Table 3. FBT factorial

Condition	Mix	Specimen Name
Dry	PG64-10	1-10 FBT 1]
		2-10 FBT [1]
		2-10 FBT[2]
	PG58-22	5-22 FBT [1]
		5-22 FBT[2]
		6-22 FBT1]
Wet	PG64-10	3-10 FBT [1]
		4-10 FBT[2]
		Ex-10 FBT
	PG58-22	6-22 FBT [2]
		7-22FBT[2]
		8-22 FBT[2]

Semi-Circular Bend (SCB) Test

This test was used to characterize the fracture resistance of asphalt mixtures based on a fracture mechanics concept. The critical strain energy release rate, which called the critical value of J-integral or J_c was determined for each semi-circular specimen that was tested. Three notch depths of 25.4-, 31.8- and 38.0 mm (1-, 1.25-, and 1.5-in) were used in this study. The tests were conducted at 20 °C. A semi-circular specimen was loaded monotonically until fracture under a constant cross-head deformation rate of 0.5 mm/min (0.02 in./min.) in a three-point bend load configuration as shown in figure 3. The load and deformation was continuously recorded and the critical value of J-integral was determined using the following equation:

$$J_c = -\left(\frac{1}{b}\right)\frac{\partial U}{\partial a} \quad (1)$$

Where: “b” is sample thickness, “a” is the notch depth, and “U” is the strain energy to failure.

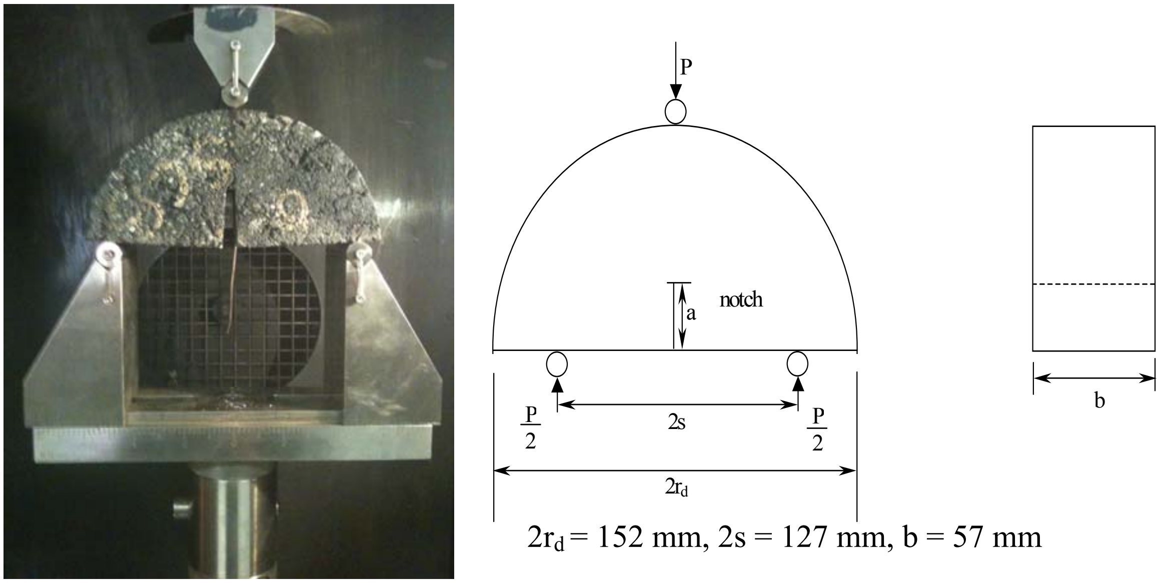


Figure 3 Set-up of semi-circular bend test

Fatigue Beam Test (FBT)

This test was conducted according to AASHTO T-321. A test temperature of 20 °C and a stain level of 350 micro-strains were used. The number of load cycles to failure was determined as the number of cycles for a 50% reduction in initial stiffness and dissipated energy.

From a slab compacted in accordance to the method described above, six AC mixture beam specimens were prepared for each mix. The testing beams were 50 mm thick x 63 mm wide x 380 mm long (2.0- thick x 2.5- wide x 15 in. long). Figure 4 shows the fatigue beam test device.

Figure 4. Fatigue Beam Test (Courtesy of Inopave Inc.)

DISCUSSION OF RESULTS

Asphalt Binder Rheology

Tables 4a and 4b present the asphalt binder rheology results for both asphalt binders evaluated in this study. It can be seen that both binders met the specifications according to ASTM 6373 and AASHTO M320. Also, it should be noted that the PG64-10 had a higher mid-range temperature (28 °C) compared to PG58-22 (22 °C).

