Impact of Asphaltenes on Permanent Deformation of Stabilized Base Course Using Asphalt Emulsion

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Paper prepared for presentation at
Green Technology in Roadway/Embankment Materials and Geotechnical Engineering

2021 TAC Conference & Exhibition, Online.

Abstract

The pavement base course has a significant impact on pavement long-term performance. One of the methods to improve pavement strength is stabilization of the base course with asphalt emulsion for an adequate response to traffic loading and weather condition. Regardless of the advantages of this method, asphalt emulsion stabilized materials usually suffer from low resistance to permanent deformation, and to overcome this problem, additives are added to the mixtures. Asphaltenes derived from Alberta oil-sands, which is a by-product of bitumen deasphalting process, could be used as an additive, and it is expected to enhance the mechanical properties of mixtures considering it to be a polar fraction of asphalt binder. This study investigates the application of asphaltenes-modified asphalt emulsion for stabilization of granular base aggregates. The effect of asphaltenes powder on the permanent deformation properties of the modified mixtures was studied through three different tests including Marshall stability and flow test, Hamburg Wheel-Tracking (HWT) and flow number tests. The test matrix included the samples with two asphaltenes contents (1 and 2% per total mix) for the same optimum emulsion content. The optimum emulsion content was found to be 3.7% according to the test matrix, while for asphaltenes, the optimum content was found to be 1%. According to the performance tests result, The Marshall stability test indicates that there is an increase of about 47.9% and 96.9% in stability values for 1% and 2% asphaltenes-modified mixtures, respectively. In addition, Marshall quotient and HWT test results indicate that modified mixtures are more resistant to rutting as compared to the unmodified mixtures. Rutting resistance index (RRI) increases about 140% for both asphaltenes contents. Flow number test results showed about an 81% decrease in deformation of modified samples in comparison to unmodified samples. Thus, the overall results show the resistance of asphaltenes-modified mixtures to permanent deformation was significantly greater than unmodified mixes.

Keywords: Cold mix asphalt, Base course stabilization, Asphalt emulsion, Asphaltenes, Permanent deformation.

INTRODUCTION AND BACKGROUND

Pavement construction uses unbound granular materials in high volumes. Base, subbase and lower layers contain a huge amount of these materials, and their properties are an important factor in ensuring a good pavement structure (Yideti et al., 2014). Stabilization of the base material in the pavement structure helps to increase the strength and stability of the layer. Improved base course results in well-supported pavement structures (Little & Nair, 2009; Wirtgen cold recycling manual, 2012; Wegman et al., 2017). Shear strength, stiffness, durability, resistance to fatigue and grade change restrictions are the different properties of the pavement that could be enhanced using stabilization of the base course in the asphalt structure (Branch, 2005). Increasing the thickness of the base layer is one way to strengthen this important layer (Christopher et al., 2006), but this process increases the time and cost and causes environmental problems such as using excessive amounts of materials.

Unbound material mainly contains the crushed stones and gravel, and this mixture transfers the load within the particles to the lower layers and subgrade (Wirtgen cold recycling manual, 2012; Yideti et al., 2014). Bounding this material increases the tensile strength, which unbound materials lack due to the nature of the structure (Brown, 1996; Adu-Osei, 2001). Using asphalt emulsion to stabilize the unbound layers has advantages such as low-temperature application, less energy consumption, lower emissions and less hazard compared to hot mix asphalt. More importantly, this material is more environmentally friendly than cutback asphalts (Salmon, 2006; Asphalt Institute, 2008). Higher shear strength, stiffness, durability and moisture susceptibility are expected from the asphalt emulsion stabilized materials (Branch, 2005). However, longer curing time with lower early performance are disadvantages of stabilized mixes with asphalt emulsion. Another important disadvantage of asphalt emulsion stabilization is the lower rutting resistance of the layers (Khweir et al., 2004; Du, 2016; Du, 2018).

Overcoming the disadvantages of stabilized layers requires considerable attention, and active fillers such as cement, lime and fly ash have been found to increase the performance properties (Little and Nair, 2009; Wegman et al., 2017; Patel, 2019). These materials provide higher mechanical properties, stiffness modulus, permanent deformation resistance, moisture susceptibility, and fatigue strength (Brown and Needham, 2000; Hodgkinson and Visser, 2004). Retained strength is also an important factor in some materials stabilized by asphalt emulsion. Active fillers such as hydrated lime or cement in an amount of 1% by mass could be added to these mixtures. These active fillers affect the breaking of asphalt emulsions and enhance the retained strength and moisture resistance for asphalt emulsion stabilized material (Wirtgen cold recycling manual, 2012; Fang et al., 2016). On the other hand, these additives, such as cement and lime, have negative effects like slow strength gain, high curing time, and environmental hazards due to the nature of their production (Gutierrez et al., 2012; Fang et al., 2016; Modarres and Ayar, 2016).

