

Impact of Cement or Asphaltenes on Low-Temperature Performance of Asphalt Emulsion-Stabilized Base Courses

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Abstract

A pavement's structure gradually deteriorates due to repeated traffic load and environmental effects. These effects lead to distresses such as permanent deformation, fatigue cracking and thermal cracking. Granular base course stabilization using asphalt emulsion is one of the most popular techniques to enhance the layer performance in order to achieve sufficient bearing capacity and resistance to pavement distresses. The major drawbacks of asphalt emulsion-stabilized base course, though, are its low early strength, long curing time, and low resistance to permanent deformation and moisture damage. To address these drawbacks, the asphalt emulsion-stabilized layer is usually modified with cement, which can improve its early strength and performance properties. However, using the cement makes the treated base course more prone to shrinkage cracking. Asphaltene is a waste material derived from Alberta oil-sands with no significant use in the pavement industry. Asphaltene is one of the polar fractions of asphalt binder, and its addition to asphalt binder has been found to have a considerable effect in increasing stiffness. In this context, the present study compares the impact of cement versus asphaltene on the asphalt emulsion-stabilized base performance properties. For this purpose, different concentrations of cement and asphaltene (1% and 2% per weight of total mixture) are added to asphalt mixtures, and the mechanical properties of the mixtures, including the low-temperature performance, are evaluated. It is concluded that both asphaltene and cement are effective in improving a mixture's strength and rutting resistance. However, cement-modified mixtures are found to be more prone to low-temperature cracking than are asphaltene-modified mixtures.

Keywords: Base course stabilization, Asphalt emulsion, Cement, Asphaltene, Creep compliance, Indirect tensile strength

Introduction

The base course plays a major role in providing load-support to the other pavement layers through load distribution [1]. This layer distributes loads to the subbase and subgrade layers by dampening the stress exerted on pavement by the traffic load [2]. Base courses are generally constructed using a dense graded aggregate structure, which may be composed of crushed stone, or other untreated or stabilized materials [3]. Asphalt emulsion is a typical material used for base course stabilization, and this type of mixture is classified as cold mix asphalt. As the name implies, in this type of mix, asphalt emulsion and unheated aggregates are mixed and compacted at ambient temperatures with no heating required in the preparation [4,5]. Consequently, these mixes offer various advantages over conventional hot mix asphalt [5]. Unlike hot mix asphalt, cold mix asphalt can be produced either at the job site or in a plant. This benefit brings a reduction in the cost of hauling as well as a significant decrease in energy consumption. These and other benefits make this type of mix a cost-effective alternative to hot mix asphalt [4].

Asphalt emulsion has a considerably lower viscosity than asphalt itself, making it effective for application at reduced temperatures. The low-temperature characteristic not only minimizes

emissions and energy consumptions but also prevents oxidation of the asphalt. Additionally, emulsions are compatible with water and active fillers such as cement and lime, resulting in beneficial properties such as improved strength retention, resistance to moisture, and traffic load accommodation [6]. In cold climates, cold recycling using a stabilizing agent is also beneficial for pavement maintenance.

Although asphalt emulsion assists with stabilizing the granular base, it has some drawbacks, such as low early-stage strength, extended curing time, inadequate resistance to moisture damage, and low rutting resistance [7,8]. As such, cement, hydrated lime, and fly ash are often used as active fillers to improve the performance of the asphalt emulsion mixture in terms of strength and resistance to permanent deformation and the adverse effects of moisture [6]. The active filler chemically functions as a second binder in gripping the aggregates and reacting within the mixture with existing water content to form hydration products that act as a catalyzer [9]. As a result, during the early stages of the asphalt's service life, the trapped water is absorbed in the hydration process to improve the mixture strength. In this manner, the chemical composition of the asphalt binder can have a significant impact on the properties of the asphalt emulsion mixture [10].

Cement is the commonly used active filler in asphalt emulsion-stabilized mixtures. However, the use of cement in stabilized mixtures poses some significant disadvantages, including increased cost and increased thermal cracking potential. Furthermore, cement's production entails high energy consumption and CO₂ emissions [11]. Hence, ongoing research is underway to find alternative and innovative materials to replace cement in such applications [12,13].

Asphalt binders are classified by chemical composition in terms of their content of saturates, aromatics, resins, and asphaltenes, these components being referred to collectively as "SARA". The polarity of asphalt binder compounds and their interactions play important roles in influencing the rheological properties of the asphalt binders. Asphaltenes obtained through the deasphalting process of oil sands bitumen is a by-product material with little value in current practice and no significant industrial applications. Asphaltenes have a relatively high rate of production in oil sands bitumen refineries. It has been estimated that, in northern Alberta facilities, asphaltenes is produced at a high proportion of as much as 17.5% (as a ratio of asphalt production) [14]. It has also been demonstrated that the addition of asphaltenes can improve the performance properties of stabilized layers with asphalt emulsion [15]. Asphaltenes is a viscoelastic material. Hence, it is expected that the low-temperature properties of mixes stabilized using asphaltenes will outperform those stabilized with cement.

The main objective of our research study was to investigate and compare the impact of the addition of asphaltenes versus cement on the low-temperature properties of mixtures stabilized using asphalt emulsion. For this purpose, a mix design was prepared for a well-graded granular base course material using a cationic slow-setting (CSS) asphalt emulsion (i.e., CSS-1H). Using the same granular material, asphalt emulsion-stabilized mixtures both with cement and with

asphaltenes were prepared, and the low-temperature properties of the mixtures were compared using creep compliance and indirect tensile strength tests.

