Cracking and Rutting Performance of Asphalt Mixes for a Balanced Mix Design: Pilot Study

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Abstract

The balanced mix design approach considers a matrix of volumetric properties as well as cracking and rutting performance in the selection of asphalt mix constituents. In Manitoba, asphalt mix design and mix acceptance are becoming more and more complex with the increasing uses of recycled materials, binder additives/modifiers, and multiple warm-mix asphalt technologies. The objective of this study is to conduct a pilot performance-testing program to evaluate the asphalt mixes, for potential field performance in terms of cracking and rutting to optimize asphalt mix constituents for moving towards the balanced mix design. Hot-mix asphalt and warm-mix asphalt laboratory compacted specimens along with field compacted specimens were assessed for cracking and rutting performance using the Illinois Flexibility Index Test and Hamburg Wheel-Tracking Test, respectively. Results showed that warm-mix asphalt mixtures have a lower cracking potential than hot-mix asphalt mixtures. The well-compacted field mixtures displayed a low rutting potential. Low mixing/compacting temperatures using WMA additives, proper voids in mineral aggregate content, and adequate field compaction (low air voids) were found to be viable candidates for an effective balanced mix design approach.

Keywords:

Balanced mix design, Hot-mix asphalt, Warm-mix asphalt, Illinois Flexibility Index Test, Hamburg Wheel-Tracking Test.

1.0 Introduction

1.1 Background

Traditionally, asphalt mixture designs have been developed based on the volumetric properties of mixes. Recently, the increased use of reclaimed/recycled binder and aggregate, binder additives such as polymers, and multiple warm-mix asphalt technologies forced agencies to look beyond the volumetric asphalt mixture design [1]. Consequently, the incorporation of performance testing became necessary for accepting the asphalt mix design. Performance tests provide better predictions of distresses and support the exploration of innovative designs. They involve tests mainly for cracking, rutting, and moisture susceptibility. As performance tests became ubiquitous, the development of the balanced mix design (BMD) was brought to light. The FHWA Expert Task Group defined BMD as "asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate and location within the pavement structure" [2]. In brief, BMD considers the volumetric properties as well as the cracking and rutting performance in the selection of asphalt mix ingredients. This will help to mitigate the production of weak or brittle mixes for ensuring durable pavements.

1.2 Objectives and Scope

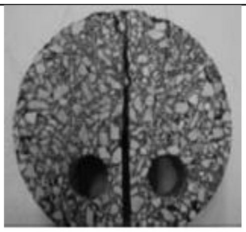
In this study, a pilot performance-testing program has been conducted at the University of Manitoba to utilize the cracking and rutting performance of asphalt mixes currently in use in Manitoba. In the experimental phase of this pilot program, specimens were obtained from both laboratory compacted and field compacted mixtures. The cracking performance was assessed using the Illinois Flexibility Index Test (I-FIT), and the rutting performance was assessed using the Hamburg Wheel-Tracking Test (HWTT).

The objective of this study is to produce an approach for optimizing the resistance to rutting and cracking of asphalt mixes and then, guide towards producing balanced mix designs. The relationship of the parameters from the cracking and rutting test with the material and volumetric properties of the corresponding sample groups is discussed. Such analysis allowed the assessment of the influence of material and volumetric properties on these two fundamental properties of asphalt mixes. Finally, a balanced mix design approach that integrates the results of the two laboratory performance tests (I-FIT and HWTT) was investigated. This investigation allowed the assessment of the current asphalt mix constituents and assisted in providing recommendations for making changes to move towards a more efficient balanced mix design.

2.0 Performance Tests

Several competing performance test methods have been developed recently to evaluate asphalt mixes. These include Disk-Shaped Compact Tension Test (DCT), Semi-Circular Bend Test (SCB), Illinois Flexibility Index Test (I-FIT), Indirect Tensile Strength Test (IDT), Indirect Tension Asphalt Cracking Test (IDEAL-CT) and Hamburg Wheel-Tracking Test (HWTT). Table 1 shows a summary of these laboratory performance test methods.

Table 1: Summary of laboratory performance test methods [3]

Test Configuration		**Purpose**	**Specimen dimensions**	**Specimen preparation**	**Test output**
Disk-Shaped Compact Tension Test (DCT)		Cracking resistance	150 mm diameter, 142.5 mm height, 50 mm thickness	61.5 mm notch, 2 holes, 3 cuts and extensometer required	Fracture energy, Peak-load, Critical displacement
Semi-Circular Bend Test (SCB)		Cracking resistance	150 mm diameter, 75 mm height, 50 mm thickness	15 mm notch, 3 cuts and external LVDT's required	Fracture energy, Peak-load, Critical displacement
Illinois Flexibility Index Test (I-FIT)		Cracking resistance	150 mm diameter, 75 mm height, 50 mm thickness	15 mm notch and 3 cuts required	Fracture energy, Post-peak slope, Flexibility index
Indirect Tensile Strength Test (IDT)		Tensile strength	150 mm diameter, 50 mm thickness	2 cuts and external LVDT's required	Maximum horizontal strain at maximum load and strength
Indirect Tension Asphalt Cracking Test (IDEAL-CT)		Cracking resistance	155 mm diameter, 62 mm thickness	No notching, coring, cutting or any instrument required	Fracture energy, Peak-load, Critical displacement, Cracking test index

Hamburg Wheel-Tracking Test (HWTT)		Rutting resistance and moisture sensitivity	150 mm diameter, 62 mm height	4 specimens for 1 test and cutting required	Rut depth at stripping inflection point and number of passes at maximum rut depth
Asphalt Pavement Analyzer (APA)		Rutting resistance	150 mm diameter, 75 mm height	6 specimens for 1 test and cutting required	Average rut depth at the end of 8000 cycles
Flow Number Test		Rutting resistance	100 mm diameter, 150 mm height	Cutting and coring required	Flow number (FN)

3.0 Methodology

In this study, the I-FIT test was conducted on laboratory and field compacted asphalt mixtures because it is a simple, reliable, yet robust and affordable test. The test was performed following the Illinois Modified AASHTO TP 124-18 [4]. The output parameters from the I-FIT test are used to assess the fatigue cracking potential of asphalt mixes. The HWTT was conducted following the recent HWTT specification AASHTO T324-17 [5]. The output parameters from the HWTT are used to assess the rutting and stripping performance of asphalt mixes.

