Comparative Evaluation of New Hampshire Mixtures on Basis of Laboratory Performance Tests

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ABSTRACT:

A major challenge in flexible pavement design is incorporation of the long-term performance of mixtures under different in-service climatic and loading conditions which can result in different types of distresses such as rutting, fatigue, and thermal cracking. Different failure criteria have been proposed to evaluate and select the appropriate mixture for the pavement structure. This study characterizes 9 asphalt mixtures commonly used as wearing, binder and base layers in different regions of New Hampshire (NH) in the United States. Mixtures were characterized in the laboratory using the resilient modulus, complex modulus, S-VECD fatigue and semi-circular bend (SCB) tests. The performance of the mixtures was compared to general expectations from nominal properties of the mixtures such as binder grade, aggregate size, asphalt and RAP content and design traffic level. Two performance index failure criteria were selected for each distress type to rank the mixtures in terms of distress susceptibility. The performance index property values agreed well with nominal mixture properties in that stiffer mixtures revealed better rutting resistance while resulting in poor fatigue and thermal cracking performance and vice-versa. Study demonstrates need for balanced mix design to avoid distresses and using full rheological characterization, to explain the complexity of mixtures performance.

Keywords: Distress Ranking, Resilient Modulus, Complex Modulus, S-VECD Fatigue, Semi-Circular Bend (SCB)

1. INTRODUCTION

Asphalt mixtures are complex materials that are highly influenced by a number of parameters including the type and amount of binder, aggregate size and gradation [1]. Also, their performance is a direct function of temperature, loading frequency and mode of loading which may result in different types of distresses such as rutting, fatigue cracking and thermal cracking. Hence, it is important to design the proper mixture with respect to the conditions that the pavement will encounter during its service life. Since different types of distresses are related to specific failure mechanisms, the mixtures should be characterized and ranked through different characterization approaches. For instance, bottom-up fatigue cracking results from repeated tensile strains in the asphalt layer [2] while low temperature cracks initiate when the thermal stresses in the asphalt concrete approach the tensile strength of the mixture [3]. Researchers have developed different lab testing procedures and numerical models to predict the different distresses in asphalt mixtures [4]. Traditionally, resilient modulus has been used to characterize asphalt mixtures in terms of stiffness and strain recovery [5]. In the linear viscoelastic domain, the relationship between stress and strain can be fully described using the complex modulus (dynamic modulus, |E*|, and phase angle) [5]. The |E*| master-curve indicates the stiffness of the mix over a broad range of loading frequencies at a reference temperature and can be used as a tool to compare mixtures in terms of their behavior at different loading frequencies and temperatures. The phase angle master-curve reflects the relative extent of viscous and elastic response of the mix at a given temperature and frequency with higher phase angle generally indicating better cracking resistance [6]. The simplified viscoelastic continuum damage (S-VECD) fatigue approach is a mode-of-loading independent mechanistic model with which the fatigue cracking performance can be predicted under various stress/strain amplitudes [7]. The semi-circular bend (SCB) test is designed to capture cracking resistance of the mixtures. Fracture energy (G_f), defined as the amount of energy required to create unit fracture surface, is determined from the area under the load-displacement curve divided by fracture area [8] and the Illinois flexibility index (FI) is calculated through normalizing the fracture energy by the post peak slope at the inflection point [9].

The objective of this paper is to investigate the discriminability of different tests and rheological indices to rank the mixtures in terms of expected distresses with respect to general mixture design properties. Performance indices calculated from several lab tests related to three primary asphalt pavement distresses are shown in Table 1.

Table 1. Tests and Distress Criteria

Distress	Rutting		Fatigue		Thermal Cracking	
Related Test	Resilient Modulus	Dynamic Modulus at 1.59Hz & 40°C	S-VECD Fatigue	Complex Modulus at 15Hz & 12°C	Semi-Circular Bend (SCB)	Dynamic Modulus at 15Hz & -18°C
Performance Index	M_r at 25°C	|E*| (high temperature)	N_f @ G^R = 100	|E*| (intermediate temperature)	Illinois Flexibility Index	|E*| (low temperature)

2. RESEARCH APPROACH AND MATERIALS

This study includes nine asphalt mixtures as wearing, binder and base course with different aggregate size and gradation, binder type, and RAP content that are commonly used on New Hampshire highways. The specifications of the material used for characterization purposes is summarized in Table 2. It should be noted that the amount of RAP in the table is the percent virgin binder replacement. All the specimens in this study were produced using a gyratory compactor and were compacted to 6±0.5% air void level.

