Experimental Methods for Material Selection, Quality Control, and Forensic Investigations of Asphalt Paving Materials

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Abstract. The Minnesota Road Research Project (MnROAD) and the National Center for Asphalt Technology (NCAT) have formed a partnership to execute asphalt mixture performance testing experiments with a nationwide implementation impact. As part of this partnership, a pooled-fund study, called MnROAD Cracking Group (CG) experiment, was conducted to identify laboratory experiments that can best address low-temperature cracking performance. The construction of the test cells at MnROAD was done in 2016 and original binders and loose mix were collected and used to prepare testing specimens for laboratory experiments. In this paper, the viability of using three test methods for asphalt mixtures and one test method for asphalt binders in the material selection process, quality control, and forensic investigations of asphalt paving materials is discussed. These test methods are the Bending Beam Rheometer (BBR) for creep and strength of asphalt mixtures; low temperature SCB (Semi-Circular Bending) fracture testing for asphalt mixtures; |E*| (Dynamic Modulus) testing of asphalt mixtures using the IDT (Indirect Tensile) configuration; and BBR strength testing of asphalt binders. First, the materials used are described and the test methods are discussed. The experimental results are presented and statistical tools are used to identify significant factors in predicting low temperature cracking resistance of the set of asphalt materials used in the CG experiment. Conclusions are drawn based on preliminary field performance data.

Keywords: Asphalt mixture · Asphalt binder · Low temperature cracking · Test methods

1 Introduction

Low temperature cracking is the main distress in asphalt pavements located in cold temperature regions. Many test methods have been developed to evaluate the low temperature cracking resistance of asphalt materials. In this paper, the viability of four low temperature cracking resistance tests is investigated. The test methods are the Bending Beam Rheometer (BBR) for creep and strength of asphalt mixtures; low

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temperature SCB (Semi-Circular Bending) fracture testing for asphalt mixtures; |E*| (Dynamic Modulus) testing of asphalt mixtures using the IDT (Indirect Tensile) configuration; and BBR strength testing of asphalt binders.

First, the materials used are described and the test methods are discussed. The experimental results are presented and statistical tools, including analysis of variance (ANOVA) and Tukey's method, are used to identify significant factors in predicting low temperature cracking resistance of the set of asphalt materials used in the CG experiment. Based on the results from the statistical analyses and preliminary field performance data, recommendations are made regarding the use the experimental methods investigated.

2 Materials

The Minnesota Road Research Project (MnROAD) and the National Center for Asphalt Technology (NCAT) have formed a partnership to execute asphalt mixture performance testing experiments with a nationwide implementation impact. The construction of the test cells at MnROAD was done in the summer of 2016 and original binders and loose mix were collected and used to prepare testing specimens for laboratory experiments. Table 1 summarizes the information of the eight mixtures.

Table 1. Information of the Asphalt mixtures investigated

Cell no.	Binder	RAP %	RAS %	TotalAC %	Virgin AC %	NCAT Mix ID
16	PG 64S-22	20	5	5.27	3.17	30–40% ABR with RAS
17	PG 64S-22	10	5	5.43	3.94	20–30% ABR with RAS
18	PG 64S-22	20	0	5.43	4.20	20% ABR
19	PG 64S-22	20	0	5.70	4.46	20% ABR 100 gyration, 3.0% air void, 100 Ndes
20	PG 52S-34	30	0	5.32	3.47	35% ABR with PG 52S-34
21	PG 58H-34	20	0	5.38	4.15	20% ABR with PG 58H-34
22	PG 58H-34	20	0	5.73	4.5	20% ABR with LMS
23	PG 64E-34	15	0	5.23	4.31	20% ABR with PG 64E-34

Note: The data listed are the percentages by the total weight of mixture. RAP and RAS stand for reclaimed asphalt pavement and reclaimed asphalt shingle. AC stands for asphalt content. ABR stands for asphalt binder replacement. LSM stands for large molecular size binder.