3.1 Materials

For laboratory compacted samples, four types of mixtures were included in this study, namely the hot-mix asphalt with no additive (HMA), and warm-mix asphalt with three Evotherm dosages as a percent of binder content (WMA 0.3%, WMA 0.5%, and WMA 0.7%). Evotherm is a chemical additive that improves the coating and workability of the mix at lower production temperatures [6]. For field compacted samples, pavement cores with a diameter of 150 mm were extracted from HMA mixtures on a regional road in the City of Winnipeg that had been opened to traffic for some time, according to AASHTO R67 [7].

The aggregate and asphalt cement that were used in the preparation of HMA and WMA mixtures in this study were characterized using routine type of tests to ensure that they meet the specification requirements of the City of Winnipeg [8]. Table 2 shows the aggregate gradations of HMA and WMA mixtures as well as the specifications outlined by the City of Winnipeg [8].

Table 2: Aggregate gradation of laboratory compacted mixtures

Sieve Size (mm)	**Passing (%)**				**Specification**	
	HMA	**WMA 0.3%**	**WMA 0.5%**	**WMA 0.7%**	**Min. (%)**	**Max. (%)**
20.00	100.0	100.0	100.0	100.0	100	100
16.00	100.0	100.0	99.2	100.0	99	100
12.50	92.8	94.8	94.5	94.6	-	-
10.00	78.5	86.6	80.9	82.2	70	88
5.00	56.6	66.7	60.8	64.4	55	70
2.50	47.2	55.1	51.0	55.1	40	60
1.25	37.8	43.8	40.9	44.6	25	50
0.63	24.7	28.3	26.6	29.2	15	40
0.315	11.6	12.6	12.4	13.6	5	28
0.16	4.8	5.0	5.1	5.6	4	11
0.08	3.4	3.5	3.6	4.0	3	7
Crushed Content	90%	89%	89%	91%	60% minimum	

The volumetric properties of HMA and WMA mixtures were determined using Marshall tests and were found to meet the specifications of the City of Winnipeg, as shown in Table 3 [8].

Table 3: Volumetric properties of laboratory compacted mixtures

Marshall Properties	**HMA**	**WMA 0.3%**	**WMA 0.5%**	**WMA 0.7%**	**Specifications**
Air Voids (%)	4.5	4.6	4.4	4.6	3 to 5
Stability (KN)	11.7	9.9	10.6	8.8	7 minimum
Flow (mm)	8.5	8.0	7.2	6.8	6 to 16
VMA (%)	14.1	14.3	14.2	14.5	14 minimum
Density (kg/m^3)	2389	2384	2390	2381	-
Absorption (%)	0.92	0.93	0.93	0.95	-
Bulk Specific Gravity (G_{sb})	2.65	2.65	2.65	2.65	-
Maximum Specific Gravity (G_{mm})	2.509	2.507	2.506	2.504	-

PG 58-28 binder was used in both HMA and WMA mixtures. The mixing/compacting temperature was 160/145°C for HMA and 130/115°C for WMA.

3.2 Specimen Preparations

Laboratory test specimens were prepared using a Superpave Gyratory Compactor (SGC) according to AASHTO T312 [9]. Two sets of 150 mm diameter samples for each of the four asphalt mixture types were produced. One set of samples included asphalt mixes compacted to a height of 160 mm, and the other set had the mixes compacted to a height of 140 mm. The purpose of this approach was an attempt to minimize the variation in air void content between the specimens that will be extracted from these SGC samples. On the other hand, field test specimens were prepared by sawing the top lifts of all the extracted field cores prior to any cracking or rutting test.

For the I-FIT, two discs with a thickness of 50±1 mm were cut from the top and bottom of each SGC sample for each mixture type. Thus, a total of 16 discs (eight for each set) were produced. Subsequently, each disc was cut into two identical halves to produce the I-FIT specimen (as shown in Figure 1). Finally, a notch with a depth of 15±1 mm and width less than or equal to 2.25 mm was cut in the middle of each I-FIT specimen to create a total of 32 samples for the cracking test. On the other hand, two field core top lifts were randomly selected and sawed again to a 50±1 mm thickness. The two discs were then split into two halves, and a notch was created similar to the laboratory samples to produce a total of four field samples for the cracking test.

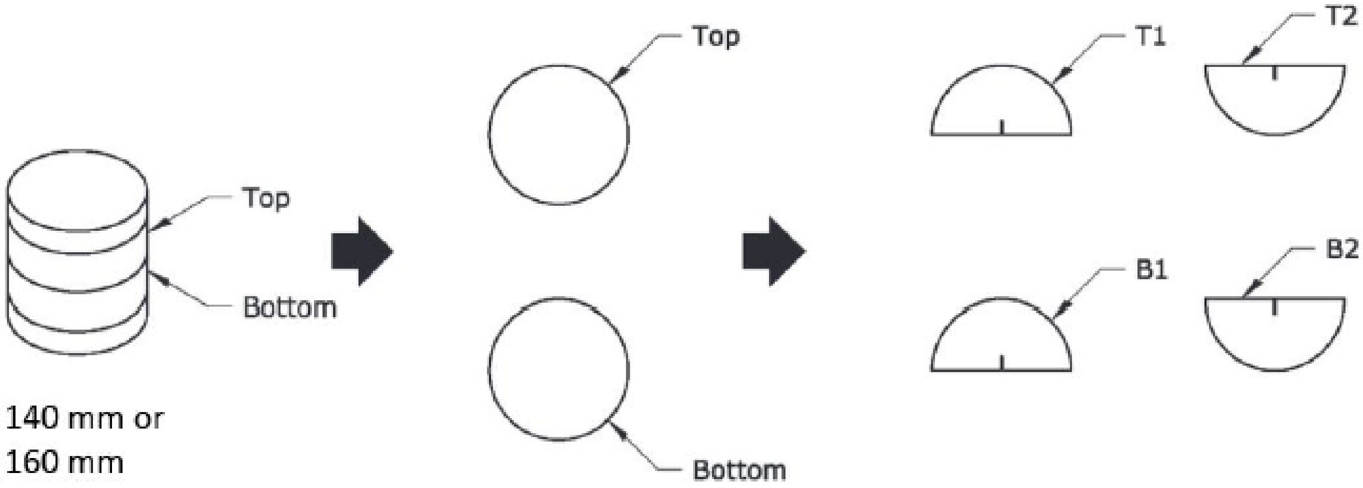


Figure 1: I-FIT specimen preparation [4]