Table 4a. Asphalt cement binder PG58-22 rheology

Test	Result	Test Method	Specification
Rotational Viscosity, 135 ºC, Pa.s	0.261	AASHTO T316	3.0 Maximum
Flash, COC, ºC	298	AASHTO T48	230 Minimum
Solubility in TCE, w%	99.7	AASHTO T44	99.0 Minimum
Dynamic Shear Rheometer, 58 ºC		AASHTO T315	
Complex Viscosity, η* , Pa.s	163.5		
G*, kPa	1.64		
Phase Angle, º	88.1		
G*/Sin δ, kPa	1.641		1.00 Minimum
RTFO-Aged			
Mass Change, w%	-0.115	AASHTO T240	1.00 Maximum
Dynamic Shear Rheometer, 58 ºC		AASHTO T315	
G*, kPa	4,285		
Phase Angle, º	84.9		
G*/Sin δ, kPa	4.302		2.20 Minimum
Ductility, 25 ºC, cm	150+	AAHSTO T51	75 Minimum
PAV-Aged, 2.1 MPa, 20 Hrs, 100 ºC		AAHSTO R28	
Dynamic Shear Rheometer, 22 ºC		AASHTO T315	
G*, kPa	6015		
Phase Angle, º	47.2		
G*Sin δ, kPa	4416		5000 Maximum
Bending Beam Rheometer, -12 ºC		AASHTO T313	
Stiffness, MPa	139		300 Maximum
m-value	0.333		0.300 Minimum
Specific Gravity, 60 ºF	1.018	AASHTO T228	
API Gravity, 60 ºF	7.5		

Table 4b. Asphalt cement binder PG64-10 rheology

Test	Result	Test Method	Specification
Rotational Viscosity, 135 ºC, Pa.s	0.345	AASHTO T316	3.0 Maximum
Flash, COC, ºC	310	AASHTO T48	230 Minimum
Solubility in TCE, w%	99.8	AASHTO T44	99.0 Minimum
Dynamic Shear Rheometer, 64 ºC		AASHTO T315	
Complex Viscosity, η* , Pa.s	150		
G*, kPa	1.503		
Phase Angle, º	88.4		
G*/Sin δ, kPa	1.504		1.00 Minimum
RTFO-Aged			
Mass Change, w%	-0.190	AASHTO T240	1.00 Maximum
Dynamic Shear Rheometer, 64 ºC		AASHTO T315	
G*, kPa	3,874		
Phase Angle, º	85.5		
G*/Sin δ, kPa	3.886		2.20 Minimum
Ductility, 25 ºC, cm	150+	AAHSTO T51	75 Minimum
PAV-Aged, 2.1 MPa, 20 Hrs, 100 ºC		AAHSTO R28	
Dynamic Shear Rheometer, 28 ºC		AASHTO T315	
G*, kPa	3180		
Phase Angle, º	53.8		
G*Sin δ, kPa	2568		5000 Maximum
Bending Beam Rheometer, 0ºC		AASHTO T313	
Stiffness, MPa	47		300 Maximum
m-value	0.454		0.300 Minimum
Specific Gravity, 60 ºF	1.022	AASHTO T228	
API Gravity, 60 ºF	7.0		