Table 2. Material Used for Characterization

Mix	ARGG-1	ARGG-2	W6428H	W5828L	W5834L	W7628H	B6428H	B5834L	BB6428L
Course	Wearing	Wearing	Wearing	Wearing	Wearing	Wearing	Binder	Binder	Base
Binder	58-28	58-28	64-28	58-28	58-34	76-28	64-28	58-34	64-28
NMAS	12.5	12.5	12.5	12.5	12.5	12.5	19	19	25
Asphalt (%)	7.8	7.6	5.4	5.8	5.4	5.4	4.8	4.6	4.8
Air Void (%)	5.4	3.0	3.5	4.3	6.9	6.2	5.2	4.9	4.4
Gyration	75	75	75	50	50	75	75	50	50
RAP (%)	0.0	6.6	18.5	17.2	18.5	18.5	20.8	21.7	20.8

2.1 Resilient Modulus

The resilient modulus test was conducted at 25°C in accordance with ASTM D7369-11 standard test method with three replicate specimens. The results from this test are shown in Figure 1. The error bars on the graph show one standard deviation. In general, the mixtures with higher stiffness are considered to be more prone to fatigue and thermal cracking. The overall trend of the results agrees well with the mixture properties such that the ones with stiffer binder and higher level of gyration resulted in higher resilient modulus values. For instance, it can be seen from the results that the ARGG-2 has a higher M_r value compared to

ARGG-1 which is mainly related to the difference in RAP percentage. According to mix properties W6428H is expected to have a higher modulus than W5828L, while the M_r values for both mixtures are very similar. One possible explanation is that the single testing temperature and single loading frequency is not able to capture the viscoelastic properties of the mixtures.

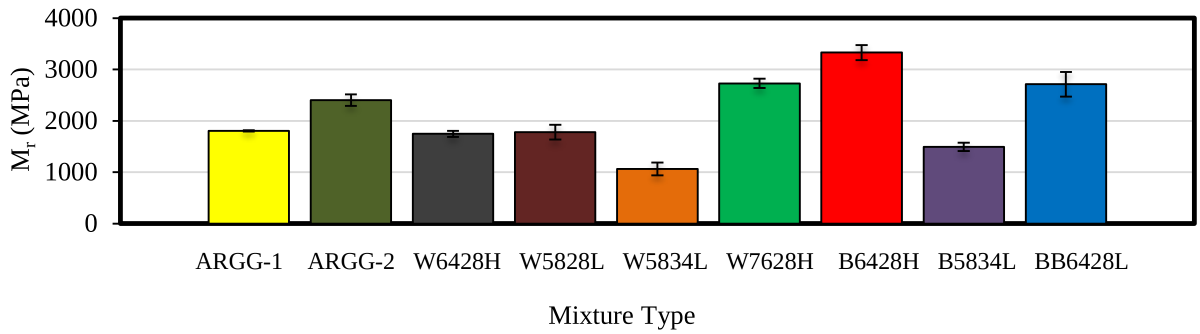

FIGURE 1. M_r Test Results

2.2 Complex Modulus

The complex modulus test was performed in accordance with AASHTO T342 standard using an Asphalt Mixture Performance Tester (AMPT) on three replicates. The master-curves were constructed at a reference temperature of 21.1°C using the time-temperature superposition principle. The rutting criterion was selected to represent high temperature and low frequency condition as a worst case scenario for rutting which still maintains the linear viscoelastic condition. The fatigue criterion was selected based on the average of recommend S-VECD fatigue test temperature selection by AASHTO TP 107 for majority of mixtures in this study. The thermal cracking criterion was selected to comply with the binder bending beam rheometer (BBR) test temperature selection for majority of mixtures in this study. The selected frequency for fatigue and thermal cracking is a representative of 90 km/h traffic speed.

The dynamic modulus master-curves and the |E* | distress criteria are depicted in Figure 2 and Figure 3 respectively. Overall, the results agree with the presumed distresses with respect to mixture specifications as mixtures with stiffer binder, bigger aggregate size, higher level of gyration and RAP content have higher |E* | at 40°C values and more rutting resistance. However, considering the low temperature criteria at -18°C the B5834L which contains a soft binder, the |E* | value is the highest among all. This might have been a result of relatively lower binder content in this mixture compared to the other mixtures.