For the HWTT, three replicates of samples were prepared and tested for the laboratory asphalt mixtures, whereas only one test was conducted on the field samples collected. Two discs were aligned next to each other and fitted in mounting moulds. For field samples, the discs had to be aligned in the same direction following the traffic direction in the field. Traffic direction was marked on the pavement cores during their extraction from the field. The contact surfaces between the two aligned discs were sawed (approximately 7 mm from each cylinder) to provide enough width for the motion of the contact wheel. As the apparatus consists of two contact wheels, two moulds and a total of four discs were required to conduct the HWTT. The moulds have a diameter of 150 mm, which is equivalent to the diameter of the specimens. According to the specifications of Illinois and Texas Departments of Transportation [10 and 11], the height of the paired cylinders should be adjusted to be the same and within the 62±2 mm range from the bottom of the testing mould. The two testing moulds were then fixed into the apparatus so that the contact wheels travel in the direction of traffic. Figure 2 shows the mounting system of the specimens for both the I-FIT and HWTT directly before conducting the test.

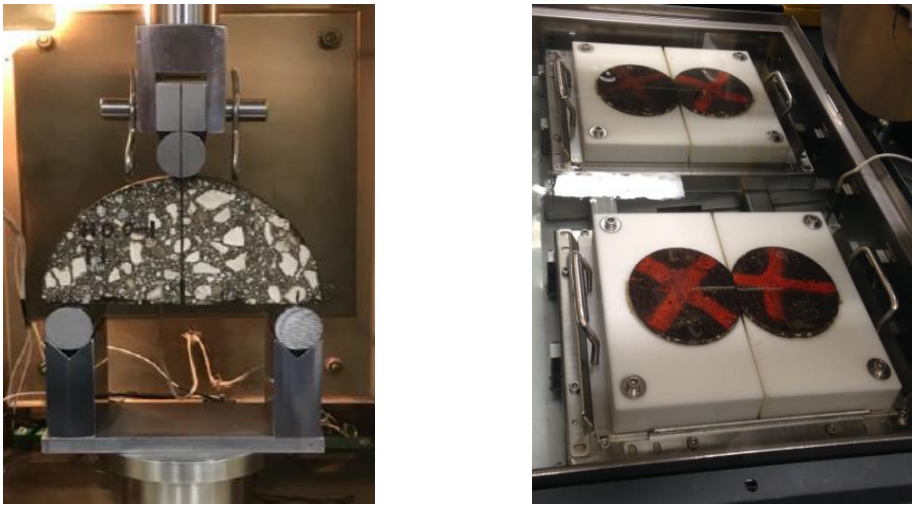


Figure 2: I-FIT (left) and HWTT (right) specimen before testing

3.3 Dimensional and Volumetric Properties

Dimensional and volumetric properties of I-FIT specimens have a significant impact on the cracking test results. Dimensional properties of a specimen include its diameter, thickness, ligament length, and notch depth and width. Figure 3 shows the standard dimensions of an I-FIT specimen.

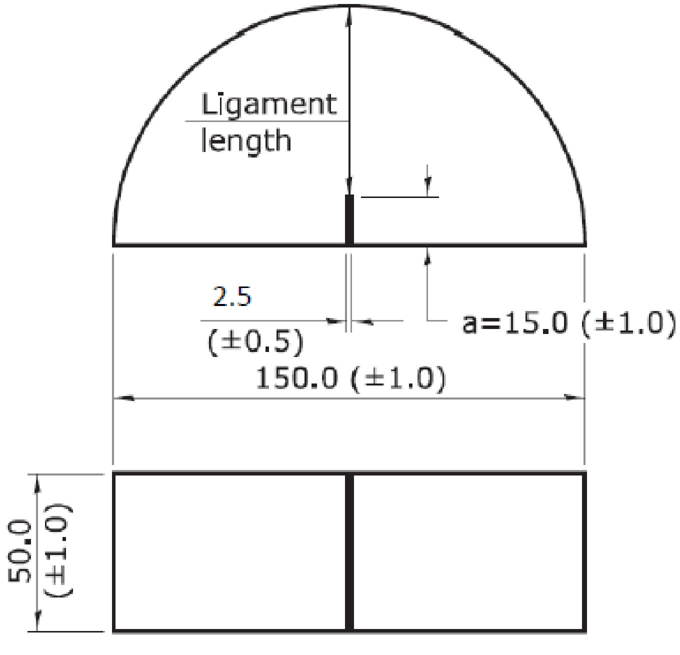


Figure 3: I-FIT specimen dimensions [4]

The AASHTO TP 124-18 [4] provides a limitation for the air voids of laboratory prepared specimens to be within the range of 7±1 %. Hence, before cutting the notch, the percentage of air voids was calculated for each I-FIT specimen. The cracking test was not conducted on specimens that had a percentage of air voids not within the stipulated range. Overall, eight samples (out of 32) did not comply with the specified range of air voids and were subsequently discarded. In addition, other volumetric properties such as voids in mineral aggregate (VMA), nominal maximum aggregate size (NMAS), and binder content were determined to describe the laboratory I-FIT specimens. For the field samples, these properties were provided directly in the Marshall Analysis reports by the materials testing consultant. Table 4 shows the statistics of each dimensional and volumetric property for both laboratory and field sample groups.