Jiang et al. (2020) indicated that asphalt emulsion stabilization has a lower rutting resistance, which needs improvement, and polymer modification could significantly improve this property. Dynamic modulus and flow number tests were two of the main tests that confirmed this result. Modarres and Ayar (2014) studied the performance of adding coal waste and ash in recycled asphalt using asphalt emulsion. They added the coal waste and ash to the asphalt emulsion stabilized mixture and conducted Marshall stability, tensile strength and resilient modulus tests. Results showed that coal waste and ash both increase the Marshall stability and resilience modulus. However, moisture resistance was not significantly affected by coal waste, unlike the ash. Yan et al. (2014) studied the performance properties of asphalt emulsion cold recycling process using reclaimed asphalt pavement (RAP) and cement. Marshall stability, indirect tensile strength and dynamic modulus of the mixtures were evaluated, and results indicated that RAP and cement would improve the high-temperature properties of mixtures, as well as moisture susceptibility and fatigue performance. This encourages the use of different additives and materials in the stabilization and evaluation of their performance effect. Yan et al. (2015) specifically focused on the dynamic modulus result of the cold recycled material with virgin limestone and cement. Results were promising, showing that high temperature and low frequency of mixture were significantly affected.

Asphaltenes extracted from the Alberta oil sands is one of the materials that does not have any significant application in the pavement industry. Asphaltenes is a part of polar components of the asphalt, which is responsible for the viscous properties (Sultana and Bhasin, 2014). Saturates, aromatics, resins and asphaltenes are the main components of the asphalt and they are abbreviated as SARA. Resins are also part of polar components, unlike the aromatics and saturates that are non-polar (Xu et al., 2019). As the result, it is expected that increasing the polar components could increase the stiffness of the material (Sultana and Bhasin, 2014; Xu et al., 2019). Additional to the performance improvement, the lower cost of using asphaltenes and more environmentally friendly use of this material in comparison to similar additives such as cement is an important advantage.

OBJECTIVES AND METHODS

The main objective of this study is to investigate the impact of the addition of asphaltenes on the permanent deformation of stabilized mixes using asphalt emulsion. In this study, a cationic slow setting (CSS-1H) asphalt emulsion was selected to stabilize a well-graded granular base course using asphaltenes as an additive in the asphalt emulsion. One source of asphaltenes derived from Alberta oil sand bitumen was used. Asphalt Institute (2008) was used for the mix design. In this research, Marshall stability and flow, Hamburg wheel tracking, and flow number tests were conducted to study the permanent deformation properties of asphaltenes modified mixtures in comparison to the unmodified control samples.

MATERIALS AND EXPERIMENTAL PROCEDURES

Three phases of the experimental program have been conducted in this study. In the first phase the aggregate gradation, optimum emulsion content (OEC) and optimum moisture content (OMC) for compaction has been determined. The second phase contains the Indirect Tensile Strength (ITS) and Marshall stability and flow tests in order to evaluate the strength and stability of the mixtures prepared. As for the third phase, resistance to permanent deformation of the mixtures was evaluated using the Marshall stability, Hamburg wheel tracking and flow number tests.

Aggregates

A single source of aggregate was used to prepare the mixtures in this study. Limitations and envelopes were provided by Wirtgen Cold Recycling Manual (2012), Alberta Transportation documentation (Soliman et al., 2014) and City of Edmonton (2012) regulations as shown in Table 1. A well-graded aggregate gradation was selected in order to satisfy the limitation provided in Table 1.

Table 2 presents the selected aggregate gradation with skeleton consisting of 57.27% coarse aggregates, 36.73% fine aggregates and 6% filler. Additionally, bulk specific gravity (G_{sb-agg}) of the aggregates batch was determined as 2.601.

Table 1 Aggregate distribution limits

Size	Edmonton		Wirtgen		Alberta	
	Min (%)	Max (%)	Min (%)	Max (%)	Min (%)	Max (%)
50	-	-	100	100	100	100
37.5	-	-	87	100	96	99
26.5	-	-	76	100	70	94
20	100	100	65	100	61	88
16	-	-	-	90	55	85
12.5	60	96	55	80	-	-
9.5	-	-	48	70	43	73
6.7	-	-	41	62	-	-
5	36	75	35	47	31	61
2	24	54	25	36	22	49
1.25	20	43	18	27	-	-
0.63	14	34	12	24	-	-
0.4	11	29	10	21	10	29
0.315	9	26	8	16	-	-
0.16	6	20	3	10	-	-
0.08	2	10	2	-	2	10

Table 2 Determined aggregate gradation

Sieve size (mm)	% Passing	% Retained	Coarse-Fine	
20.000	100	0.00	57.27%	Coarse
12.500	75	24.83		
10.000	61	13.94		
8.000	55	6.23		
6.300	48	7.00		
5.000	42	5.27		
2.500	32	10.65	36.73%	Fine
1.250	25	6.47		
0.630	18	6.68		
0.315	13	5.93		
0.160	9	4.00		
0.080	6	3.00		
Filler (Pan)	0	6.00	6%	Filler

Table 3 presents the aggregate tests performed in order to determine the physical properties of the gradation selected. Wirtgen Cold Recycling Manual (2012) and City of Edmonton (2015) were used to define the limits for the amount of filler used in the stabilization of the granular base layers and Los Angles test for aggregates selected.