3 Test Methods and Results

Four low temperature cracking resistance tests were investigated in this study. They are the BBR creep and strength test of asphalt mixtures; low temperature SCB fracture testing for asphalt mixtures; |E*| testing of asphalt mixtures using the IDT configuration; and BBR strength testing of asphalt binders.

The BBR creep and strength tests of mixture were performed according to the procedure proposed by Marasteanu et al. (2012). The results of this test include the creep stiffness, m-value, strength, and failure strain. Tests were conducted at three temperature levels, 0, −12, and −24 °C. Due to the limitation of space, only the results of creep stiffness and strength are shown in Fig. 1 and Fig. 2 respectively.

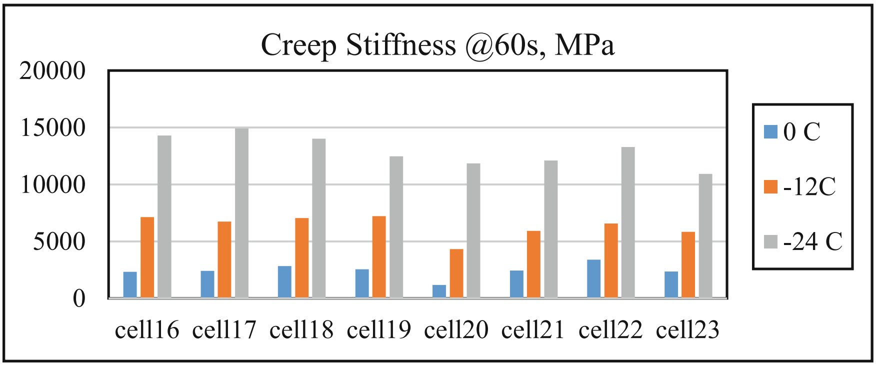

Fig. 1. BBR creep stiffness at 60 s of all mixtures.

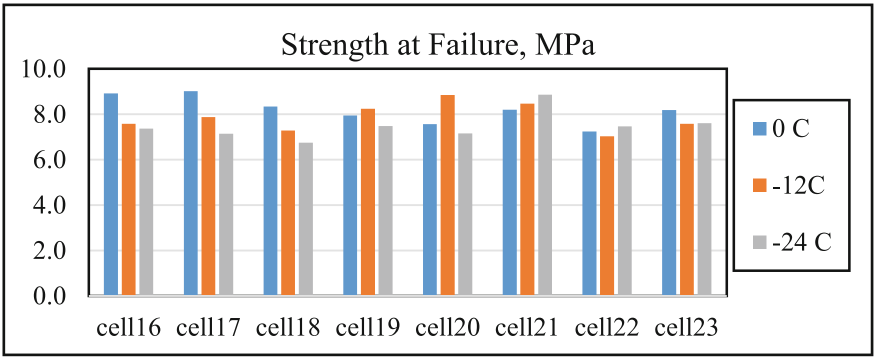

Fig. 2. BBR strength of all mixtures.

The SCB fracture tests were performed according to AASHTO TP-105 (2013). Tests were performed at two temperatures, −12 and −24 °C. Tests results include fractural energy and fractural toughness. The results of fractural energy are shown in Fig. 3.

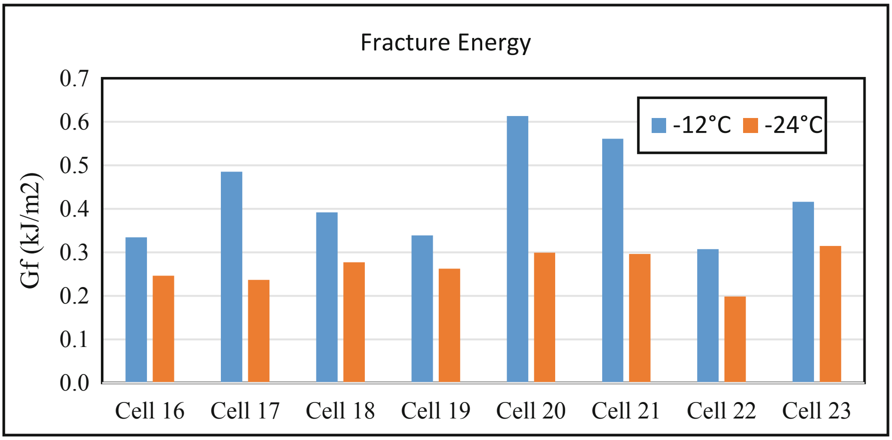

Fig. 3. SCB fracture energy for all mixtures.