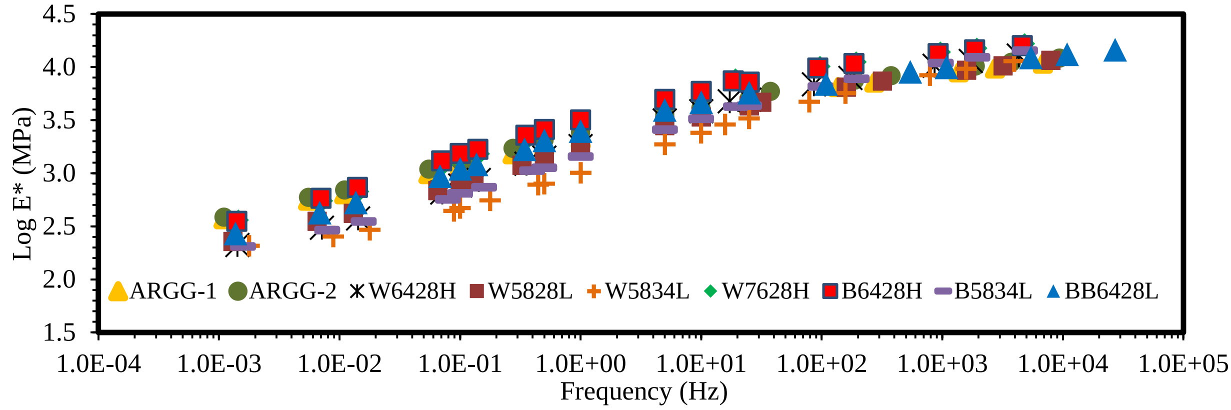

FIGURE 2. |E*| Master-curve (Reference Temperature = 21.1°c)

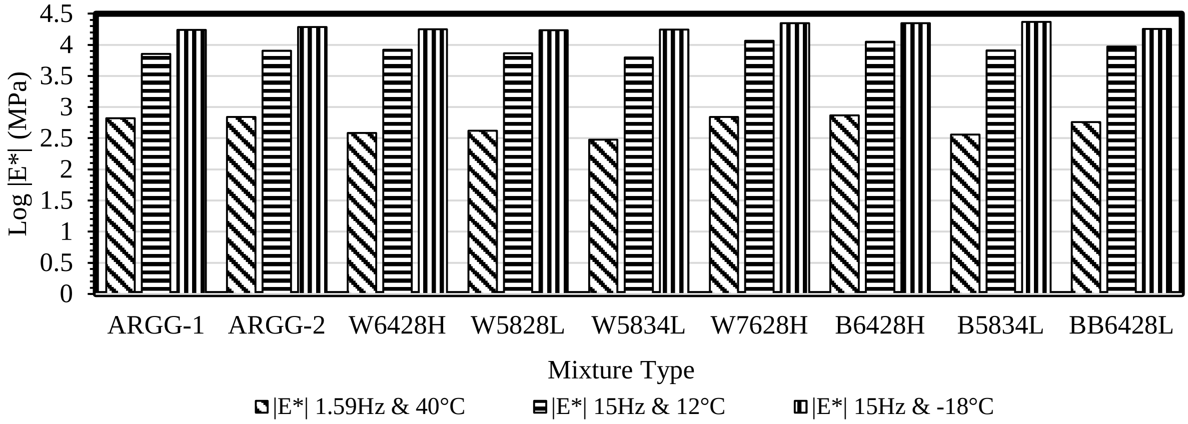

FIGURE 3. |E*| Distress Criteria Measurement

2.3 S-VECD Fatigue

The uniaxial fatigue test was performed in accordance with AASHTO TP 107 standard on four replicates. The results from N_f at G^R=100 (FIGURE 4) can be used to discriminate good and poor crack resistance of mixtures; mixtures with higher N_f values indicate better performance. The graph clearly reveals that the wearing courses have superior fatigue performance over the base and binder courses which agrees with general expectation from base course mixtures (bigger aggregate size and lower asphalt content) to have inferior cracking resistance. The results show consistency when compared to other performance test results such as complex modulus master-curves and the mixture properties depicted in Table 2.