Table 3 Physical properties of the aggregates

Property (unit)		Standard	Result	Limitation
Amount of material finer than 75-µm (No. 200) sieve in aggregate (%)		ASTM C117	6	2-9
Fine aggregates	Specific gravity (G_{fa})	ASTM C128	2.604	-
	Absorption of water (%)		0.624	
Coarse aggregates	Specific gravity(G_{ca})	ASTM C127	2.598	-
	Absorption of water (%)		0.870	
Abrasion of coarse aggregates (%)		ASTM C131	23	Max 40
Proctor test	OMC (%)	ASTM D698	6.3	-
	Dry density (kN/m^3)	(Modified D1557)	15.4 max.	-

Optimum moisture content (OMC) for aggregates was determined by proctor test based on ASTM D698. OMC is necessary for the calculation of the extra water that aggregates need to mix with the asphalt emulsion. Figure 1 presents the dry density of the compacted aggregate gradation with different water contents and determined to be 6.3%.

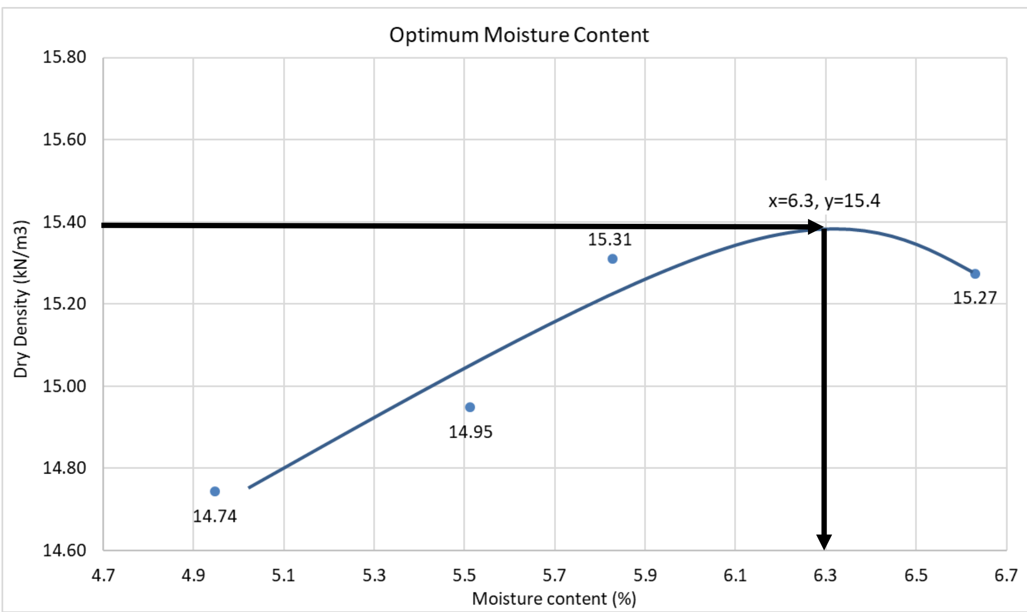

Figure 1 Proctor test results

Asphalt Emulsion

Cationic slow setting asphalt emulsion is the typical material used in base stabilization. The slow setting emulsion has the workability and time to disperse in the mixture and provides higher stability. A hard binder (penetration grade of 85-100) with a proportion of 61% asphalt and 39% water was used to prepare a CSS-1H asphalt emulsion for this study. Properties of the asphalt emulsion are stated in Table 4.

Table 4 Asphalt emulsion properties (Husky Asphalt, 2019)

Property (unit)	Standard ASTM/AASHTO	Specification		Typical Analyses
		Min.	Max.	
Tests on Emulsion				
Specific gravity (Density) at 15.6˚C (kg/L)	T59	-	-	1.020
Residue by distillation (% by mass)	T59	57	-	61
Viscosity at 25˚C (S.F.S)	T59	20	100	22
Oversized particles (sieve) (% by mass)	T59	-	0.3	0.008
Settlement (24 hours) (% by mass)	T59	-	1.0	0.5
Particle charge test	D7402	Positive		Positive
Tests on Asphalt Residue				
Penetration at 25˚C (100 g, 5 s) (dmm)	T49	40	125	95
Ductility at 25˚C (5 cm/min) (cm)	T51	40	-	>40
Solubility in Trichloroethylene (% by mass)	T44	97.5	-	>97.5

Asphaltenes

A single source of asphaltenes was used to prepare the samples in this study. It was provided in Solid form (Figure 2a), crushed into powder and sieved through the No. 100 mesh sieve (Figure 2b) and used in the mixture. SARA result were measured for the sample provided and results are presented in Figure 3.