Table 4: Dimensional and Volumetric Properties of I-FIT Specimens

Dimensional/ Volumetric Property	**Statistical Property**	**Laboratory compacted**				**Field compacted**
		HMA	**WMA 0.3%**	**WMA 0.5%**	**WMA 0.7%**	**HMA**
Ligament Length (mm)	Average	58.06	57.41	57.77	57.83	57.32
	Minimum	57.16	57.08	57.23	57.38	56.45
	Maximum	58.85	58.26	58.33	58.51	57.82
	Standard Deviation	0.68	0.48	0.38	0.49	0.65
	Coefficient of Variation (%)	1.17	0.84	0.65	0.86	1.13
Thickness (mm)	Average	49.71	49.94	50.38	49.64	50.41
	Minimum	49.16	49.50	49.97	48.64	49.93
	Maximum	50.57	50.63	50.69	51.30	50.99
	Standard Deviation	0.64	0.43	0.25	1.00	0.45
	Coefficient of Variation (%)	1.28	0.87	0.50	2.01	0.90
VMA (%)	Average	17.23	17.04	17.20	17.35	15.06
	Minimum	16.47	16.43	16.80	16.56	14.80
	Maximum	18.08	17.46	17.69	17.53	15.50
	Standard Deviation	0.71	0.45	0.37	0.19	0.18
	Coefficient of Variation (%)	4.09	2.67	2.14	1.09	1.19
NMAS (mm)	Average	12.50	12.50	12.50	12.50	-
	Minimum	-	-	-	-	12.50
	Maximum	-	-	-	-	16.00
Binder Content (%)	Average	5.00	5.10	5.10	5.20	5.24
	Minimum	-	-	-	-	5.00
	Maximum	-	-	-	-	5.80
	Standard Deviation	0.00	0.00	0.00	0.00	0.20
	Coefficient of Variation (%)	0.00	0.00	0.00	0.00	3.83
Air Voids (%)	Average	6.76	6.73	6.90	6.97	4.58
	Minimum	6.15	6.03	6.46	6.08	3.70
	Maximum	7.30	7.19	7.45	7.18	4.90
	Standard Deviation	0.50	0.51	0.41	0.21	0.31
	Coefficient of Variation (%)	7.36	7.61	6.01	3.05	6.77

Table 4 shows that the physical dimensions of both laboratory and field specimens are approximately the same. The averages of thickness and ligament length have less than a 1 mm difference along with very low standard deviations and coefficients of variation. This is because all I-FIT specimens must have uniform dimensions as stipulated in AASHTO TP 124-18 [4], regardless of the type of mixture being tested. Hence, it is the volumetric properties that mainly impact the cracking performance (as well as the rutting performance) of asphalt mixes in these two tests. Table 4 also shows that the NMAS and binder contents are almost the same for both laboratory and field specimens. It is only the air voids and VMA of field specimens that are noticeably less than those of laboratory sample groups (by 2.2% approximately) of the four mixture types.

3.4 Testing Procedure

According to AASHTO TP 124-18 [4], the I-FIT specimens were conditioned in an environmental chamber at 25°C for a minimum of 2 hours prior to being mounted on the test apparatus. Initially, a load of 0.1 KN is applied to the specimen in stroke control with a loading rate of 0.05 KN/s. When a contact load of 0.1 KN is reached, a load with a displacement rate of 50 mm/min is applied to the specimen. Finally, the test stops when the load drops below 0.1 KN.

The HWTT specimens were submerged in the HWT water tank to be preconditioned for 45 minutes at 45±1°C test temperature. This test temperature was selected based on the authors' experiences with the local mixtures and the HWTT equipment. A maximum of 10,000 cycles (20,000 passes) and 12.5 mm rut depth were selected as test end criteria. These criteria were selected according to the specifications of the Illinois and Texas Departments of Transportation [10 and 11]. The test was then conducted so that the contact wheels apply a load of 705±4.5 KN over the entire length of the wheel path [5]. Figure 4 shows the shapes of specimens directly after the I-FIT and HWTT.

Figure 4: I-FIT (left) and HWTT (right) specimen after testing

3.5 Test Output Parameters

The recorded data of each I-FIT specimen was analyzed using the specified I-FIT software developed at Illinois Center for Transportation. The output of the software includes a load-displacement curve for each specimen that demonstrates certain parameters, as shown in Figure 5. These parameters are Fracture energy, Peak-load, Post-peak slope, Flexibility Index, Tensile strength, and Critical displacement.

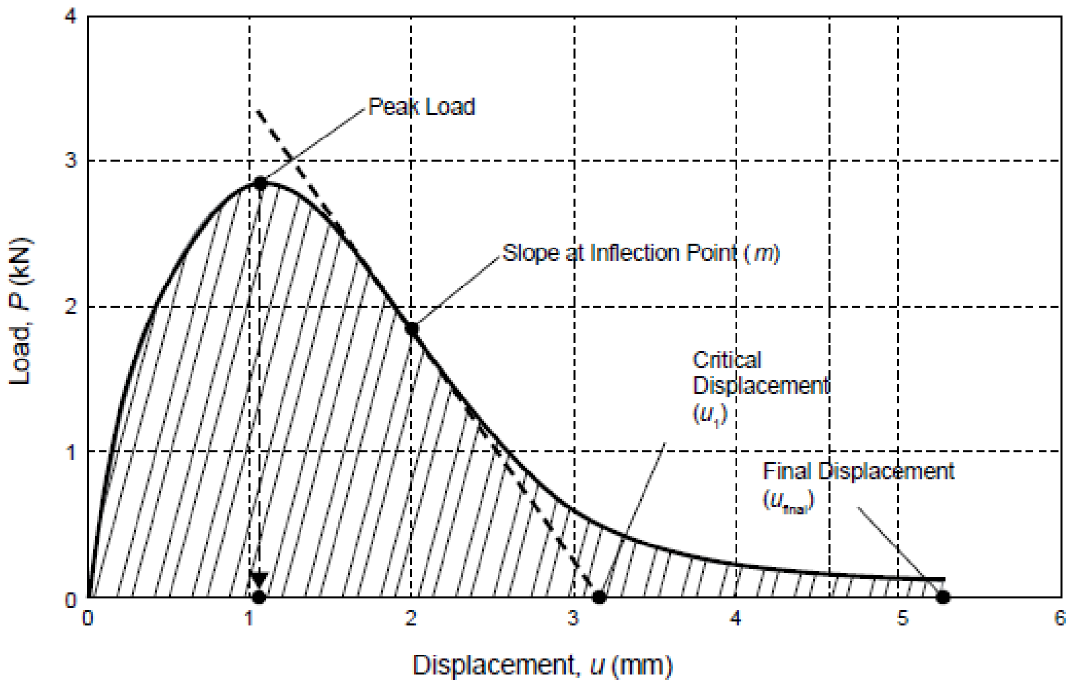


Figure 5: Load-displacement curve of an I-FIT specimen [4]