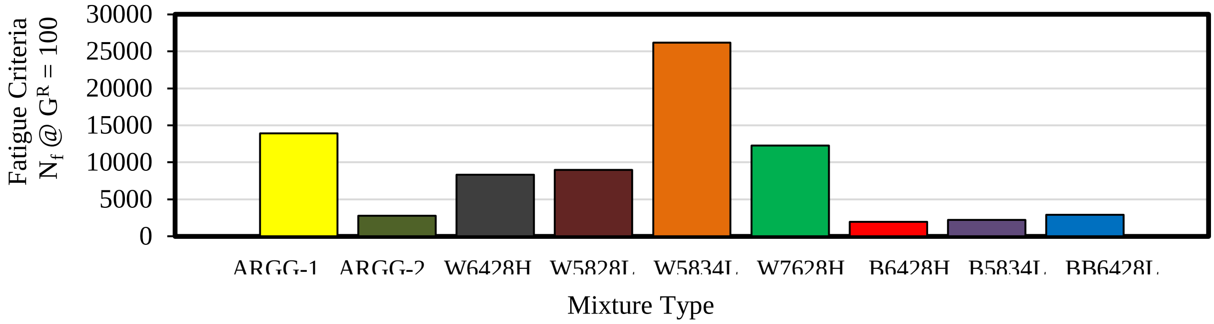

FIGURE 4. G^R-N_F Failure Criterion

2.4 Semi-Circular Bend (SCB)

Semi-Circular Bend test was conducted in accordance with AASHTO TP 105 standard. The results from fracture energy is depicted in FIGURE 5. The results indicate that fracture energy is not able to fully differentiate the cracking resistance of different mixtures. For example, as the previous test results indicated the ARGG-2 to be a stiffer mixture compared to ARGG-1 and is expected to have a lower cracking resistance. On the other hand, the results from flexibility index (FIGURE 6) agrees well with the other test results and crack resistance expectations.

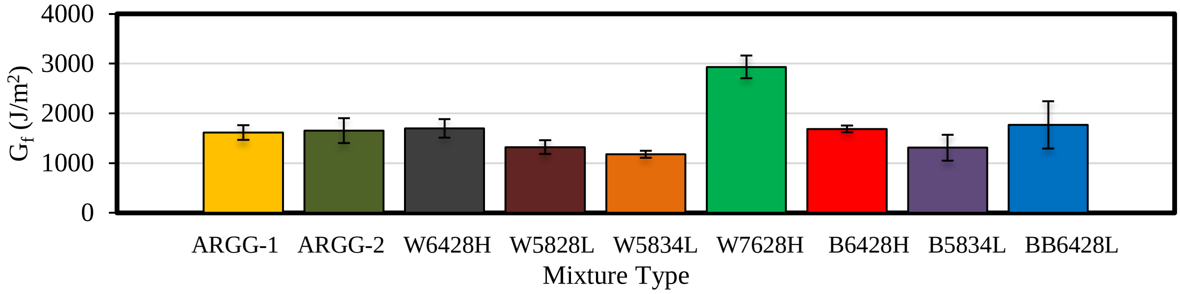

FIGURE 5. Fracture energy (G_f) plots

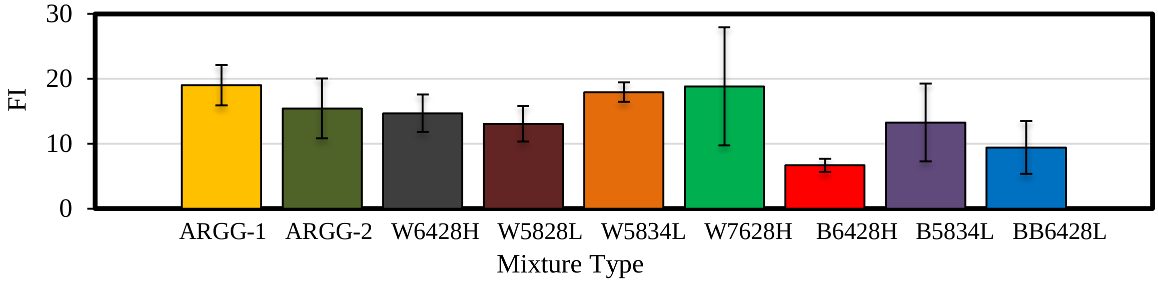

FIGURE 6. Flexibility Index Plots

3. MIXTURE PERFORMANCE RANKING

The mixture performance ranking is shown in Table 3. Mixture ranking was done in two ways: first using the individual criteria for each distress and second using the average of the two rankings for each distress (calculated using equations 1-3). The second process ranked some mixtures equally.