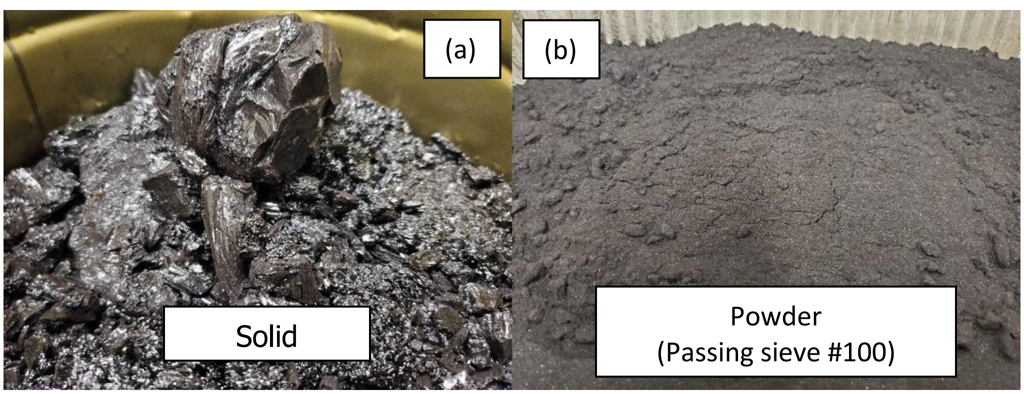

Figure 2 Asphaltenes provided for mixing solid form (a), powder (b)

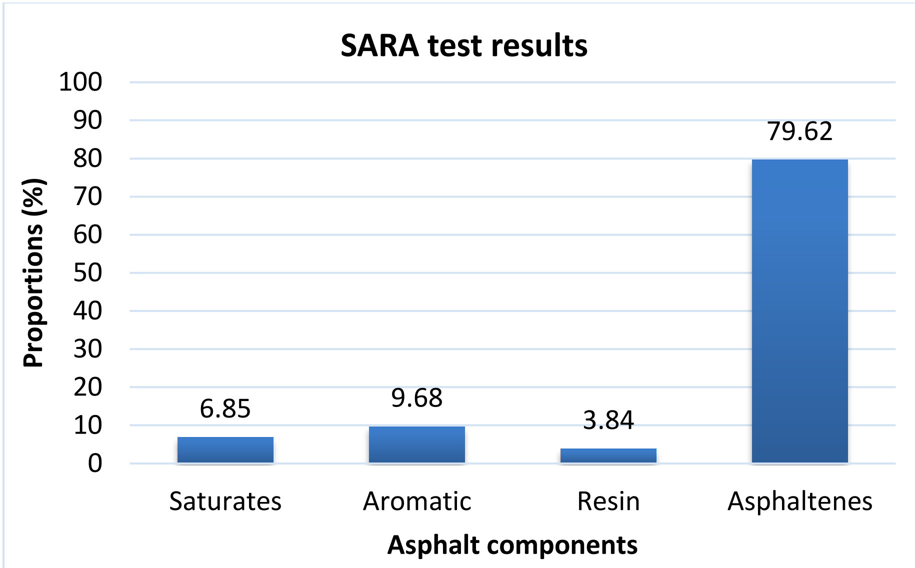

Figure 3 Asphalt binder components using SARA test

MIXTURE PREPARATION AND DESIGN MATRIX

Design Matrix for Optimum Emulsion Content

Since there is no specific standard for base course stabilization, the Asphalt Institute (2008) standard was selected to prepare the mixtures. A well-graded granular aggregates were selected and Asphalt Institute (2008) method was followed. Asphalt emulsion to be used in this method was calculated with respect to Equation 1, which is suggested for the aggregate gradation. This equation requires the result of the ASTM D6997 test. The test result indicates that the amount of the material retained after distillation is 61%.

$$\text{Base mixture: Asphalt Emulsion } \% = \frac{(0.06\text{B} + 0.01\text{C})100}{\text{A}} \qquad \textbf{(1)}$$

Where:

A = Percentage of the residue of asphalt emulsion remaining after distillation

B = Percentage of dry aggregate passing through a No. 4 sieve

C = Percentage of dry aggregate retained on a No. 4 sieve.

The approximate asphalt emulsion content was calculated to be 5.14% per total aggregates and four different asphalt emulsion contents with 1% intervals were prepared for determination of optimum emulsion content (OEC). Marshall stability and flow and ITS tests were conducted to determine the OEC and results are presented in Figures 4 and 5. Table 5 states the design matrix prepared and tested for both tests.

To prepare the mixtures, additional water was mixed with the oven-dried aggregates after cooling down to room temperature to reach the OMC. This prevented the aggregates from losing moisture. Asphalt emulsion was introduced to the uniformly mixed aggregates with water and compacted using the Marshall hammer with 50 blows per each side. Compacted samples were cured afterwards for 48 hours in an oven at 60˚C. Finally, samples were extracted from the molds following the curing process. A two-hour cooling down period was allocated to the samples before demolding and after the curing process was complete.

Marshall stability tests were conducted on the samples after three hours of conditioning in the air bath at 25˚C (Asphalt Institute, 2008).