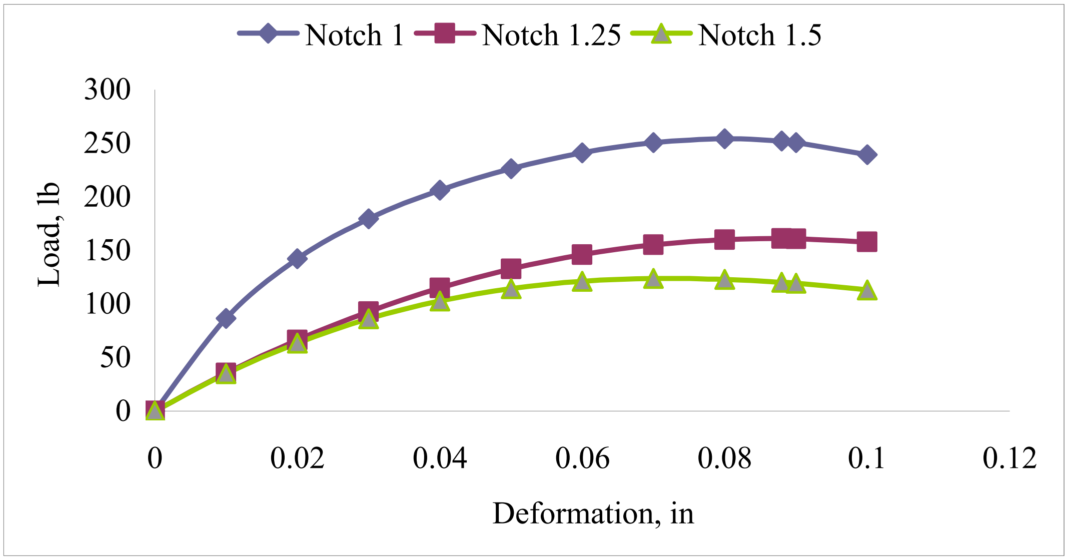
AC Mixture Characterization

Semi-Circular Bend (SCB) Test

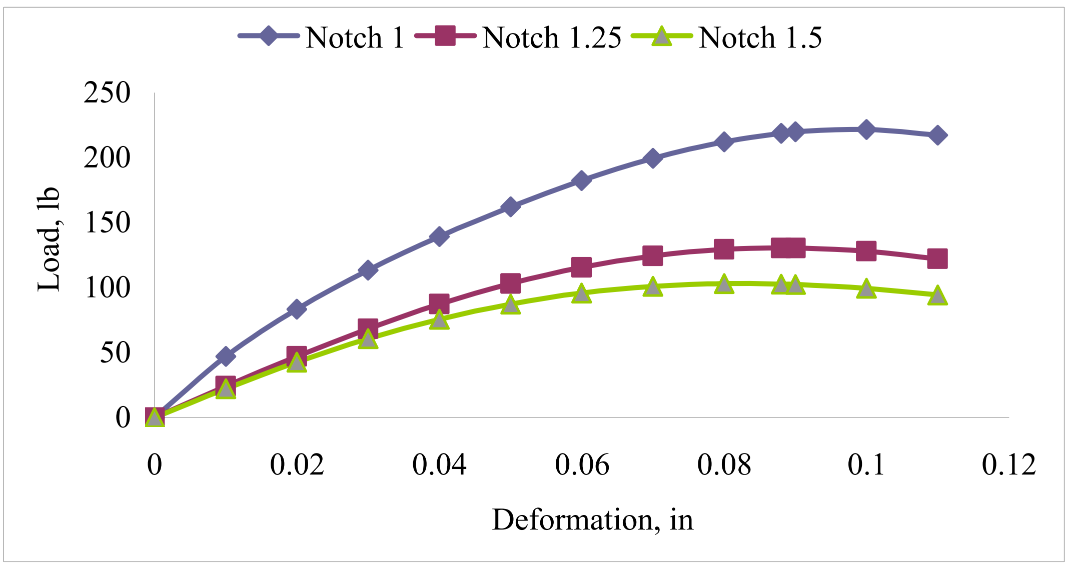
A total of 24 SCB tests were performed, 2 mixtures (PG64-10 and PG58-28), 2 conditions (Dry and Wet), 3 notch-depths (25.4-, 31.8- and 38.0 mm) and 2 replicates each. Figure 5 presents the load-displacement curves for the three notches of PG64-10 and PG58-22 mixtures for the dry and wet conditions. Figure 6 presents the strain energy curves for both mixtures at dry and wet conditions. The peak load and the displacement values were determined after each SCB test in order to calculate the critical J_c using equation (1). Figure 6 shows a decrease in the strain energy with the increase in the notch depth.

The SCB J_c values for PG64-10 and PG58-22 mixtures for the dry and wet conditions are shown in table 5. The SCB J_c values are normally distributed as can be seen in figure 7. The J_c value ranged between 1.524 kN/m and 0.268 kN/m (8.7 and 1.53 lb/in) for all the specimens in this study. The PG64-10 mixture achieved higher J_c values compared to PG58-22 mixture for both dry and wet conditions. Analysis of variance (ANOVA) was used, considering two variables, namely binder type and specimen condition. The analysis of variance results are presented in table 6.

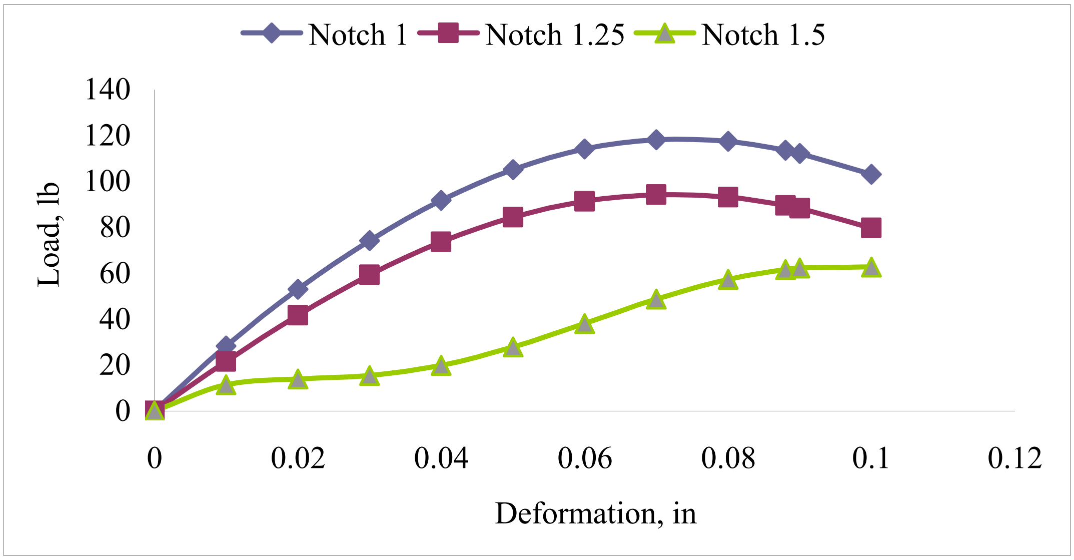
The ANOVA indicated that there is no significant effect of the mixture type on the measured SCB J_c, however, there is significant effect of the condition (dry versus wet) on the measured SCB J_c as indicated by the P-value (P-value < 0.05 indicates that the parameter is significant).