The IDT |E*| tests were performed according to the procedure proposed by Kim et al. (2004). Tests were conducted at 12 °C. The results are shown in Fig. 4.

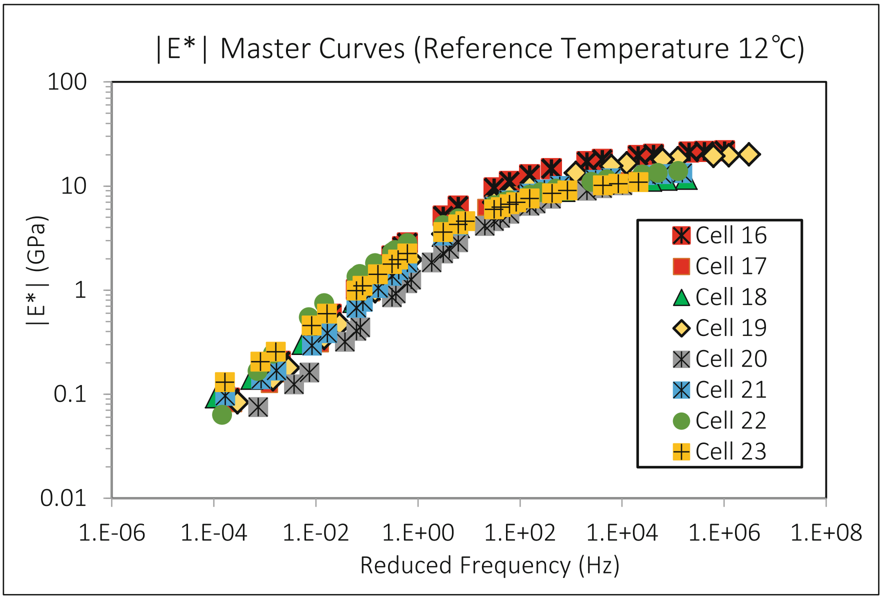

Fig. 4. IDT |E*| master curves of all mixtures.

The BBR creep and strength tests of binder were performed according to the studies of Marasteanu et al. (2017), and Matias et al. (2019). Tests were performed at two temperatures, the PG low temperature plus 4 °C (PGLT + 4) and the PG low temperature plus 10 °C (PGLT + 10). The creep stiffness and strength of the binders are shown in Fig. 5 and Fig. 6, respectively. Since cells 16, 17, 18 and 19 used the same binder, only the cell 16 binder was tested.

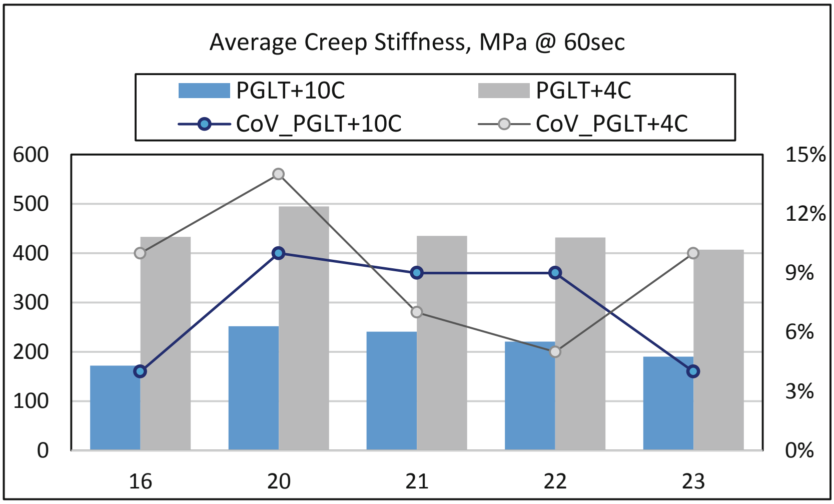

Fig. 5. BBR creep stiffness at 60 s for binders from Cell 16, 20–23.