According to AASHTO TP 124-18 [4], Fracture energy is the total energy required to fail the specimen and is represented by the total area under the load-displacement curve. It is a function of both Peak load and Post-peak slope. Peak load is the maximum load applied to the specimen during the test, and Post-peak slope is the slope at the first inflection point of the load-displacement curve after the Peak load. Post-peak slope is an indicator of the ductility of the material. The steeper the slope, the faster the energy dissipation, the brittle the material is, and vice versa. Fracture energy alone may be inadequate to distinguish between brittle and ductile asphalt mixes as it only considers the area under the load-displacement curve. Hence, the Flexibility Index, which incorporates the post-peak slope, is also considered. Flexibility Index (FI) is the Fracture energy divided by the Post-peak slope, whereas higher FI indicates a better cracking resistivity. Tensile strength is the Peak load divided by the area of the flat side of the semicircular specimen opposite to the curved edge. Critical displacement is the intercept between the tangential slope and the displacement axis. It is also an indicator of the ductility of the material (similar to the Post-peak slope). A higher Critical displacement (i.e., the lower the slope) means the more ductile the material and vice versa.

The output of the HWTT includes six parameters for each specimen demonstrated on the curve shown in Figure 6. These parameters are Creep slope, Stripping slope, Number of passes to failure, Number of passes to Stripping Inflection Point (SIP), Rut depth to failure, and Rut depth to SIP.

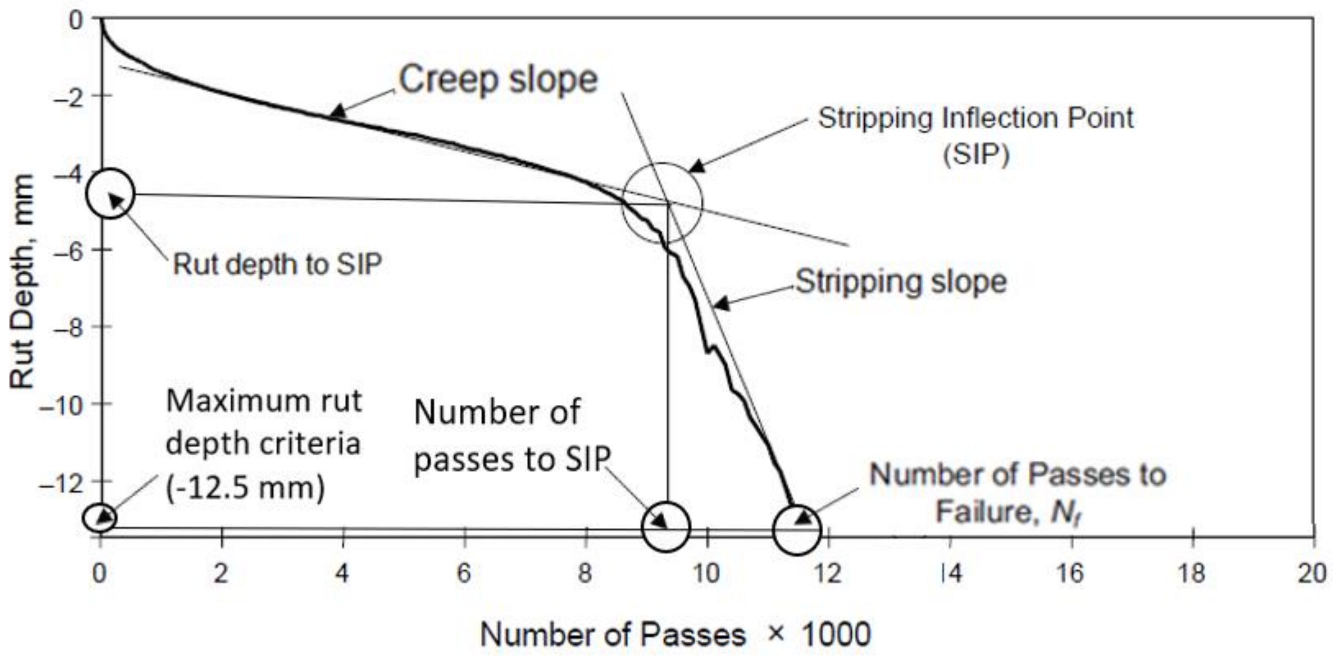


Figure 6: HWTT curve with test parameters [5]

According to AASHTO T324-17 [5], creep slope is the number of passes per 1 mm deformation before stripping occurs, and stripping slope is the number of passes per 1 mm deformation during stripping. The intersection between Creep and Stripping slopes is the Stripping Inflection Point (SIP), which represents the moisture susceptibility of a specimen. A number of passes to failure is the total number of passes required to reach the maximum rut depth criteria in the middle of the wheel pass, and a number of passes to SIP is the total number of passes prior to the start of stripping. Finally, the maximum rut depth is the deformation in the middle of the wheel pass at the end of the test, and rut depth to SIP is the deformation in the middle of the wheel pass before the start of stripping. The middle of the wheel pass is where full contact and the maximum stress of the wheel are reached, therefore it is the desired location of assessing the rut depth measurements.

4.0 Results, Analysis and Discussion

The following sub-sections display the cracking and rutting test results, and the balanced mix design approach based on the results of these two performance tests.

4.1 Cracking Performance

Figure 7 shows the combined load-displacement curves of laboratory specimens of the four laboratory asphalt mixtures along with the four I-FIT field specimens.