2. Materials

2.1 Aggregates

The asphalt mixture was prepared using aggregates obtained from a single source, the aggregate gradation specifications having been selected in reference to the Wirtgen Cold Recycling Manual [6] and the parameters set out by the City of Edmonton [16] and Alberta Transportation, and in accordance with Soliman et al. [17]. The gradation of the aggregate used is presented in Table 1, with the aggregate skeleton consisting of 57.27% coarse aggregates, 36.73% fine aggregates, and 6% filler. The physical properties of the aggregates were evaluated, with the results shown in Table 2. The bulk specific gravity of the aggregates was found to be 2.601. Additionally, a proctor test was carried out to obtain the optimum moisture content (OMC) of the aggregates in accordance with ASTM D698 [18].

Table 1. Selected aggregate gradation

Sieve size (mm)	% Passing	% Retain	% Coarse/Fine/Filler
20.00	100.00	0.00	57.27
12.50	75.17	24.83	
10.00	61.23	13.94	
8.00	55.00	6.23	
6.30	48.00	7.00	
5.00	42.73	5.27	
2.50	32.08	10.65	42.73
1.25	25.61	6.47	
0.63	18.93	6.68	
0.32	13.00	5.93	
0.16	9.00	4.00	
0.08	6.00	3.00	
Filler (Pan)	0.00	6.00	6.00

Table 2. Physical properties of aggregates

Properties	Unit	Standard	Result
Specific gravity of fine aggregates	-	ASTM C128 (37)	2.604
Water absorption of fine aggregates	%	ASTM C128 (37)	0.624
Specific gravity of coarse aggregates	-	ASTM C127 (38)	2.598
Water absorption of coarse aggregates	%	ASTM C127 (38)	0.870
Abrasion of coarse aggregates	%	ASTM C131 (39)	23
Optimum moisture content (OMC)	%	ASTM D698 (35)	6.3
Maximum dry density (MDD)	kN/m ³	ASTM D698 (35)	15.4

2.2 Asphalt Emulsion

A CSS) emulsion is the most widely used emulsion for base stabilization, due to the aggregate charge as well as the minimal time needed for mixing and laying the layer [6]. This type of emulsion has a relatively high workability time, resulting in a more uniformly distributed and stable mixture. For these reasons, in our study we employed a CSS emulsion with 85–100 penetration grade base binder (CSS-1H) comprising 61% asphalt and 39% water. The properties as per the datasheet provided by the material supplier are summarized in Table 3.

Table 3. Properties of asphalt emulsion

Properties	Unit	Standard (ASTM/AASHTO)	Specification		Results
			Min.	Max.	
Specific gravity at 15.6 °C	kg/L	D6937[19]/T59[20]	-	-	1.020
Viscosity at 25 °C	S.F.S.	D7496[21], D88[22]/T59[20]	20	100	22
Residue by distillation	%	D6997[23]/T59[20]	57	-	61
Oversized particles (sieve)	%	D6933[24]/T69[20]	-	0.300	0.008
Settlement (24 hr)	%	D6930[25]/T59[25]	-	1.0	0.5
Particle charge test		D7402[26]	Positive		Positive

2.3 Cement

A general use (GU) ordinary cement type satisfying ASTM C1157 [27]/CSA A3000 [28] requirements was used as an active filler. According to its physical properties, the cement material had an initial setting time of 45 min, a final setting time of 420 min, and a compressive strength of 13 MPa after 3 days, 20 MPa after 7 days, and 28 MPa after 28 days.

2.4 Asphaltenes

The asphaltenes used in this study were sourced from Alberta oil sands bitumen. This material was obtained as a by-product of the deasphalting of oil sands bitumen in solid form, as shown in Figure 1(a). The solid asphaltenes were ground into powder, as shown in Figure 1(b), before being added to the mixture. The asphaltenes particles were also passed through a No. 100 sieve prior to use in the mixture.

The relative amounts of saturates, asphaltenes, resins, and aromatics (SARA) were determined in the asphaltenes sample, and it was found to be composed of 79.63% asphaltenes, 9.68% aromatics, 6.85% saturates, and 3.84% resin.

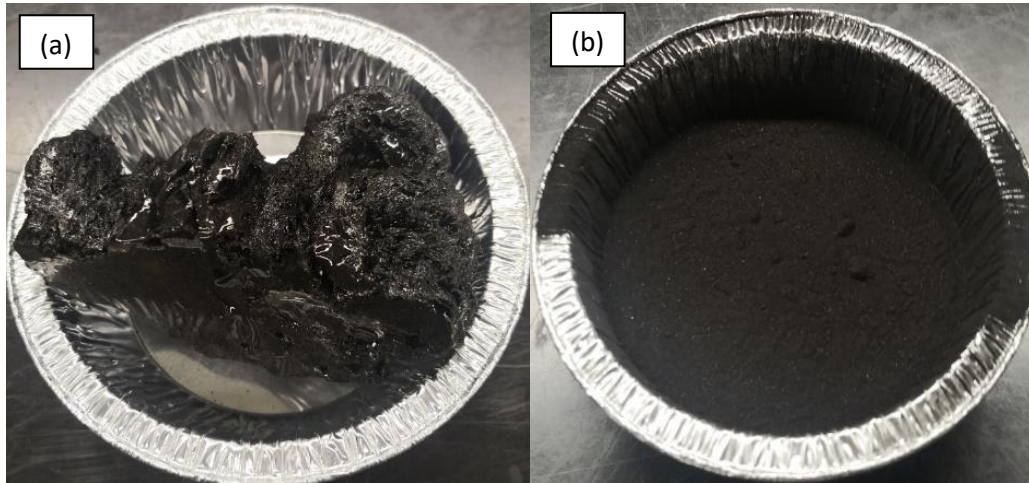


Figure 1. Asphaltenes in solid form (a), and asphaltenes in powder form prepared for mixing (b)