Table 5 Emulsion and additional water contents for design matrix

Emulsion content (% per aggregates)	Additional water (% per aggregates)	Emulsion content (% per total mixture)
3.14	5.1	3.04
4.14	4.7	3.98
5.14	4.3	4.89
6.14	3.9	5.78
7.14	3.5	6.66

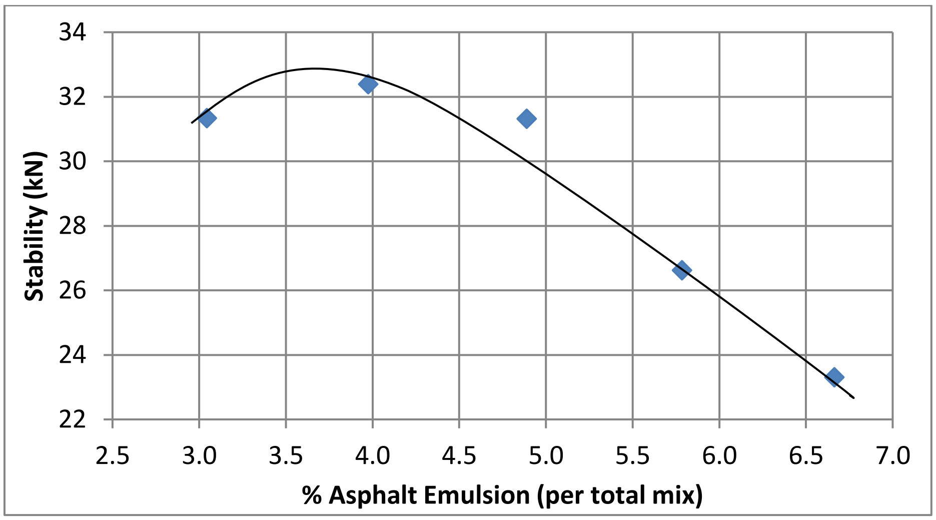

Figure 4 Stability vs. Asphalt emulsion content

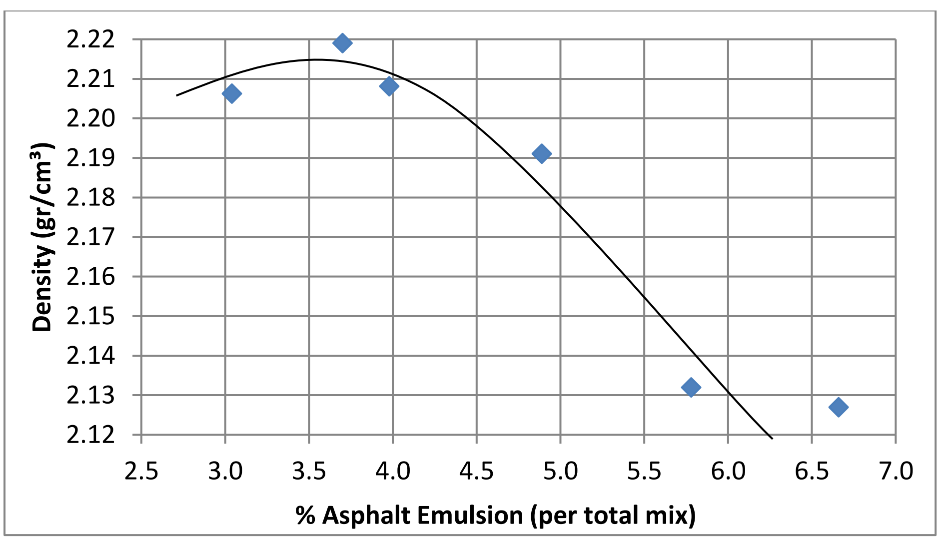

Figure 5 Density vs. Asphalt emulsion content

The minimum acceptable Marshall stability for stabilized base courses was determined to be 2.2 kN for low-volume roads. However, it has been recommended to adjust the minimum value based on the mix type and its application (Asphalt Institute, 2008). According to the results, the maximum Marshall stability and density values were achieved at an asphalt emulsion content of 3.7% per total weight of the mixture. Hence, this amount was considered to be the optimum emulsion content (OEC) with respect to the Marshall stability test. However, to confirm this result, additional samples were prepared and ITS tests were also conducted to determine the OEC as suggested by several researchers (Du, 2016; Wirtgen cold recycling manual, 2012). Results from both test considered to finalize the optimum emulsion content.

Samples for the ITS test were prepared using same asphalt emulsion concentrations plus 3.7% per total weight of mixture. These concentrations were chosen to ensure consistency with the results of the Marshall stability test. Three samples were prepared for each asphalt emulsion concentration. The samples were prepared using the same procedure as for the Marshall stability test. In addition, the same curing and conditioning processes were utilized and AASHTO T283 was used to conduct the test. After conditioning the samples, a load at a rate of 50 mm/min was applied to the samples. The maximum load applied to the sample before it failed was recorded to determine the indirect tensile strength according to Equation 2.

$$S_t = \frac{2000P}{\pi t D} \quad \textbf{(2)}$$

Where:
S_t = Indirect tensile strength (kPa)
P = Maximum applied load (N)
t = Average height of the specimen (mm)
D = Diameter of the specimen (mm).

Figure 6 presents the ITS results for the mix design samples and verifies that the maximum value was achieved after adding 3.7% of asphalt emulsion by weight of the total mix. This test confirmed the results of the Marshall stability and OEC determined to be 3.7% by weight of total mixture.