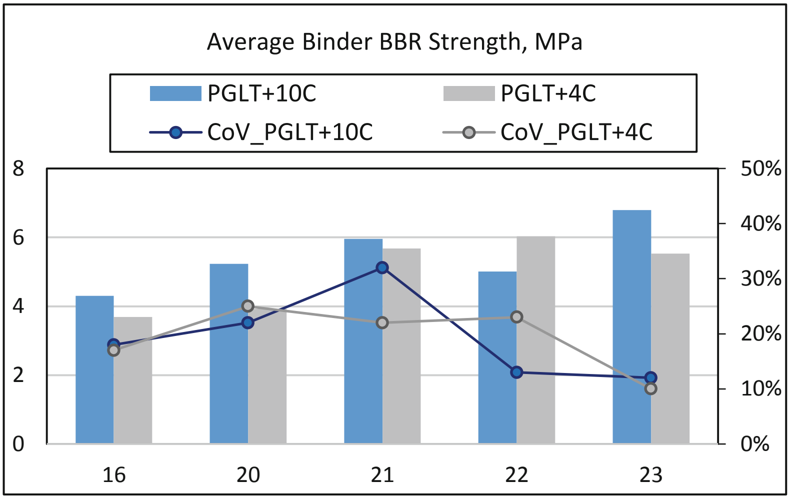

Fig. 6. BBR strength for binders from Cell 16, 20–23.

4 Data Analysis

Statistical analyses are performed to identify significant factors. The tools used include analysis of variance (ANOVA), Tukey's method, which represents a pairwise comparison technique, and correlation matrices based on Pearson's correlation.

4.1 Analysis of Variance

One-way ANOVA was performed to determine the statistical significance of the mixture properties. The significance level (α) was set at 0.05. The null hypothesis (H0) assumes that all the sample means are equal. The alternate hypothesis (Ha) states that at least one of the sample means is different. An example is given in Table 2 that shows the ANOVA results for the BBR Creep Stiffness at −12 °C.

Table 2. Summary and ANOVA results for creep stiffness at 60 s at −12 °C

Summary						
Groups	Count	Sum	Average		Variance	
Cell 16	6	40.08251	6.680419		0.519472	
Cell 17	5	34.7625	6.952501		0.570816	
Cell 18	5	35.19701	7.039402		1.194998	
Cell 19	6	42.14436	7.024061		0.575539	
Cell 20	5	22.49815	4.49963		0.562762	
Cell 21	5	26.10168	5.220336		0.396015	
Cell 22	5	32.7937	6.558741		0.122235	
Cell 23	5	29.15639	5.831278		0.10331	
Anova						
Source of variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between groups	32.2618	7	4.6088	9.0706	2.82E-06	2.2938
Within groups	17.2756	34	0.5081			
Total	49.5374	41				

The parameters in Table 2 are: Sum of Squares (SS), degrees of freedom (df), Mean Square (MS), F-value, P-value and F-critical. The degrees of freedom are obtained between groups (number of groups minus one) and within groups (number of total samples minus the number of groups). The Sum of Squares is calculated by adding the squared differences between the individual responses and the mean. The Mean Square is calculated dividing the Sum of Squares by the degrees of freedom and the F-value is calculated as the ratio of between-groups mean square to within-groups mean square (Oehlert 2000).

The F-value is greater than the F-critical value and the p-value is smaller than the alpha level selected (0.05). We can conclude that there is enough evidence to reject the null hypothesis and say that at least one of the eight cells has significantly different means and belongs to a different population. To identify these differences, Tukey's was performed.