3. Testing Program

3.1 Mix Design and Mechanical Properties of Control Sample

Although there is no universal mix design for asphalt emulsion cold mixtures in current practice, many agencies have established guidelines based on scientific formulas, laboratory studies, and field experience [29]. Working with well-graded granular aggregates, the design method for base stabilization in this study was based on the method defined by the Asphalt Institute [29]. The proportion of asphalt emulsion to be used was determined using Equation 1. The value of A, which is the amount of material retained after distillation, was found to be 61%.

$$\text{Percentage of asphalt emulsion for base mixture} = \frac{(0.06B+0.01C)*100}{A} \quad [1]$$

Where:

A = Percentage of 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 per total mixture was calculated to be 4.89%, and four different concentrations increasing at 1% intervals were prepared in order to assess the optimum emulsion content (OEC) in terms of Marshall stability and flow, as well as the ITS test. Based on the results of the proctor test for determining the OMC of the aggregates, the required water was added to the oven-dried aggregates so that the total moisture from the asphalt emulsion and the added water would be equal to the OMC, and it was then mixed until the water was evenly distributed. The asphalt emulsion was applied to the wet aggregates in the design matrix contents determined in Table 4 and compacted with 50 blows on each side of the sample using a Marshall hammer.

Table 4. Asphalt emulsion and additional water content for design matrix.

Asphalt emulsion content (% per total mix)	Additional water (% per total aggregates)
3.04	5.1
3.98	4.7
4.89	4.3
5.78	3.9
6.66	3.5

3.1.1 Marshall Stability and Flow for OEC

For the different concentrations of asphalt emulsion calculated in the design matrix for OEC values as shown in Table 4, the Marshall stability test was performed in accordance with ASTM D6927-15 [30]. The samples compacted with a Marshall hammer were cured 48 hr at 60 °C and cooled for at least 2 hr before being extracted from the molds after conditioning. Three replicates are prepared for each of the asphalt emulsion concentrations. It should be noted that the Marshall stability test was performed after three-hour conditioning in an air bath at 25 °C [29].

The Marshall mix design results showed that the maximum stability and density values were reached at about 3.7% of asphalt emulsion. For the purpose of conducting the performance tests, this proportion of asphalt emulsion per total mix was chosen as the OEC. It should be noted that various researchers have recommended that the ITS test be used to validate the findings obtained from Marshall stability testing [6,7].

3.1.2 ITS Test for OEC

The ITS test was performed in accordance with AASHTO T283 [31]. The asphalt emulsion concentrations defined in the design matrix for OEC were used to prepare the samples for the ITS test. For each asphalt emulsion concentration, three samples were prepared. The samples were compacted with a Marshall hammer using the same protocol used in the Marshall stability tests. In accordance with AASHTO T283 [31], these samples were cured using the same technique Marshall stability test and conditioned for 3 hr in an air chamber at 25 °C. Following conditioning, the samples were subjected to loading at a rate of 50 mm/min. The maximum load applied to the sample before failure was reported, and the ITS was calculated using the following equation:

$$S_t = \frac{2000P}{\pi tD} \quad [2]$$

where

S_t = Indirect tensile strength (kPa)

P = Maximum applied load (N)
t = Average height of specimen (mm)
D = Diameter of specimen (mm)

The ITS test results followed the same pattern as the Marshall test results. Based on the performance of both the Marshall and ITS samples, OEC was set at 3.7% per total mixture. Following the specifications in the Wirtgen Cold Recycling Manual [6], the lower limit for asphalt emulsion-stabilized mixes was determined to be 225 kPa, and the ITS was measured as 298 kPa for the OEC that meets the minimum requirement.

3.2 Mechanical Properties for Modified Samples

3.2.1 Samples Preparation with Cement or Asphaltenes

Throughout the analysis, the asphaltenes- and cement-modified mixtures were prepared using the OEC. The control samples were prepared in the same manner as the OEC design samples and were then compared to the asphaltenes- and cement-modified samples.

Asphaltenes was added to the asphalt emulsion before mixing with the aggregates in accordance with the mix design. In light of the experimental findings, this process was chosen due to the relative ease with which asphaltenes can be mixed in the asphalt emulsion compared to mixing with aggregates. Asphaltenes in concentrations of 1% and 2% of total mixture weight were applied to the asphalt emulsion and combined with the aggregates. For each stage of asphaltenes material, three replicates were prepared. Increasing the amount of asphaltenes in the emulsion made preparation more difficult because the asphaltenes caused the emulsion to break down quickly. To make the 2% asphaltenes samples less viscous and easier to mix, more water was added to the asphalt emulsion [15].