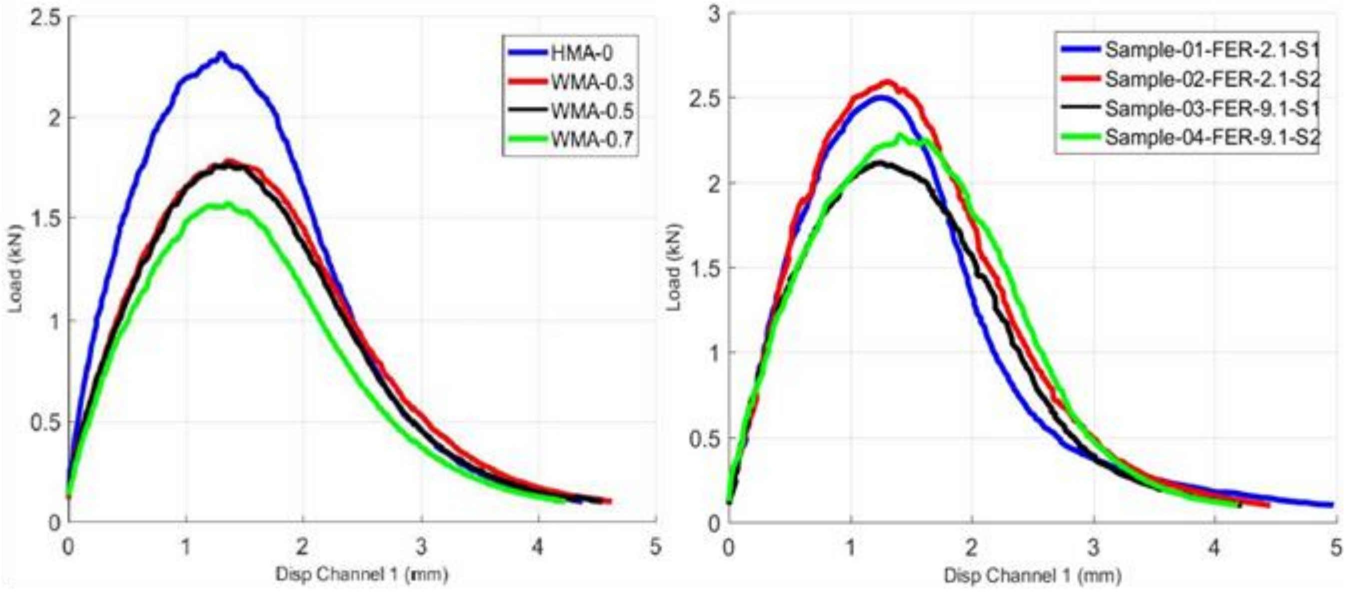


Figure 7: Combined I-FIT load-displacement curves of laboratory mixtures (left) and field specimens (right)

The characteristics of the curves shown in Figure 7 are represented by the statistics of the cracking test output parameters in Table 5. Table 5 shows that field compacted samples had relatively lower Flexibility Index (FI) than the laboratory compacted HMA and WMA mixture samples, which indicates that field compacted mixes have lower cracking resistivity. The field samples provided the lowest FI with the lowest air voids and VMA, and the highest AC contents among all the samples. Since a higher AC content and lower air voids provide better resistance to cracking, the lower FI for the field mixes can be attributed to the lower VMA content, which is known to be a fundamental volumetric property of any asphalt mix. Table 5 also shows that HMA samples have a higher cracking potential than WMA samples. This is probably due to the higher mixing/compacting temperatures of HMA which cause the binder to age more rapidly and reduction in penetration grade (as binder becomes stiffer) resulting in less flexible asphalt mixtures than the WMA mixtures.

Other parameters in Table 5 also demonstrate significant properties of the sample groups. The values of fracture energy indicated that they alone cannot represent the cracking potential of the mixes. HMA laboratory and field compacted samples had the highest fracture energy although they had the least cracking resistivity. The observation regarding the fracture energy can be justified the fact the HMA had steeper post-peak slopes and lower critical displacements than WMA samples, both of which lead to lower FI values. Additionally, HMA laboratory and field samples had higher peak loads due to their greater stiffness which resulted in higher tensile strengths for these two sample groups (considering that all sample groups have similar dimensional properties).

The impact of the amount of chemical additive on the cracking performance of WMA mixtures must also be taken into consideration. Table 5 shows that the FI values decreased slightly at higher dosages of Evotherm. This indicates that small amounts of WMA additive can decrease the cracking potential of WMA mixes to a certain extent, but it is not as influential as the effect of other mix properties such as AC content and percentage of air voids.

Table 5: Illinois Flexibility Index Test Results

Parameter	**Statistical Property**	**Laboratory compacted**				**Field compacted**
		HMA	**WMA 0.3%**	**WMA 0.5%**	**WMA 0.7%**	**HMA**
Fracture Energy (J/m^2)	Average	1698.0	1431.8	1390.3	1218.3	1677.0
	Minimum	1391.1	1073.9	1250.3	1096.0	1542.2
	Maximum	1868.6	1868.2	1794.3	2043.5	1818.7
	Standard Deviation	153.92	230.02	109.06	97.24	113.99
	Coefficient of Variation (%)	9.06	16.07	7.84	7.98	6.80
Peak Load (KN)	Average	2.32	1.83	1.80	1.59	2.37
	Minimum	1.96	1.65	1.68	1.39	2.11
	Maximum	2.52	2.20	2.00	1.79	2.59
	Standard Deviation	0.25	0.23	0.12	0.16	0.22
	Coefficient of Variation (%)	10.84	12.34	6.68	10.30	9.15
Post-Peak Slope	Average	-1.69	-1.15	-1.11	-1.03	-1.76
	Minimum	-1.37	-0.78	-0.97	-0.73	-1.50
	Maximum	-1.94	-1.43	-1.28	-1.32	-2.13
	Standard Deviation	0.24	0.24	0.10	0.27	0.27
	Coefficient of Variation (%)	14.06	21.13	9.01	26.37	15.46
Flexibility Index	Average	10.11	13.11	12.59	12.38	9.68
	Minimum	7.48	8.39	10.97	9.07	7.77
	Maximum	10.92	20.99	17.25	19.46	10.38
	Standard Deviation	0.87	4.46	1.52	2.76	1.27
	Coefficient of Variation (%)	8.60	34.03	12.05	22.30	13.15
Tensile Strength (Psi)	Average	46.28	36.69	35.54	31.78	47.17
	Minimum	39.91	33.24	33.43	28.05	42.06
	Maximum	49.90	44.22	39.74	34.95	51.42
	Standard Deviation	4.47	4.46	2.47	2.80	4.23
	Coefficient of Variation (%)	9.66	12.17	6.95	8.82	8.97
Critical Displacement (mm)	Average	2.99	3.35	3.26	3.16	2.96
	Minimum	2.63	2.87	3.04	2.87	2.63
	Maximum	3.19	4.33	3.75	3.37	3.18
	Standard Deviation	0.16	0.45	0.19	0.23	0.24
	Coefficient of Variation (%)	5.20	13.31	5.74	7.19	7.95