4.2 Tukey Analysis

Since ANOVA only indicates if one or more mixtures have different means, it is necessary to run an additional test to find out the specific differences. Tukey's method, a pairwise comparison technique, was chosen because it constructs simultaneous confidence intervals for differences of all pairs of means and controls the probability of making one or more Type I errors (Oehlert 2000).

The confidence intervals and boxplot were generated for all mixtures and corresponding properties. The boxplot provides a visual interpretation of the confidence intervals in which mixtures are grouped according to their means; mixtures with the same color and letter belong to the same group. Figure 7 shows an example of the Tukey and boxplot results.

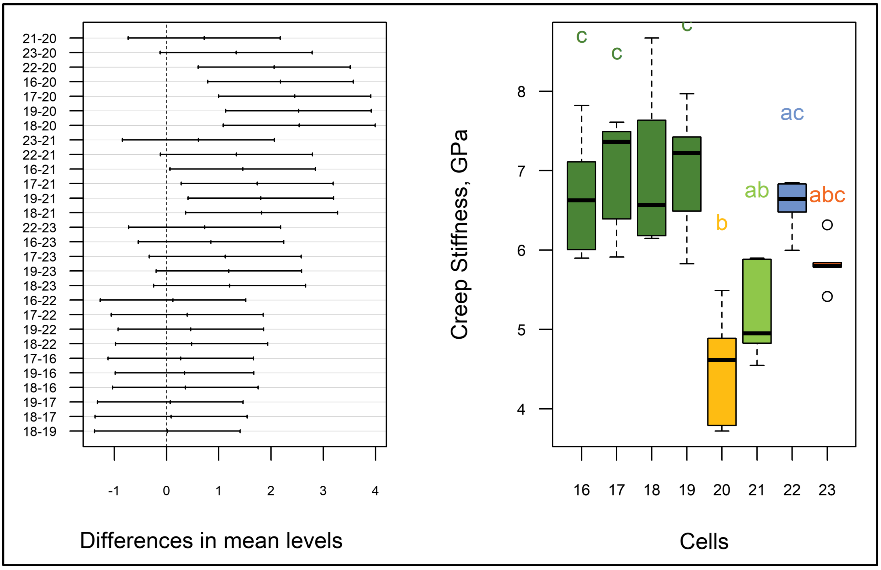

Fig. 7. (a) Confidence intervals (Tukey) for BBR creep stiffness at −12 °C.

5 Discussion

Through the ANOVA and Tukey analyses, the mixtures can be grouped by different tests at different temperatures. The results are summarized in Fig. 8.