After cooling the aggregates to room temperature, the cement was mixed with oven-dried aggregates, and water was added and mixed until a consistent mixture was reached. Asphalt emulsion was then applied, and compaction and curing were performed in the same manner as in the case of the control sample.

The ITS values and curing time of asphalt emulsion-stabilized mixtures changes increasing linearly with cement content, as noted by Xu et al. [32]. For this reason, the curing conditions were kept constant to maintain identical conditions for the purpose of comparing asphaltenes and cement. A creep compliance and strength test was performed on the prepared specimens, with the results contrasted between the unmodified, cement-modified, and asphaltenes-modified samples in order to evaluate the low-temperature performance of the mixtures.

3.2.2 Marshall Stability and Flow Test

A Marshall stability test was carried out in accordance with ASTM D6927-15 [30]. The test specimens for asphalt emulsions with two different amounts of asphaltenes or cement were

prepared. The Marshall samples had a 100 mm diameter, and the aggregates required for each sample were weighed and oven-dried before mixing to remove moisture from the aggregates. Using a Marshall compactor, specimens were compressed with 50 blows on each side. The compacted samples were cured in the oven for 48 hr at 60 °C before being removed from the molds. Samples were taken from the molds after they had cooled for at least 2 hr. For the purpose of testing, three specimens were made of each asphaltene concentration and of each cement concentration. After conditioning the specimens in a water bath at 60 °C for 40 minutes, the Marshall stability test was performed.

For the asphaltene-modified samples, the oven-dried aggregates, water, and asphaltene-modified asphalt emulsion were mixed together. For the cement-modified samples, oven-dried aggregates, cement, water, and asphalt emulsion were mixed together.

3.2.3 Indirect Tensile Strength (ITS) Test

The ITS test was carried out in accordance with the AASHTO T283 standard [31]. The test specimens were prepared for asphalt emulsions modified with 1% and 2% of asphaltene or cement content, respectively. The prepared mixes were placed into molds and compacted with a Marshall compactor using 50 blows on each side. The compacted specimens were cured for 48 hr at 60 °C. Once the samples had been allowed to cool to room temperature, they were removed from the molds. It should be noted that the samples were conditioned in an air chamber at 25 °C for 3 hr prior to carrying out the ITS test. A universal testing machine (UTM) was used to apply a load at a rate of 50 mm/min during the testing. Equation 2 was used to compute the indirect tensile strength of the specimen using the peak load observed prior to failure.

3.2.4 Creep Compliance and Strength Test

Following the ITS test, the samples were subjected to creep compliance and strength testing in accordance with AASHTO T322-07 [33]. (This procedure is used to determine how well mixtures perform at low temperatures.) For the creep test, samples were prepared in the same manner as for the Marshall test, except that the surface of each sample was cut to a height of 38 mm to 50 mm in accordance with the relevant standard. The samples were conditioned in an air chamber for 3±1 hr at the test temperature before being tested. A fixed static load was applied to the samples for 100±2 seconds during the creep test, and linear variable displacement transducers (LVDT) reported the deformation of the specimen in both the horizontal and vertical axes. After the creep test, an ITS test was applied to the same sample at 12.5 mm/min until reaching failure. (Figure 3 depicts the test configuration prior to testing.) The fracture energy of the samples was calculated at both temperatures using the load-deformation values obtained from the test results, and the ITS of the samples was calculated using Equation 2 as previously stated.



Figure 3. Creep compliance and strength test setup

4. Results and Discussion

4.1 Marshall Stability and Flow Tests

The Marshall stability test results for the control, cement-modified, and asphaltenes-modified mixes were compared in order to evaluate the influence of asphaltenes and cement as additives (see Table 5 and Figure 4). The results showed that both the cement- and asphaltenes-modified mixtures had much higher stability values than the control mixture. The 1% and 2% asphaltenes enhanced the stability by roughly 48% and 97%, respectively, when compared to the control. Similarly, when comparing the cement-modified mixes to the control sample, adding 1% and 2% cement content improved the stability by 46% and 89%, respectively. Furthermore, the Marshall stability of the samples was found to increase as the proportion of additive increased. A considerable improvement in stability was observed for both the asphaltenes and cement samples when increasing the additive content from 1% to 2%.

Furthermore, when comparing the Marshall quotient (MQ) results—which are calculated by dividing the Marshall stability of the mixtures by the flow value of the mixtures—it can be seen that the samples modified with cement or asphaltenes had a greater MQ than the control samples. The modified mixtures had higher MQ values, indicating higher stiffness and, therefore, higher resistance to rutting. In addition, comparing the cement-modified samples to the asphaltenes-modified samples at the same additive concentration, the cement-modified mixes had a higher MQ

than the asphaltenes-modified mixtures. This shows that cement-modified samples are more rigid compared to asphaltenes-modified samples.