Notch 1
Notch 1.25
Notch 1.5
Load, lb
300
250
200
150
100
50
0
0
0.02
0.04
0.06
0.08
0.1
0.12
Deformation, in

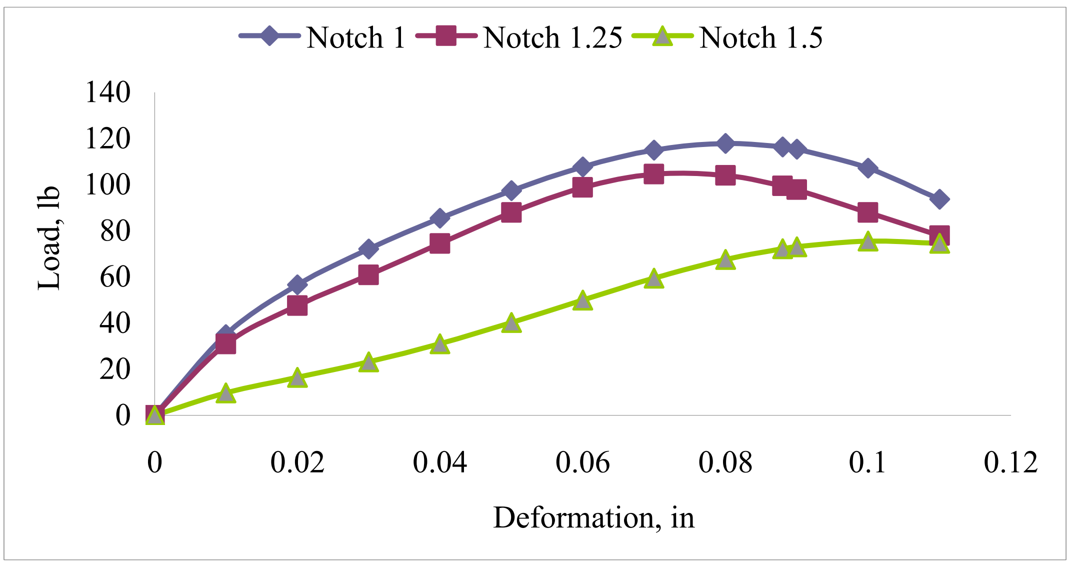
(a)


Notch 1
Notch 1.25
Notch 1.5
Load, lb
250
200
150
100
50
0
0
0.02
0.04
0.06
0.08
0.1
0.12
Deformation, in

(b)

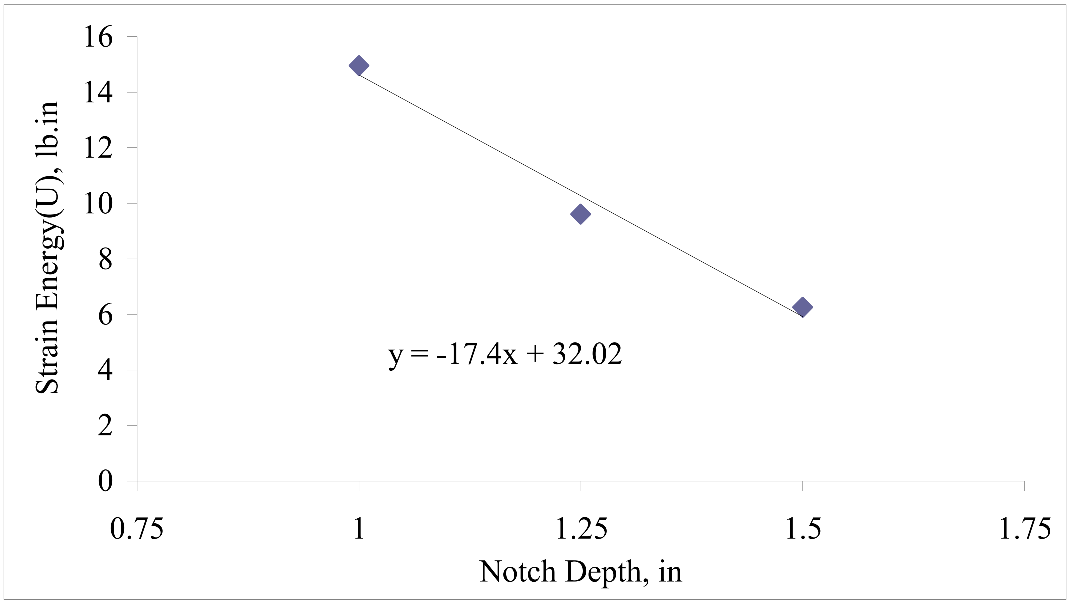


(c)