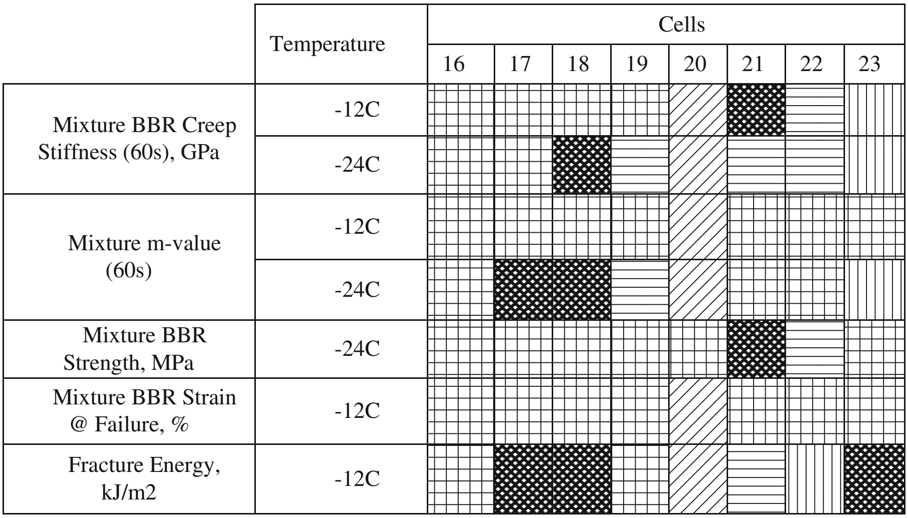

Fig. 8. Summary of boxplots for mixture results

As shown in Fig. 8 the testing methods investigated provide repeatable results that follow trends similar to the one observed using traditional methods. The results also show that the properties are highly temperature dependent and the ranking observed at one temperature can change at a different temperature. In addition, it is observed that materials with similar rheological properties, such as complex modulus absolute value |E*|, creep stiffness S, and m-value, do not necessarily have the same fracture resistance. These results confirm one more time the need for a fracture/strength test for correctly evaluating cracking resistance of asphalt materials.

As also shown in Fig. 8, in general, the mixtures used in this experiment have similar properties, which may indicate similar service performance. The only exceptions appear to be the mixture from cell 20 that has the highest RAP content and the mixture from cell 23 that contains a highly modified binder; for most properties evaluated, the two mixtures were each grouped separately from the other mixtures. The results also indicate that, for some properties, there is no clear separation between the mixtures prepared with the PG-22 binder and the mixtures prepared with the PG-34 binders due to the addition of RAP and RAS in the mix design.

6 Preliminary Field Performance Data

The MnRoad test cells 16 to 23 are located on the mainline of I-94 (westbound). Each test cell has a width of 38 feet (11.6 m) and a length of 500 feet (152.4 m). The average traffic volume on those cells was 696059 ESALs (equivalent single axle loads) per year after 2016. The average lowest air temperature in winter is approximately −30 °C.

The field performance of these sections has been closely monitored since their construction in 2016, and the results are summarized in Table 3. There is less than

5 mm of rutting in each section. The IRI values are below 95 in/mile and they have stayed consistent since construction. A wide array of cracking has developed in several of the sections, however, there is very little traditional low temperature transverse cracking that the experiment was intended to investigate. Cell 17 has the greatest amount of transverse cracks observed, while Cell 20 has zero transverse cracks. All sections have longitudinal construction joints (both centerline and driving lane-edge) cracking that were sealed in October 2019. Sections 17, 18, and 23 have significant amounts of fatigue cracking with pumping of base materials through the asphalt concrete. MnROAD is utilizing other tools to forensically identify the cause/and severity of cracking not related to material selection, such as: paver-mounted infrared cameras during construction, falling weight deflectometer testing, instrumentation embedded in the pavement structure (strain gauges, pressure cells, thermocouples, and moisture sensors), pavement cores, ground penetrating radar, and visual distress surveys. Although there is a large amount of cracking in these sections, the IRI is steady and in the “Good” category.

Table 3. Preliminary field data

Cell number	Load related		Construction related		LTC
	Fatigue	Longitudinal wheel path	Center line joint	Shoulder joint	Transverse
	(m^2)	(m)	(m)	(m)	(m)
16	5.3	36.3	121.9	137.2	17.7
17	62.5	24.1	149.3	152.4	21.3
18	33.7	26.5	152.4	152.4	10.7
19	1.6	10.7	141.4	133.2	18.6
20	1.3	3.4	52.4	0.0	0.0
21	7.9	14.3	152.4	20.7	8.5
22	21.3	78.6	152.4	152.4	15.2
23	135.4	101.8	152.4	152.4	13.1

7 Conclusions

In this study, four tests were investigated to evaluate the performance of asphalt pavements at low temperatures. It was found that:

1. The testing methods investigated provide repeatable results that follow trends similar to the one observed using traditional methods.
2. The properties are highly temperature dependent and the ranking observed at one temperature can change at a different temperature.
3. It was observed that materials with similar rheological properties, such as complex modulus absolute value |E*|, creep stiffness S, and m-value, do not necessarily have

the same fracture resistance. These results confirm one more time the need for a fracture/strength test for correctly evaluating cracking resistance of asphalt materials.

4. Preliminary field data confirms the general conclusion that cells should have similar performance. The exception is Cell 23 for which performance may have been affected by other factors that are not related to asphalt material mechanical properties.

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