Table 5. Marshall Stability and Marshall Quotient (MQ)

Sample Description	Stability (kN)	Flow (mm)	Marshall Quotient (kN/mm)
Control Sample	11.54	5.55	2.08
1% Asphaltenes	17.06	5.26	3.24
2% Asphaltenes	22.72	7.48	3.04
1% Cement	16.91	4.50	3.76
2% Cement	21.85	4.41	4.95

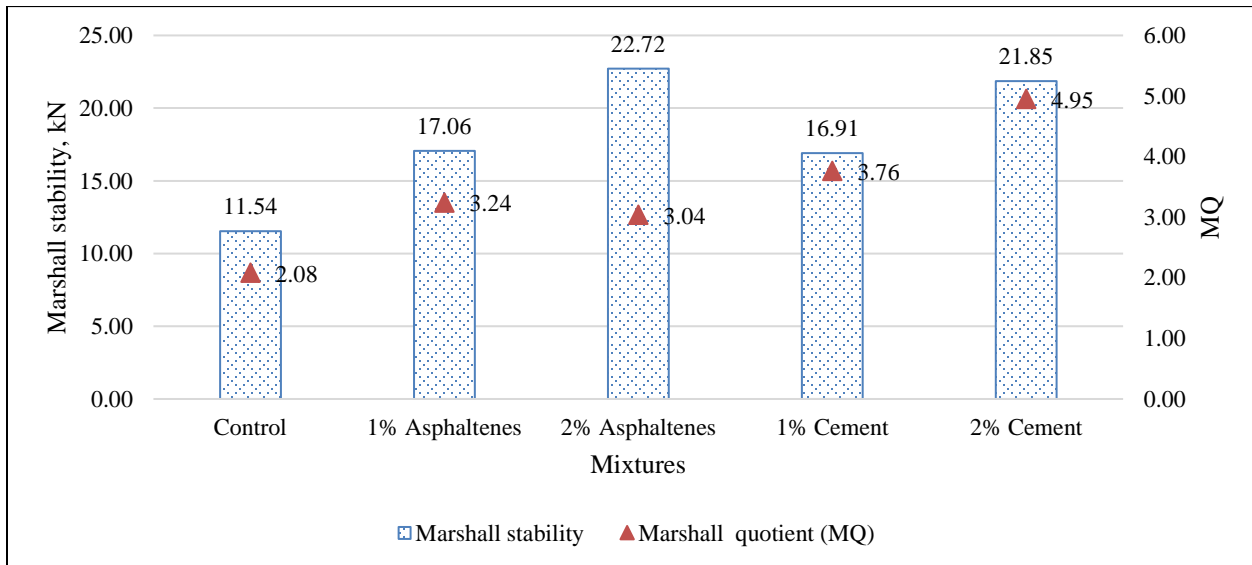


Figure 4. Marshall Stability and Marshall Quotient (MQ) results

4.2 Indirect Tensile Strength (ITS) Test

Table 6 shows the ITS test results for the control, cement-, and asphaltenes-modified samples. Comparing the dry ITS findings of the control with those of the modified samples, it is clear that the modified samples had a higher tensile strength than the control samples. Furthermore, comparing the dry ITS of the modified mixes, the samples modified with asphaltenes were found to be more efficient than the samples modified with cement. Comparing the tensile strength of the asphaltenes and cement mixes at equal concentrations, meanwhile, it was found that 1% asphaltenes enhanced the tensile strength by approximately 106% compared to the control, whereas 1% cement increased the tensile strength by about 51%. The 2% asphaltenes and 2%

cement samples followed a similar pattern, with 193% and 88% increases in tensile strength, respectively, compared to the control.

Table 6. Indirect tensile strength test results

Sample Description	Indirect Tensile Strength (kPa)
Control Sample	297.78
1% Asphaltenes	613.20
2% Asphaltenes	872.80
1% Cement	449.70
2% Cement	561.10

4.3 Creep Compliance and Strength Test

Creep compliance tests were performed at temperatures of 0 °C and -10 °C in accordance with AASHTO T 322-07 [33]. Table 7 presents the ITS for the samples at both temperatures tested. Unlike the ITS results at 25°C, at low temperatures, there is no significant difference between the ITS values of modified and unmodified samples. It can be seen that the tensile strength of all samples increased by decreasing temperature from 0 °C to -10 °C, except for the modified sample with 2% asphaltenes. Figures 5 and 6 show the load versus deformation graphs for 0 °C and -10 °C, respectively. The slope of the graphs for the modified samples after the peak point is steeper than the control sample, indicating faster crack propagation.

Table 7. Tensile strength for creep test

Mixtures	ITS at 0 °C, kPa	ITS at -10 °C, kPa
Control	1,083.1	1,357.3
1% Asphaltenes	1,170.1	1,255.3
2% Asphaltenes	1,164.0	1,033.3
1% Cement	1,080.5	1,238.8
2% Cement	1,144.6	1,366.1