Rutting Rank = (Rank from |E* | 1.59Hz@40°C + Rank from M_r)/2 Equation 1

Fatigue Rank = (Rank from |E* | 15Hz@12°C + Rank from N_f @ G^R=100)/2 Equation 2

Thermal Cracking Rank = (Rank from |E* | 15Hz|@-18°C + Rank from FI)/2 Equation 3

Table 2. Mixture Performance Ranking

Test and Parameter		ARGG-1	ARGG-2	W6428H	W5828L	W5834L	W7628H	B6428H	B5834L	BB6428L
		Individual Criteria Ranking (9: Best; 1: Worst)								
Rutting	E* 1.59Hz 40°C	6	8	3	4	1	7	9	2	5
	M_r at 25°C	5	6	3	4	1	8	9	2	7
Fatigue	E* 15Hz 12°C	8	6	4	7	9	1	2	5	3
	N_f @G^R=100	8	3	5	6	9	7	1	2	4
Thermal Cracking	E*15Hz -18°C	8	4	6	9	7	2	3	1	5
	SCB (FI)	9	6	5	3	7	8	1	4	2
Distress		**Average Criteria Ranking (9: Best; 1: Worst)**								
Rutting		5	7	3	4	1	8	9	2	6
Fatigue		8	5	5	7	9	4	1	2	2
Thermal Cracking		9	4	6	7	8	4	1	2	3

The M_r and |E*| at 1.59Hz and 40°C rank the mixtures in similarly which confirms the capability of M_r test as a tool to assess the rutting susceptibility of the mixtures. The overall average rutting ranking also agrees well with the general expectations from the mixture properties. Mixtures with stiffer binder, lower asphalt content and higher level of gyration generally have better rut resistance except for the W6428H, this warrants more binder property and RAP quality investigation for that specific mixture. The two ARGG mixtures also reveal good rutting ranking which is expected due to the modification of the binder with crumb rubber.

The fatigue ranking from both criteria are close for most of the mixtures which indicates the good discriminability of |E*| at 15Hz and 12°C, this makes it a promising criterion with a simpler testing requirement. The overall fatigue ranking of the mixtures also agrees with the mixture properties. For example: the W5834L mixture, with a relatively softer binder and higher asphalt content is the best ranked. Although B5834L contains the same binder type and gyration level as W5834L, the bigger aggregate size (19mm), higher RAP percentage (21.7%) and relatively lower asphalt content (4.6%) resulted in poor fatigue ranking for this mixture.

Both of the ARGG mixtures show relatively good fatigue ranking with ARGG-1 as the highest ranked.

Although the ranking from the two selected criteria is very similar for four of the nine study mixtures, the results indicate substantial discrepancy between two thermal cracking criteria for remaining mixtures. The main reason for this difference between the ranks from the two criterion may initiate from the SCB testing temperature of 25°C, which might be too high for the wearing course mixtures with softer binders, while the other reason hypothesized as the closeness of |E*| at 15Hz and -18°C to the upper asymptote of the master-curve. However, the average ranking of the mixtures agrees well with the general expectations from the nominal properties. Interestingly, the thermal cracking ranks are very similar to ones from fatigue with minimal difference such that the mixtures with softer binder, higher asphalt content, lower gyration level and smaller aggregate size rank better than the others. The other compelling observation is the superior thermal cracking rank of ARGG-1, this is mainly anticipated due to the crumb rubber modified binder and its influence on the mixture's superior relaxation capabilities.

4. SUMMARY, CONCLUSION, AND FUTURE WORK

This research evaluated 9 asphalt mixtures commonly used in New Hampshire highways. Characterization of the mixtures was conducted through lab performance tests: resilient modulus (M_r), complex modulus (E*), S-VECD fatigue and Semi-Circular Bend (SCB). Certain distress criteria were selected from each test for further investigations to rank the expected performance of the mixtures and determine correlations between the mixtures performance and their nominal properties such as binder grade, aggregate size, binder content, RAP amount and traffic level (level of gyration) to verify if the performance complies with the general expectations of the mixtures properties. The observations of the test results and the selected distress criteria agreed well with the general expectations from the mixture properties. The following conclusions were made based on the results:

- Both the M_r at 25°C and |E*| at 1.59Hz and 40°C were observed to be capable of explaining the rutting susceptibility of the mixtures.
- |E*| at 15Hz and 12°C may offer a simpler criterion as compared to S-VECD testing and analysis for identifying the fatigue ranking of mixtures.
- The asphalt rubber gap graded mixtures (ARGG) are projected to exhibit very good cracking resistance, this was observed to be better for the mixture without RAP.
- As expected, all study criteria showed that mixtures with lower amount of binder and higher aggregate size have a potential for lower crack resistance.

This study only evaluated the dynamic modulus portion of complex modulus; it is critical to incorporate the effect of phase angle on the mixture performance ranking and future efforts should include additional rheological indices that utilize both dynamic modulus and phase angle. Furthermore, as a future step in characterizing the mixtures, it is necessary to track the field condition to evaluate suitability of mixture properties that prolong the pavement service life and also to verify the selected failure criterion in this study.

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