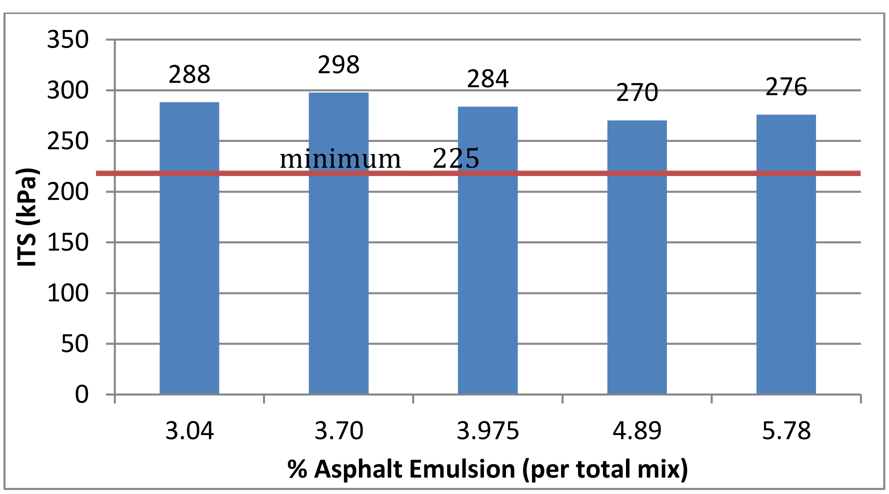

Figure 6 ITS results for mix design samples

Design Matrix for Asphaltenes Modified Samples

In order to add asphaltenes into the mixture, optimum emulsion content was selected as the constant content for all the mixtures. Control samples were also prepared with the same process of OEC and without any asphaltenes to compare with the modified samples.

Asphaltenes were added to the asphalt emulsion for the modified samples before mixing it with the wet aggregates. This mixing process was selected due to the ease of mixing as compared to adding it to the aggregates. Samples were prepared by adding 1%, 2% and 3% of asphaltenes by total mixture weight into the asphalt emulsion and then mixed with wet aggregates. During preparations, it was found that adding 1% of asphaltenes to the emulsion is relatively easy for mixing and compaction.. However, increasing the asphaltenes contents caused problems by fast breaking the emulsion and causing difficulty for mixing. To overcome this issue, more water was added to the asphalt emulsion in order to make it less viscous and easy to mix. Hence, 25% and 50% water by total weight of asphalt emulsion was then selected to be added to the emulsion prior to the mixing with asphaltenes. Table 6 presents the ITS results for modified samples with different asphaltenes and additional water contents, and Figure 7 presents the samples after the ITS test. It was observed the addition of extra water to the samples with 2% asphaltenes, would result in lower tensile strength. Hence, 25% extra water was chosen for the sample preparation. It can also be observed in table 6 that the addition of 3% of asphaltenes did not change the ITS value significantly. Hence, the maximum asphaltenes cotent was limited to 2% in this study. Sample IDs are defined as SX-Y-Z where SX is the asphaltenes source used. Y indicates the asphaltenes content in the mixture (1%, 2%, and 3%), and Z provides the amount of extra water added to the asphalt emulsion during the mixing process (0%, 25%, and 50%).

Table 6 Design matrix for Asphaltenes modification

Sample ID	Asphaltenes (% per total mix)	Extra water (% per total emulsion)	ITS (kPa)	Air voids (% per total mix)
Control	0	0	298	10.934
S1-1-0	1	0	613	12.187
S1-2-25	2	25	873	12.994
S1-2-50	2	50	785	14.534
S1-3-50	3	50	813	17.907

Figure 7 Compacted samples by Marshall hammer after performing ITS test

PERFORMANCE TESTS AND RESULTS

Permanent deformation of the base course was studied in this research, and in order to evaluate that Marshall stability and flow, Hamburg wheel tracking and flow number tests were conducted. Selected samples in this phase of the research were Control, S1-1-0, and S1-2-25 due to the reasons explained.

Marshall Stability and Flow Test

Marshall stability and flow tests were conducted with respect to ASTM D6927-15. Samples were tested after conditioning them in the water at 60 ˚C for 40 minutes. The average values for stability, flow and density of the samples from Marshall test are presented in Table 7. Marshall quotient was calculated as the ratio of stability and flow number for each sample. As shown in the results, increasing the asphaltenes content will result in a slight increase for air voids and density will decrease accordingly. Additionally, comparing Marshall stability of different samples indicated increase in stability about 47.9% and 96.9% for 1% and 2% asphaltenes, respectively. In addition, Marshall quotient values indicate that asphaltenes increase the stiffness of modified samples in comparison to the control sample. This increase is about 55.8% and 46.2% for 1% and 2% asphaltenes, respectively. Figure 8 shows the samples after Marshall stability and flow test.