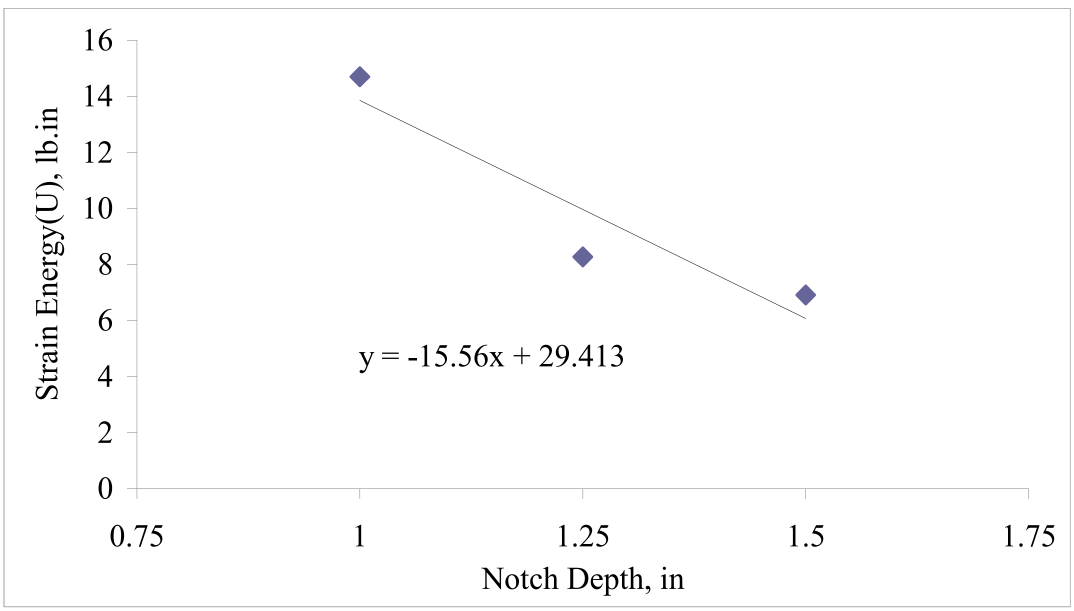
(d)

Figure 5. Load-deflection curves for a) Dry PG64-10 b) Dry PG58-22 c) Wet PG64-10, and d) Wet PG58-22



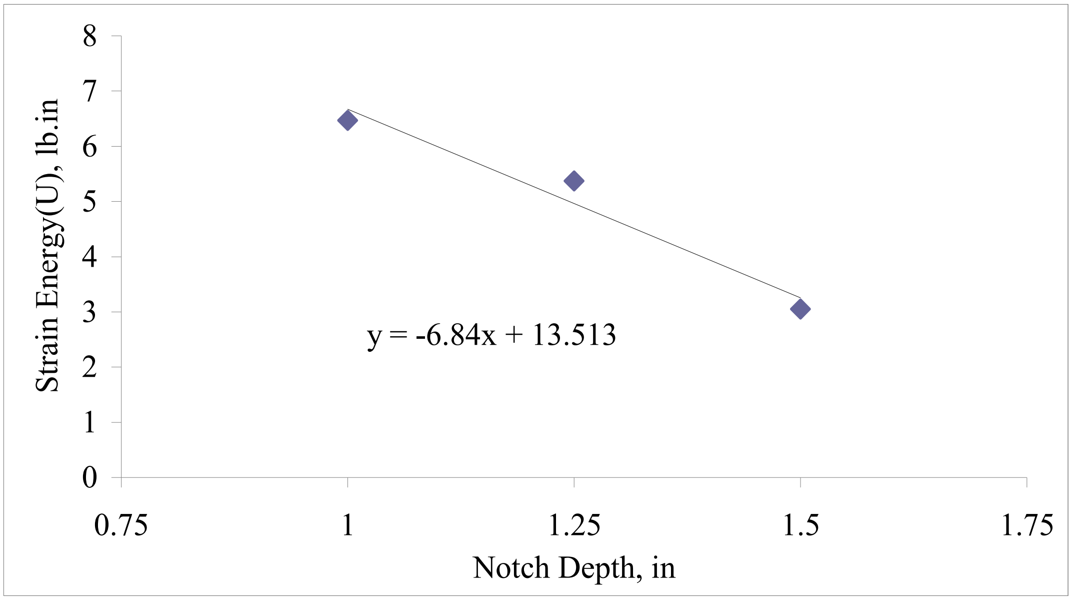
16
14
12
10
8
6
4
2
0
Strain Energy(U), lb.in
y = -17.4x + 32.02
0.75
1
1.25
1.5
1.75
Notch Depth, in

(a)