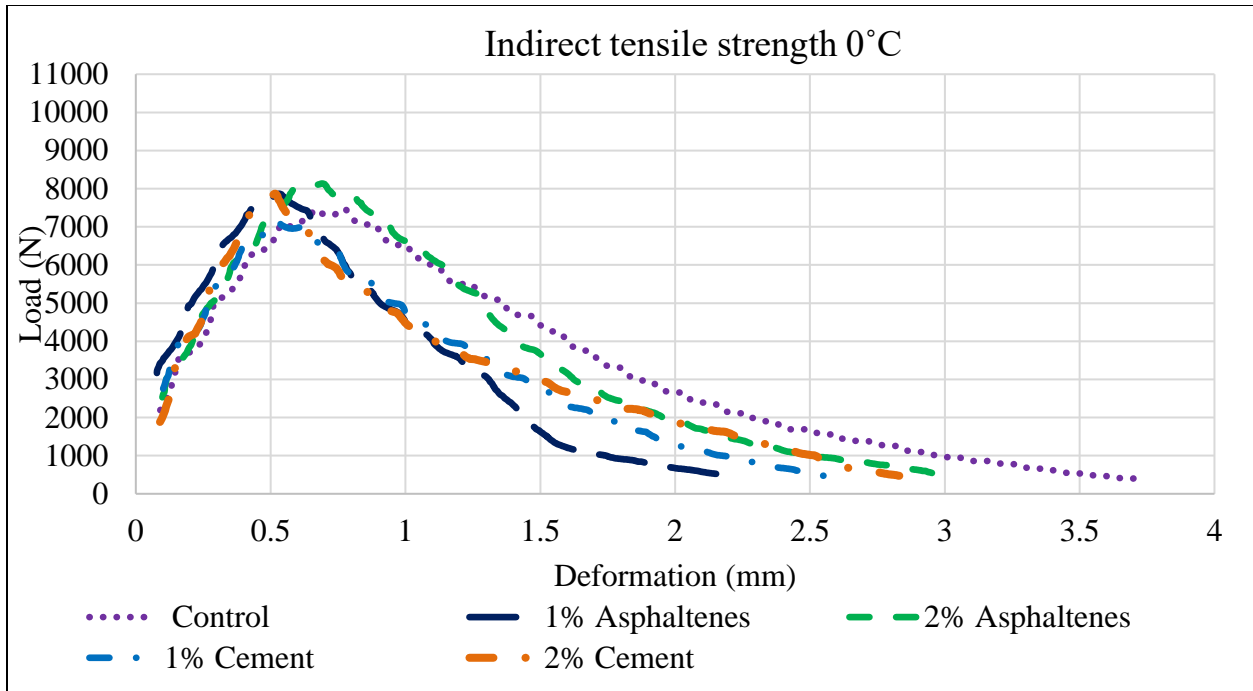


Figure 5. Load-deformation graph at 0 °C

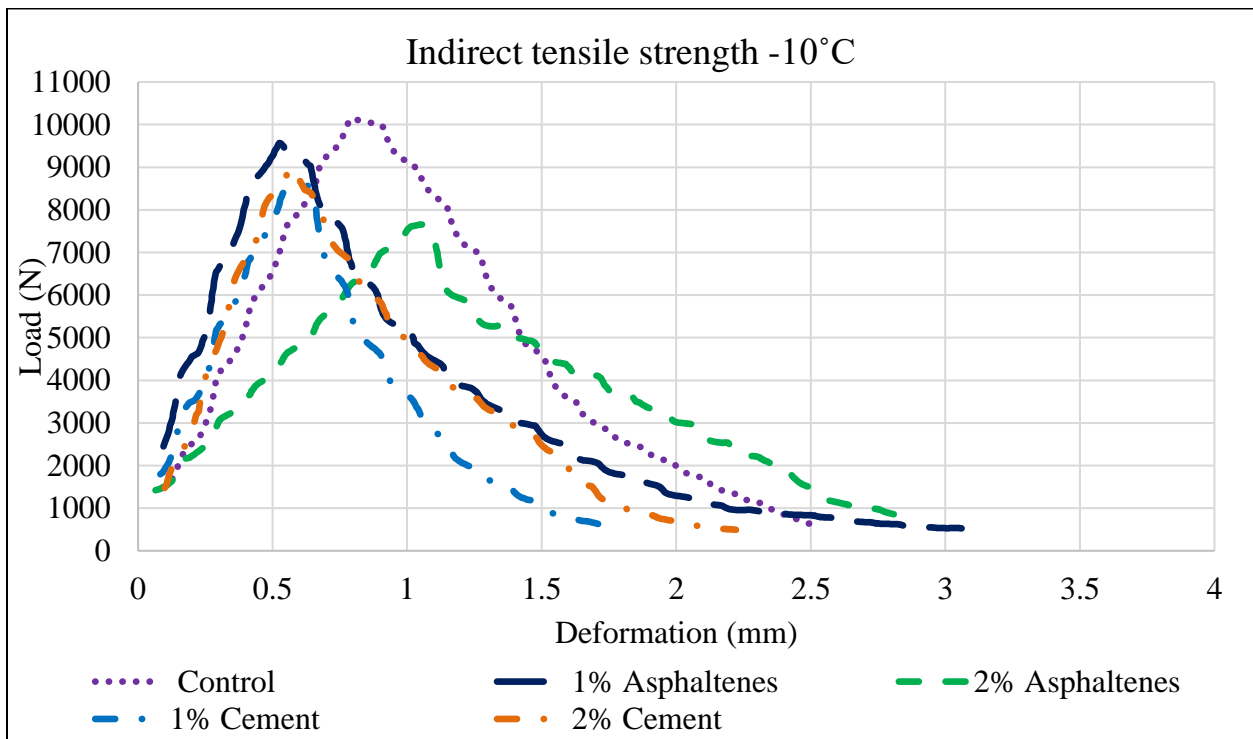


Figure 6. Load-deformation graph at -10 °C

The fracture energy results are shown in Table 8 and Figure 7. It can be seen that despite of the comparable ITS values at 0 °C, the fracture energy of the 1% asphaltenes, 2% asphaltenes, 1% cement, and 2% cement samples decreased by 24.0%, 17.7%, 36.9%, and 41.4%, respectively, while, at -10 °C, the 1% asphaltenes, 2% asphaltenes, 1% cement, and 2% cement samples decreased by 25.1%, 21.9%, 45.4%, and 26.7%, respectively. These findings indicate that the modified samples had lower fracture energy than the unmodified samples.