Table 7 Marshall test results and air voids

Sample ID	Stability (kN)	Density (gr/cm3)	Flow (mm)	Marshall Quotient (kN/mm)	Air voids (% per total mix)
Control	11.536	2.197	5.545	2.08	11.113
S1-1-0	17.059	2.150	5.263	3.24	11.395
S1-2-25	22.718	2.143	7.482	3.04	12.574

Figure 8 Samples after performing Marshall stability test

Hamburg Wheel Tracking Test

Hamburg wheel tracking tests were performed using AASHTO T324-19. Slab samples were prepared with dimensions of 400 mm length, 300 mm width and 80 mm height with respect to the maximum nominal size of the aggregates. A slab compactor was used to prepare the selected unmodified and modified samples, and a similar curing process used for Marshall samples was followed. Test temperature was determined to be 40 ˚C with respect to the asphalt emulsion binder grade and application of the layer as a base course. Preconditioning of the samples for 45 minutes before testing was performed, and a 705 ± 4.5 N, 47 mm-wide steel wheel with a frequency of 52 ± 2 passes per minute and a maximum speed of 0.305 m/s at midpoint was used to run the test. The termination point of the test was set at 20,000 passes or a 12 mm rutting depth, whichever was achieved first. Results presented in Table 8 and Figure 9 include the striping inflection point (SIP) and rutting resistance index (RRI) based on the rutting depth and number of passes for each sample. Figure 10 shows the samples for the HWT test after testing. Base on the RRI values in this test, rutting resistance of the modified samples increased about 141.5% and 138.4% for both the 1% and 2% asphaltenes modified samples, respectively. Improvement for the RRI in asphaltenes modified samples were almost the same for both contents of the asphaltenes. SIP values for both modified samples increased in comparison to the control sample, which is 3800 passes. These values were 8200 and 7400 for 1% and 2% asphaltenes.

Table 8 Rutting resistance of samples using HWT

Sample ID	SIP	Number of Passes	RRI
Control	3,800	3,940	2,219.74
S1-1-0	8,200	8,712	5,360.97
S1-2-25	7,400	8,604	5,291.12

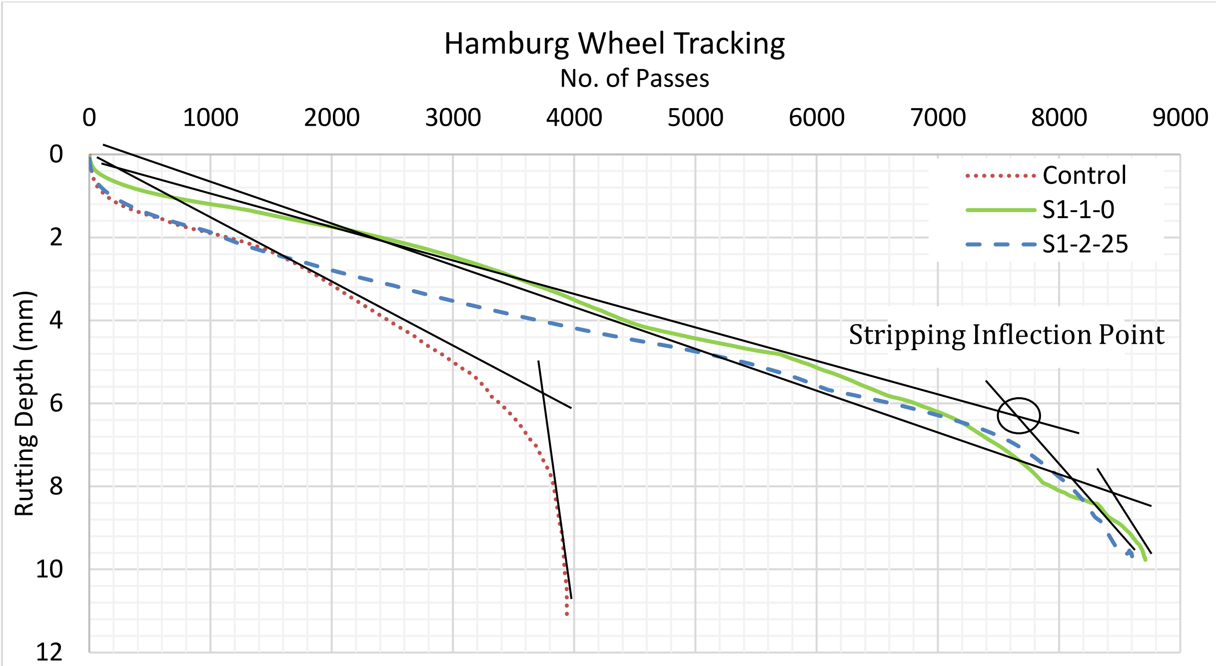

Figure 9 Hamburg wheel tracking results

Figure 10 Slab sample after HWT test

Flow Number Test

AASHTO T378 was used for conducting the flow number test to evaluate the samples permanent deformation. A universal testing machine (UTM) was used to run the test on gyratory compacted samples. Modified and unmodified samples were prepared using a gyratory compactor with constant height limitation and similar density values to the Marshall samples. Samples were prepared in dimensions of 170 mm height and 150 mm diameter and cured in the oven for 48 hours inside the mold and 24 hours after extraction from mold at 60 ˚C. Three replicates for each sample were surface cut to 150 mm and cored to 100 mm after curing and tested. Table 9 presents the properties of the samples prepared. It shows the average air void contents of the samples before and after cut and coring with bulk specific gravity (G_{mb}) values. The abovementioned specification was followed for the test procedure. The test temperature was selected as 45 ˚C, which is an estimated high adjusted performance grading temperature determined by the Long-Term Pavement Performance (LTPP) program. The project location was considered in the City of Edmonton, and climatic data from the nearest weather stations were used in the program to estimate the temperature. The contact load and deviator stress were selected as 3kPa and 69kPa, respectively. Haversine axial compressive loading patterns with loading periods of 0.1 seconds and 0.9 second resting were applied. The termination points were set to be 20,000 cycle numbers or the maximum 50,000 microstrain, whichever comes first. Figure 11 presents the result from the test, which indicates that all samples were terminated at maximum cycle number. The control sample has the highest deformation and accumulated microstrain value in comparison to the modified samples. This value was similar for both the 1% and 2% asphaltenes modified samples and considerably lower than the control sample. The decrease in the deformation of samples were about 81.4% and 84.5% for 1% and 2% asphaltenes modified samples, respectively. Accumulated microstrain for the control samples were 4760.79 με and this value for 1% and 2% asphaltenes modified samples decreased to 884.32 and 736.68 με, respectively. The flow point for the samples was calculated using the Francken model and fitted flow point at 20,000 cycles. Figure 12 presents the samples after cutting and coring ready to test.