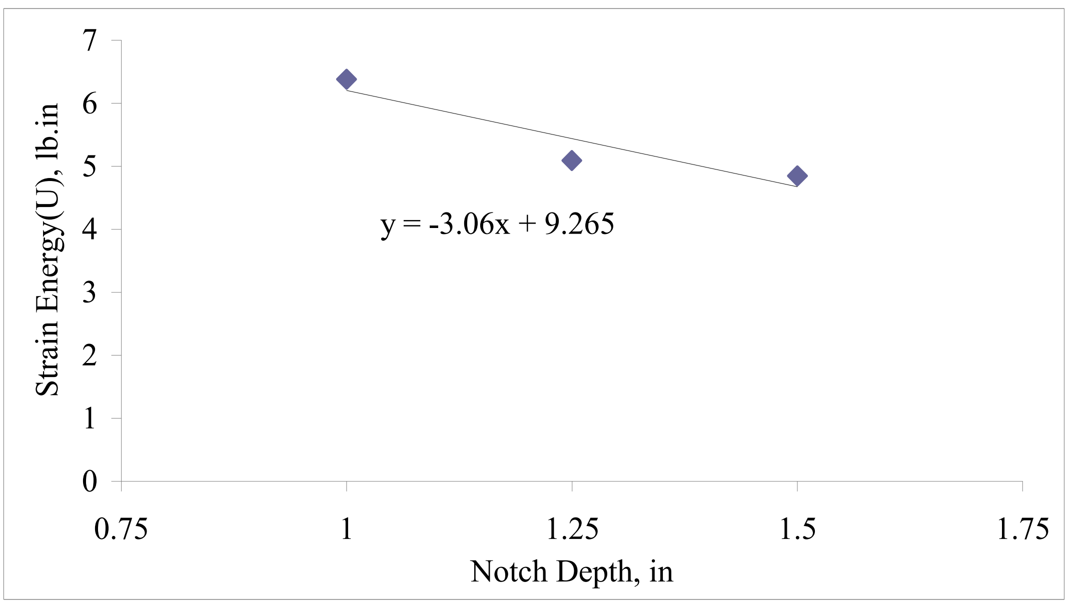


16
14
12
10
8
6
4
2
0
Strain Energy(U), lb.in
y = -15.56x + 29.413
0.75
1
1.25
1.5
1.75
Notch Depth, in

(b)



(c)



(d)

Figure 6. Strain energy curves for a) Dry PG64-10 b) Dry PG58-22 c) Wet PG64-10, and d) Wet PG58-22

Table 5 Critical value of J- integral (J_c) for all mixtures

Mixture		J_c				
		Specimen		Mean	%CV	Rank
		J_c (lb/in)	J_c (kN/m)			
Dry	PG64-10	8.7	1.524	8.70	0.0	1
		8.7	1.524			
	PG58-22	9.31	1.630	8.55	12.7	2
		7.78	1.362			
Wet	PG64-10	3.42	0.599	4.06	22.3	3
		4.7	0.823			
	PG58-22	1.53	0.268	2.00	33.2	4
		2.47	0.433			

Table 6. ANOVA for the SCB J_c

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Condition	1	62.552	62.552	62.552	73.66	0
Mixture	1	2.453	2.453	2.453	2.89	0.15
Error	5	4.246	4.246	0.849		
Total	7	69.251				

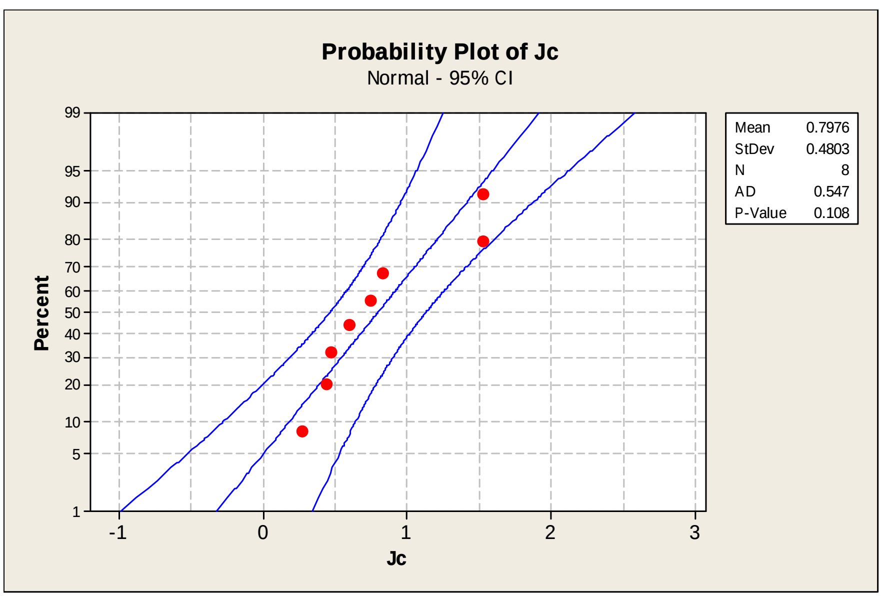


Figure 7. probability plot for of J_c

Fatigue Beam Test (FBT)

A total of 12 FBT were performed: 2 mixtures (PG64-10 and PG58-28), 2 conditions (dry and wet), and 3 replicates each. The test was performed according to AASHTO T-321 at 20 °C and stain level of 350 micro-strain. The Initial Dissipated Energy, and the cycles to failure (N_f) were determined. Table 7a represents the FBT results for the PG64-10 and PG58-22 AC mixtures, at both conditions (dry and wet), evaluated in this study. It can be seen that the results had a high coefficient of variation (%CV) (27 to 93%). The authors decided to examine and reduce the results by eliminating the outlier sample to reduce variability of the results. Table 7b presents the reduced FBT results for the PG64-10 and PG58-22 AC mixtures, under both conditions (dry and wet), evaluated in this study. The %CV was reduced to the range of 16.5 to 48%. The data are normally distributed as can be seen in figures 8a and 8b.