4.2 Rutting Test Results

The average results of the three replicates for the laboratory mixtures were used for comparison with the results of the single field core sample. In both cases, the average rut depth of the two specimens under the two wheels were used to represent the final rut depth value of a single test. The same concept was applied to evaluate the final results of the other HWTT output parameters. Field specimens were shown to withstand the desired number of cycles (10,000) in the HWTT before failure (12.5mm rut depth), thus the rut depth corresponding to 20,000 passes (10,000 cycles) was reported. On the contrary, no laboratory specimens could withstand the desired 10,000 cycles, and therefore, the test was stopped when the latter specimen reached the maximum allowable rut depth (12.5 mm). As a result, one of the samples in the HWTT will normally rut more than the other sample. Ultimately, the average rut depth at 20,000 passes was estimated by extrapolation for each laboratory sample group for a comparative analysis of the HWTT results. This was done via multiplying the average Stripping slope of the two specimens by the additional number of passes which is required to reach the desired number (20,000) of passes from the number of passes at failure and adding the result to the maximum allowable rut depth of 12.5mm. Figure 8 shows the HWTT curves of the four laboratory asphalt mixtures and the field sample.

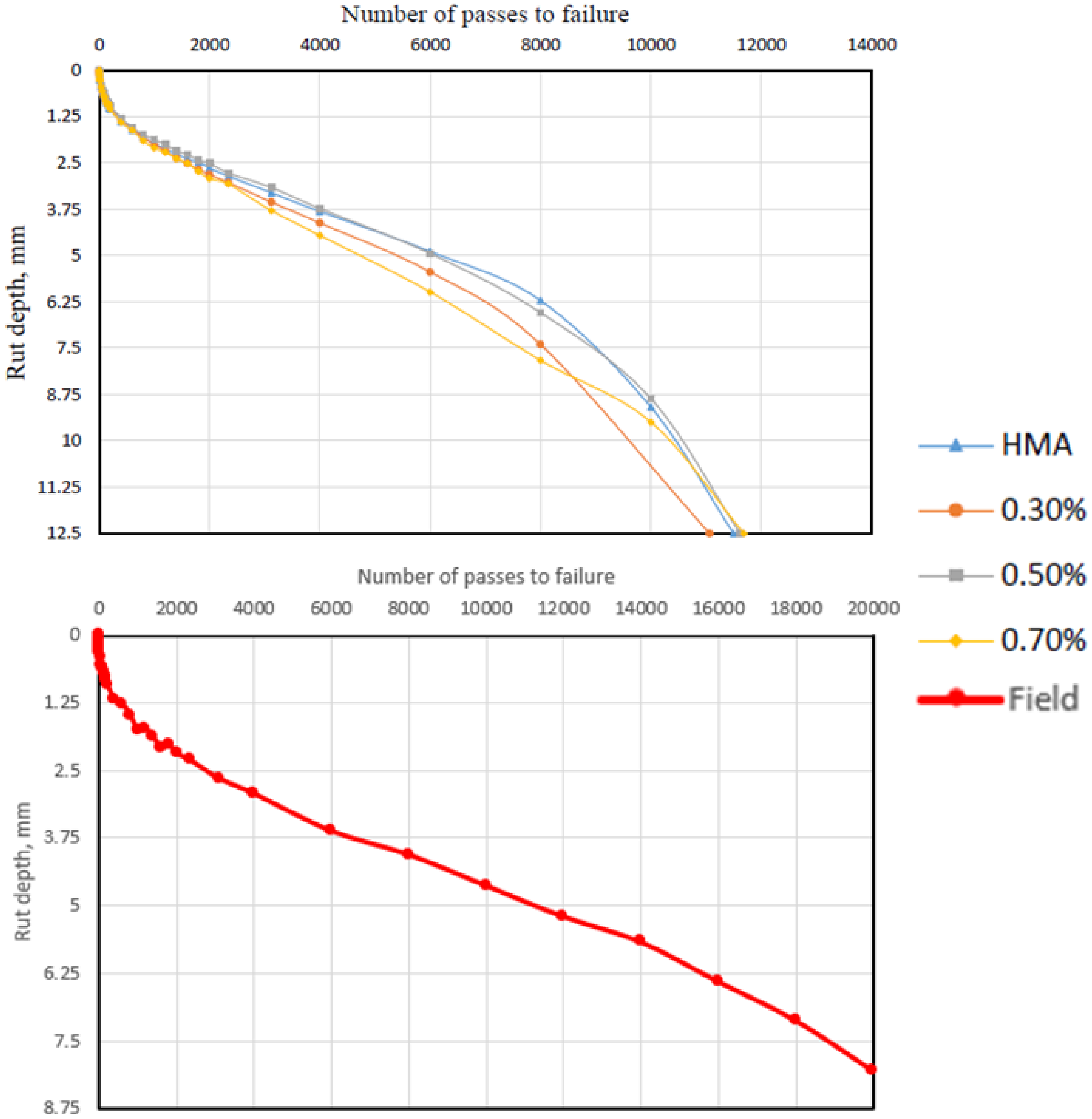


Figure 8: HWTT curves of laboratory mixtures (top) and field specimen (bottom)

The characteristics of the curves shown in Figure 8 are represented by the HWTT output parameters in Table 6.