Table 8. Fracture energy form creep test

Mixtures	FE at 0 °C, J/m ²	FE at -10 °C, J/m ²
Control	2,437.3	2,713.0
1% Asphaltenes	1,852.7	2,032.2
2% Asphaltenes	2,006.4	2,118.1
1% Cement	1,538.3	1,480.2
2% Cement	1,428.2	1,988.4

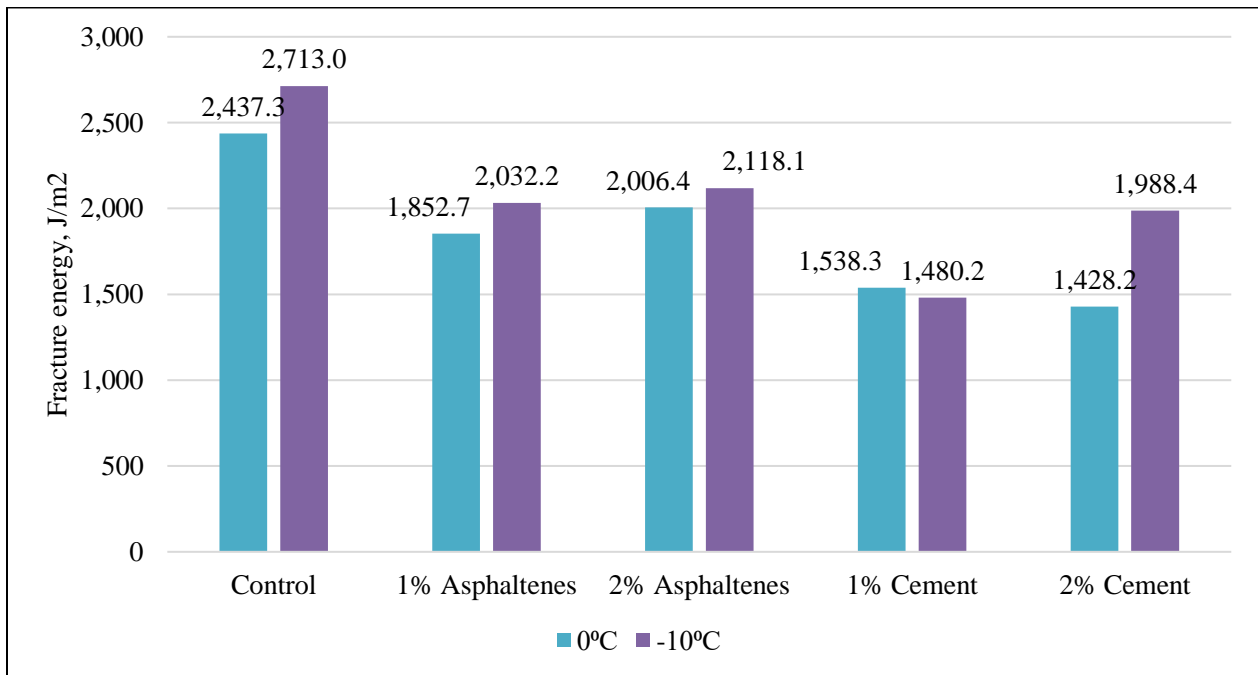


Figure 7. Fracture energy for low-temperature creep test

5. Conclusions

This study investigated and compared the performance of cement- and asphaltenes-modified asphalt emulsion mixes. From the results and analysis, the following conclusions have been drawn:

- When compared to cement-modified samples, asphaltenes modification improves the Marshall stability and tensile strength. Meanwhile, it was observed that the asphaltenes-modified

samples did not increase the Marshall Quotient as much as the cement-modified samples did. This shows that asphaltenes-modified samples are more flexible compared to cement-modified samples.

- Modification with 1% and 2% asphaltenes increased the tensile strength by roughly 106% and 193%, respectively, while modification with cement at the same concentrations resulted in a more modest improvement (51% and 88%, respectively). When comparing the performance of cement- and asphaltenes-modified mixes, it can be inferred that asphaltenes-modified mixtures improve tensile strength more effectively than do cement-modified mixtures.
- The creep compliance test results show that both asphaltenes and cement modification adversely affect the low-temperature performance of the mixture due to brittleness and stiffening, as reflected in the fracture energy analysis. However, the cement-modified mixtures were found to be more prone to low-temperature cracking than the asphaltenes-modified mixtures.
- From the results, it can be concluded that the addition of either asphaltenes or cement improves the tensile strength and rutting resistance of the mixture; however, at low temperatures, asphaltenes-modified mixtures have higher cracking resistance compared to cement-modified mixtures.