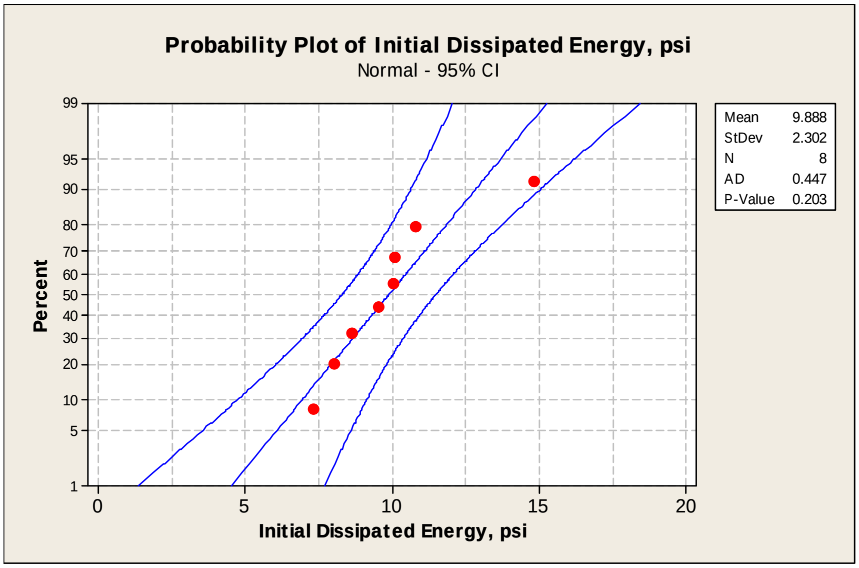
Table 7. a) Fatigue beam test results-original

Mixture		Initial Dissipated Energy, psi				Cycles to failure, N_f			
		Specimen	Avg.	%CV	Rank	Specimen	Avg.	%CV	Rank
Dry	PG64-10	0.01	0.01263	19.3	1	97,829	76,300	27.4	2
		0.0148				75,000			
		0.0131				56,070			
	PG58-22	0.0073	0.0097	23.0	4	139,133	129,954	64.1	1
		0.0101				208,293			
		0.0117				42,436			
Wet	PG64-10	0.0095	0.00905	7.0	3	14,262	10,597	48.9	4
		0.0086				6,932			
		*				*			
	PG58-22	0.008	0.00917	15.9	2	6,850	16,724	93.0	3
		0.0087				34,657			
		0.0108				8,664			

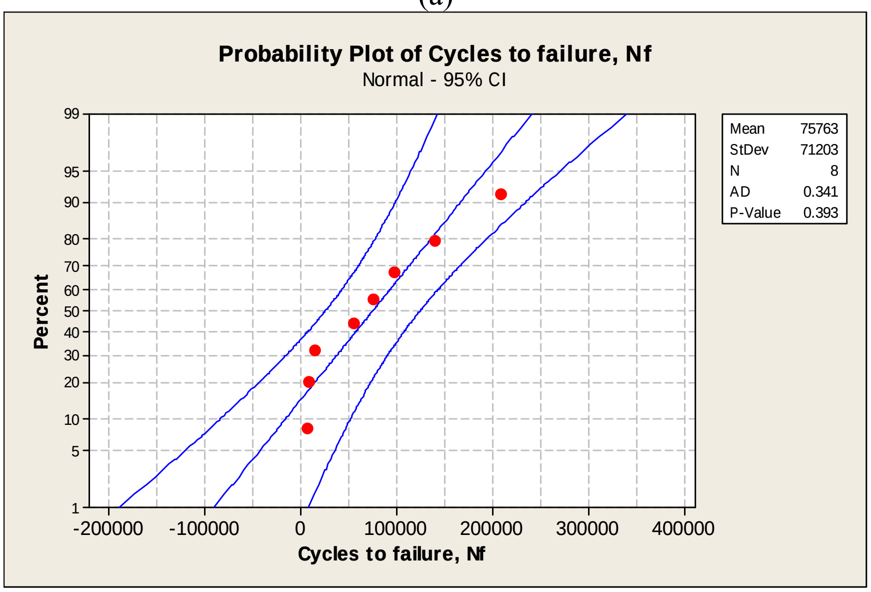
*The beam broke during the initial stage of testing

Table 7. b) Fatigue beam test results - modified

Mixture		Initial Dissipated Energy, psi				Cycles to failure, N_f			
		Specimen	Avg.	%CV	Rank	Specimen	Avg.	%CV	Rank
Dry	PG64-10	0.01	0.0124	27.4	1	97,829	86,415	18.7	2
		0.0148				75,000			
	PG58-22	0.0073	0.0087	22.8	4	139,133	173,713	28.2	1
		0.0101				208,293			
Wet	PG64-10	0.0095	0.00905	7.0	3	14,262	10,597	48.9	3
		0.0086				6,932			
	PG58-22	0.008	0.0094	21.1	2	6,850	7,757	16.5	4
		0.0108				8,664			



(a)



(b)

Figure 8. a) Probability plot for initial dissipated energy and b) Probability plot for cycles to failure N_f.