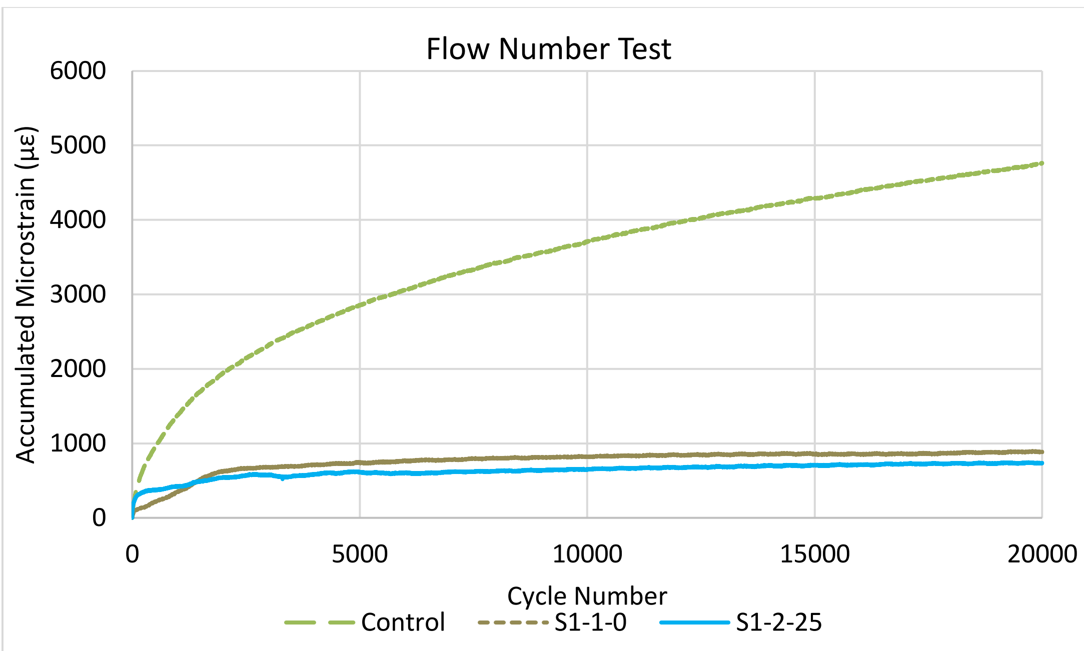

Figure 11 Flow number test results

Table 9 Properties of flow number test samples

Sample ID	Airvoids before cut (%)	Airvoids after cut (%)	G_{mb}
Control	11.937	10.753	2.281
S1-1-0	11.317	10.290	2.272
S1-2-25	11.353	10.202	2.255

Figure 12 Gyratory compacted sample for flow number test after surface cut and core

CONCLUSIONS

- From Marshall stability and ITS results, the optimum moisture and emulsion contents were calculated as 6.3% by the weight of aggregates and 3.7% by the weight of the total mixture, respectively.
- Asphaltenes increased the Marshall stability and Marshall quotient of the mixtures. Marshall stability increased with higher contents of the asphaltenes, but the Marshall quotient is slightly higher for 1% asphaltenes modified samples than 2%. The reason is the higher flow values for 2% asphaltenes modified samples.
- The rutting resistance index (RRI) for the modified samples increased about 140% compared to the control sample, and these values were almost the same for both asphaltenes contents.
- All the samples for the flow number terminated at the highest cycles possible (20,000 cycles) within the test conditions and asphaltenes modified samples have lower deformation under the repeated load of the test from 4700 $\mu\varepsilon$ to 800 $\mu\varepsilon$. This value is almost similar for both asphaltenes contents.
- The result of three permanent deformation tests indicated that asphaltenes modification increases the rutting resistance of the asphalt emulsion stabilized mixtures significantly. However, this improvement is almost similar for both 1% and 2% asphaltenes contents. Considering the ease of the mixing process and the results, 1% asphaltenes could be considered the optimum value for this modification.

ACKNOWLEDGMENTS

Funding: This work was financially supported by Alberta Innovates. Husky Energy, Lafarge Canada, Nestor Zerpa and Value Creation Inc. provided the required materials for the research. All contributions are gratefully acknowledged.

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