Table 6: Hamburg Wheel-Tracking Test Results

Parameter	**Laboratory compacted**				**Field compacted**
	HMA	**WMA 0.3%**	**WMA 0.5%**	**WMA 0.7%**	**HMA**
Creep Slope (mm/pass)	0.000530	0.000619	0.000573	0.000657	0.000253
Stripping Slope (mm/pass)	0.00284	0.00269	0.00267	0.00210	0.000519
Number of passes to SIP	9394	8978	9513	9201	5529
Rut depth to SIP (mm)	6.61	7.00	6.73	7.39	6.28
Number of passes to failure (12.5 mm)	11499	11064	11619	11687	-
Equivalent rut depth at 20,000 passes (mm)	36.64	36.54	34.88	29.96	8.04

Table 6 shows that field samples had the best rutting performance at both 20,000 passes and SIP. This is because field samples were subjected to good compaction in the field, which caused a significant drop in their percentage of air voids and hence better rutting performance. For the laboratory prepared samples, WMA 0.5% mixes showed the least sensitivity to moisture as they were able to withstand the highest number of passes prior to stripping. Moreover, HMA mixes exhibited low moisture susceptibility due to a relatively high number of passes prior to stripping and the least creep slope of all laboratory prepared samples. This can be attributed to the stiffer binder of HMA mixes in comparison to WMA mixes. Stiffer binders are more viscous; hence they tend to improve the adhesion with aggregate. WMA 0.7% mixes showed the best rutting resistance after the start of stripping due to having the least stripping slope and their ability to withstand the highest number of passes to failure. In addition, WMA 0.5% mixes also showed a high rutting resistance after stripping. Finally, WMA 0.3% mixes exhibited the highest moisture susceptibility and the least rutting resistance of all laboratory prepared samples (i.e., the weakest performance both before and after stripping occurs). In conclusion, both moisture and rutting resistance were proved to improve at higher dosages of Evotherm. This is because the WMA additive improves the coating between aggregate and binder which causes a reduction in the stripping and rutting potential.

4.3 Balanced Mix Design

Balanced mix design (BMD) aims to depict the desired properties of asphalt mixtures based on the results of the two performance tests, namely rutting and cracking. Figure 9 shows the characteristics of the five sample groups included in this study based on the average rut depth at 20,000 passes and the range of FI.

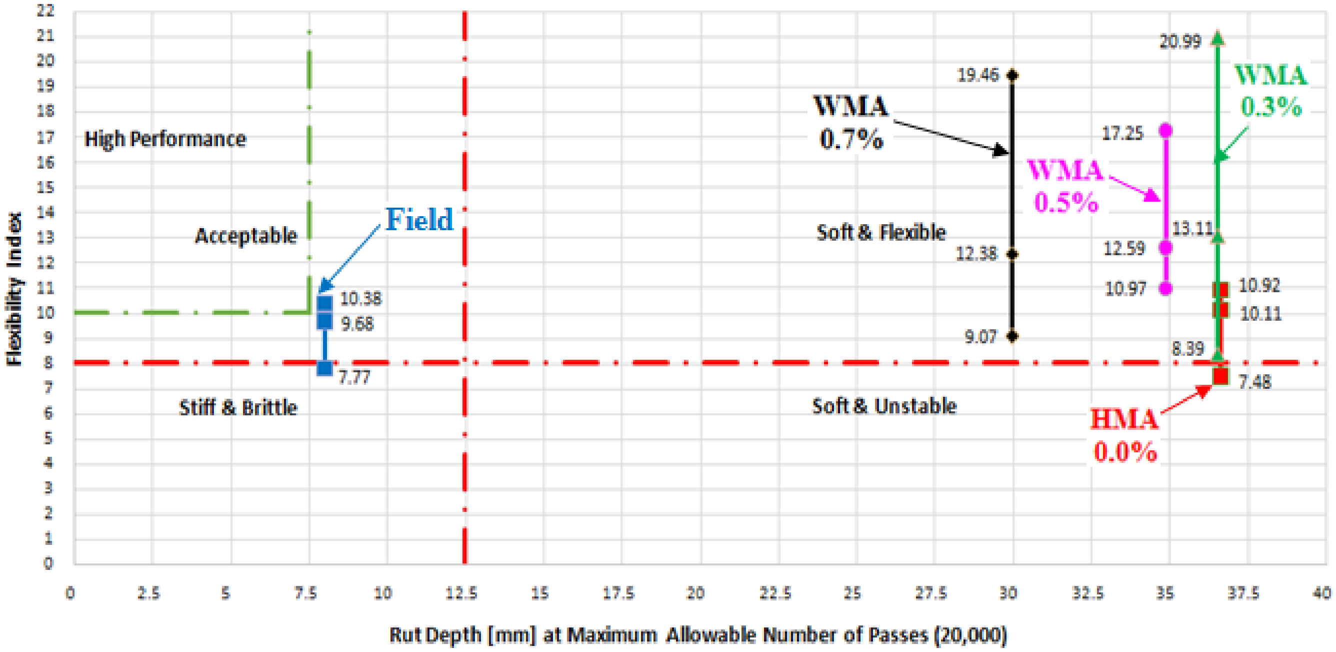


Figure 9: Performance quadrants of rutting and cracking tests results

The FI and rut depth thresholds are used to create the performance quadrants, as shown in Figure 9 were adopted from the Illinois Center for Transportation report 16-6872 [12] to assess the mixes used in this study. The ranges of rut depths were not taken into consideration in the assessment of asphalt mixtures because they did not impact the location of sample groups within the quadrant, unlike FI where the minimum value of FI interfered with other quadrants for the field and HMA sample groups.

Figure 9 shows that all laboratory sample groups are located in the soft and flexible region, which could mean that they all have high cracking resistance, but low rutting resistance. Only the field sample group is located in the stiff and flexible (i.e., acceptable) region, which could indicate that it has both a high cracking and rutting resistance.

5.0 Conclusions and Recommendations

Cracking and rutting performance of field and laboratory compacted asphalt mixture specimens were investigated using the I-FIT test and HWTT. Results showed that all mixes had relatively low cracking potential. Field specimens had very high rutting resistance probably due to high field compaction and reduced air voids. A low VMA content may contribute to a lower resistance to cracking. In addition, HMA mixtures exhibited a higher cracking potential than WMA mixtures probably due to their higher mixing/compacting temperature that accelerated binder aging. A higher quantity of Evotherm chemical additive to WMA mixtures was found to enhance rutting resistance, however its impact was not influential on the cracking resistance. Overall, cracking and rutting performance were shown to be inversely related where rutting resistance was shown to decrease with an increase in cracking resistance, as expected.

There is a need to test a broader range of mixtures to justify FI and rut depth thresholds according to local conditions such as environment and axle load spectra. This will enable road agencies to rank and optimize asphalt mixtures in terms of resistance to rutting and cracking.

6.0 References

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