Analysis of variance was performed on the effect of mixture type and the condition of the mixtures on the initial dissipated energy and the cycles to failure (N_f). The FBT initial dissipated energy ANOVA results are presented in table 8. The ANOVA indicated that there is no significant effect of the mixture type and condition on the measured initial dissipated energy.

The FBT N_f ANOVA results are presented in table 9. Similar to the SCB J_c, the ANOVA indicated that there is no significant effect of the mixture type on the measured N_f, however, there is significant effect of the condition (dry versus wet) on the measured N_f.

Table 8. ANOVA for the FBT initial dissipated energy

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Condition	1	0.0000035	0.0000035	0.0000035	0.63	0.464
Mixture	1	0.0000056	0.0000056	0.0000056	1	0.363
Error	5	0.000028	0.000028	0.0000056		
Total	7	0.0000371				

Table 9. ANOVA for the FBT N_f

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Condition	1	29227212651	29227212651	29227212651	21.67	0.006
Mixture	1	3566619111	3566619111	3566619111	2.64	0.165
Error	5	6743118760	6743118760	1348623752		
Total	7	39536950522				

Comparison between SCB J_c and FBT

The SCB J_c parameter and the FTB N_f ranked the dry mixtures higher than the wet mixtures for PG64-10 and PG58-22 mixtures. In addition, SCB J_c and FBT N_f had similar ranking for the wet mixtures. For the dry mixtures the J_c ranked the PG64-10 mixture higher than the PG58-22 mixture, however the FBT N_f ranked the PG58-22 higher than the PG64-10.

The FBT initial dissipated energy ranked the mixture different from FBT N_f and the SCB J_c. This is expected as this parameter does not reflect the fracture properties of the mixture.

In terms of coefficient of variability (%CV), the FBT N_f exhibited higher variability than those of SCB J_c.

In general, it can be seen that the SCB J_c had similar ranking to the FBT N_f. A regression analysis to assess the relation between the SCB J_c and the FBT N_f was conducted. The model is presented in equation (2).

$$J_c = 3.56 + 0.000033\ N_f \tag{2}$$

The P-value of the statistical model is (0.023) and $R^2 = 60\%$.

The SCB test has great potential as a QA/QC test of fracture properties of asphalt mixtures. However, the results of this pilot study need to be further investigated and confirmed.

CONCLUSIONS

The main objective of this study is to investigate the use of the SCB test as a quality assurance/quality control (QA/QC) measure for field construction. Comparison of fracture properties from the SCB test and the FBT was conducted. The J_c values for PG64-10 and PG58-22 mixtures on dry and wet conditions were determined. An FBT was performed on PG64-10 and PG58-28 mixtures on dry and wet conditions. The following conclusions were drawn:

- The SCB J_c and FBT N_f indicated better fracture properties for dry mixtures than wet mixtures.

- The dry PG64-10 mixture achieved similar SCB J_c values to PG58-22 mixture. However, the wet PG64-10 mixture achieved higher SCB J_c values than PG58-22 mixture.

- The dry PG58-22 mixture achieved higher FBT N_f values than PG64-10 mixture. However, the wet PG64-10 mixture achieved higher FBT N_f values than PG58-22 mixture.

- The FBT initial dissipated energy was not consistent with the SCB J_c and the FBT N_f values. This is expected as this parameter does not reflect the fracture properties of asphalt mixtures.

- In general, the SCB J_c and the FBT N_f had similar ranking of both mixtures at dry and wet conditions.

- The FBT N_f had higher variability, %CV (16.5 – 48.9%), compared to SCB J_c, %CV (0 – 33.2%).

- The ANOVA on the SCB J_c parameter indicated that there is a significant effect of the condition (dry versus wet) on the measured J_c values. In addition, the SCB J_c parameter indicated that there is no significant effect of the mixture type (PG64-10 Vs PG58-22) on the measured J_c values.

- Similar to SCB J_c, the ANOVA on the FBT N_f parameter indicated that there is significant effect of the condition type (dry versus wet) on the measured N_f values. In addition, the FBT N_f parameter indicated that there is no significant effect of the mixture type (PG64-10 Vs. PG58-22) on the measured N_f values.

- A regression analysis on the relationship between the SCB Jc and the FBT Nf indicated that the model is significant with R^2 = 60%.

- The results of this pilot study indicate that the SCB test has a great potential as a QA/QC test of fracture properties of asphalt mixtures.

RECOMMENDATION

The results of this pilot study indicated that the SCB test has great potential as a QA/QC test of fracture properties of asphalt mixtures. However, the results need to be assessed for more mixtures and variables. It is recommended that mixtures with reclaimed asphalt pavement (RAP), warm mix asphalt (WMA) of coarse, medium, and fine gradations be included.

The simplicity of performing the SCB test makes it the preferred test for the QA/QC procedure on the fracture properties of asphalt mixture. In addition, the SCB test can lend itself easily to performance modeling and finite element analysis.

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