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7. References

1. Christopher B. R., Schwartz C., Boudreaux R. Geotechnical aspects of pavements (No. FHWA-NHI-05-037). United States. Federal Highway Administration. 2006;
2. Speight J. G. Asphalt Materials Science and Technology. Butterworth-Heinemann. 2015;
3. Lavin P. G. Asphalt Pavements: A practical guide to design, production, and maintenance for engineers and architects. Vol. 53. 2003. CRC Press.
4. Piratheepan M. Designing Cold Mix Asphalt (CMA) and Cold-In-Place Recycling (CIR) Using SUPERPAVE Gyratory Compactor. 2011;(December).
5. Al-Busaltan S, Al Nageim H, Atherton W, Sharples G. Mechanical Properties of an Upgrading Cold-Mix Asphalt Using Waste Materials. Journal of Materials in Civil Engineering. 2012;24(12):1484–91.
6. Wirtgen Cold Recycling Manual. Wirtgen GmbH, 1st edition, Windhagen, Germany. 2012;
7. Du S. Performance Characteristic of Cold Recycled Mixture with Asphalt Emulsion and Chemical Additives. Advances in Materials Science and Engineering. 2015;

8. Niazi Y, Jalili M. Effect of Portland cement and lime additives on properties of cold in-place recycled mixtures with asphalt emulsion. *Construction and Building Materials*. 2009;23(3):1338–43.
9. Ebels L-J. *Characterisation of Material Properties and Behaviour of Cold Bituminous Mixtures for Road Pavements*. 2008;
10. Sultana S, Bhasin A. Effect of chemical composition on rheology and mechanical properties of asphalt binder. *Construction and Building Materials*. 2014;72:293–300.
11. Boesch ME, Hellweg S. Identifying improvement potentials in cement production with life cycle assessment. *Environmental Science and Technology*. 2010;44(23):9143–9.
12. Choudhary J, Kumar B, Gupta A. Utilization of solid waste materials as alternative fillers in asphalt mixes: A review. *Construction and Building Materials*. 2020;234:117271.
13. Wang QZ, Wang NN, Tseng ML, Huang YM, Li NL. Waste tire recycling assessment: Road application potential and carbon emissions reduction analysis of crumb rubber modified asphalt in China. *Journal of Cleaner Production*. 2020;249:119411.
14. Meisen A. *Bitumen Beyond Combustion (BBC) Project Phase 1 Report, Prepared for Alberta Innovates*. 2017;1–56.
15. Kamran F, Basavarajappa M, Bala N, Hashemian L. Laboratory evaluation of stabilized base course using asphalt emulsion and asphaltenes derived from Alberta oil sands. 2021;283.
16. City of Edmonton. *Design and Construction Standards*. Vol. 2. 2015.
17. Soliman H, Shalaby A, Kass S. Overview of specifications for unbound granular base materials in selected canadian provinces and neighbouring states. 2014 Transportation Association of Canada Conference and Exhibition: Past, Present, Future, ATC 2014. 2014;1–15.
18. ASTM International. *ASTM D698-12 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort*. West Conshohocken, PA: American Society for Testing and Materials. 2003;
19. ASTM International. *ASTM D6937 - 16 Standard Test Method for Determining Density of Emulsified Asphalt*. West Conshohocken, PA: American Society for Testing and Materials. 2016.
20. AASHTO T 59-16. *Standard method of test for Emulsified Asphalt*. AASHTO provisional standards. Washington, D.C.: American Association of State Highway and Transportation Officials. 2019.
21. ASTM International. *ASTM D7496 - 18 Standard Test Method for Viscosity of Emulsified Asphalt by Saybolt Furol Viscometer*. West Conshohocken, PA: American Society for Testing and Materials. 2018.

22. ASTM International. ASTM D88 / D88M - 07 Standard Test Method for Saybolt Viscosity. West Conshohocken, PA: American Society for Testing and Materials. 2007.
23. ASTM International. ASTM D6997 - 12 Standard Test Method for Distillation of Emulsified Asphalt. West Conshohocken, PA: American Society for Testing and Materials. 2012.
24. ASTM International. ASTM D6933 - 18 Standard Test Method for Oversized Particles in Emulsified Asphalts (Sieve Test). West Conshohocken, PA: American Society for Testing and Materials. 2018.
25. ASTM International. ASTM D6930 - 19 Standard Test Method for Settlement and Storage Stability of Emulsified Asphalts. West Conshohocken, PA: American Society for Testing and Materials. 2019.
26. ASTM International. ASTM D7402 - 09 Standard Practice for Identifying Cationic Emulsified Asphalts. West Conshohocken, PA: American Society for Testing and Materials. 2017.
27. ASTM International. ASTM C1157 / C1157M - 20a Standard Performance Specification for Hydraulic Cement. West Conshohocken, PA: American Society for Testing and Materials. 2020.
28. CSA Standard A3000-18. Cementitious Materials Compendium. Toronto, Canada. CSA Group. 2018.
29. Asphalt Institute. A Basic Asphalt Emulsion Manual. Asphalt Emulsion Manufacturers Association, Manual Series No. 19 (MS-19), 4th edition. 2008.
30. ASTM International. ASTM D6927 - 15 Standard Test Method for Marshall Stability and Flow of Asphalt Mixtures. West Conshohocken, PA: American Society for Testing and Materials. 2015.
31. AASHTO T 283-14. Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage. Washington, D.C.: American Association of State Highway and Transportation Officials. 2017.
32. Xu, Huang S, Qin Y, Li F. The impact of cement contents on the properties of asphalt emulsion stabilized cold recycling mixtures. International Journal of Pavement Research and Technology. 2011;4(1):48–55.
33. AASHTO T 322. Standard Method of Test for Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device. AASHTO provisional standards. Washington, D.C.: American Association of State Highway and Transportation Officials. 2007.