A novel framework for determining optimum fibre content in high-performance asphalt concrete mixes for low temperature applications.

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ABSTRACT

The use of fibres in asphalt concrete mixes has become popular for many applications including inhibiting premature distresses in asphalt pavements, enhancing fatigue and rutting resistance, and lowering life cycle costs. Specific to cold temperatures and increasing vehicular loads, thermal failure is a widespread phenomenon that manifests as a series of transverse cracks extending across the pavement surface. Hence, using high-strength fibres (such as steel fibres and elastomeric polymers) to increase tensile strength has become a viable solution. The traditional approach for determining the optimum dosage of any type of fibre for use in asphalt mixes includes trial and error, previous testing literature or tapping into existing agency knowledge and best practice. This study adopts a framework for determining optimum fibre content that employs asphalt volumetrics and performance tests. This framework is represented in an accept-reject criteria-based flow chart to reach the optimum fibre content for use in high performance asphalt concrete (HPAC) applications in cold regions such as Canada. In this study, we add different percentages (0.05%, 0.10%, 0.15%, 0.20% and 0.30%) of one length (6mm) of polyethylene terephthalate (PET) to prepare samples with asphaltenes-modified binders for use as a base course in cold climates. In order to determine which PET percentage gives the optimum result, different criteria are analyzed, including compactibility, dynamic modulus, as well as indirect tensile strength. In this work, the criterion for a sample's compactibility is considered as a maximum of 6% of air voids for the compacted specimens using 80 gyrations by a Superpave gyratory compactor. In addition, considering that this study aims to enhance HPAC for cold climate applications, dynamic modulus of HPAC mixes should be greater than 14 GPa at a temperature of 15˚C and a loading frequency of 10 Hz. Finally, to increase the pavement's lifespan, the mixture with optimum dosage must be prone to minimal thermal cracking at low temperatures by exhibiting the highest tensile strength and fracture energy compared with the control samples. Results show that the compactibility is not affected by the addition of PET, and that a fibre dosage of 0.15% gives the greatest increase (3.3%) in the mix stiffness and the best combined improvement effect of fracture energy (32% at 0°C) and tensile strength (13% at 0°C). This framework can be adjusted to add or omit other performance tests that are most suitable for the project location and climate in question.

Keywords: framework for optimum fibre content, high performance asphalt concrete, polyethylene terephthalate fibres, thermal cracking.

1. INTRODUCTION AND LITERATURE REVIEW

Asphalt pavement distresses are undesirable from the point of view of the pavement performance such that the more the distress intensity and extent, the shorter the pavement's life [1]. Amongst the most common distresses that could lead to "failed" pavement (or one at the end of its design life) is cracking. The nature of cracking and its cause can be attributed to different mechanisms such as thermal cracking and fatigue cracking. Thermal cracking is especially observed in cold regions such as Canada and consists of two types of cracking: low-temperature cracking and thermal fatigue cracking. The former occurs when tensile stresses developed by a non-uniform contraction of the asphalt layer at low temperatures exceed the tensile strength of the asphalt concrete, and the latter results from repetitive thermal cycles even with a mild temperature cycle amplitude [2]. This indicates that asphalt pavement with low tensile strength requires the addition of modifiers to enhance performance. One proven solution to improve tensile strength of asphalt pavement and its cracking resistance is the use of fibres [3].

The present study investigates the use of high-performance asphalt concrete for base course applications. The superior mechanical performance for such mixture is gained from its constituents represented in hard grade binder combined with a strong continuous mineral skeleton; this results in a high stiffness layer that is very resistant to permanent deformation and absorbent of traffic loads [4-7]. Results of previous research conducted at the University of Alberta showed that hard asphalt binders obtained from modifying both crude oil and Alberta oilsands binders with asphaltenes (a waste of minimal value and few applications in the industry) met and exceeded the typical high-temperature performance requirements for high stiffness applications [8]. In addition, the results of performance tests, such as the Hamburg wheel tracking (at high temperatures) and dynamic modulus (over a range of temperatures) on asphalt mixes composed of asphaltenes-modified binders proved the superior performance of the modified mixes, compared with unmodified control mixes. However, the research also confirmed that the modification does not necessarily reflect improvement in cold climates (such as in Canada) due to the asphaltene-modified mixes' low flexibility and stress relaxation capacity in that low-temperature performance testing results showed more proneness to thermal cracking. Therefore, in the current phase of this study, a method is proposed to improve low-temperature performance and reduce the cracking potential of mixtures composed of asphaltenes-modified binders by the addition of polymer fibres, namely polyethylene terephthalate (PET). The most critical question is how much fibre to add for optimum efficiency in performance. This optimum content is significant because when the dosage and number of fibres exceeds the optimum content level, the fibres clump together and cannot achieve the best effect [9]. Noorvand, et al. [10] stated that by increasing fibre addition, fibre efficiency increases up to a certain point after which too many and/or too long fibres can reduce the workability and the uneven distribution of the fibres in the mix.

The traditional approach for determining the optimum dosage of any type of fibre for use in asphalt mixes includes trial and error, previous testing literature or tapping into existing agency knowledge and best practice. In this regard, the studies in the literature are very limited when it comes to answering the former question. A very recent study by Noorvand, et al. [10] evaluated the optimum fibre length in fibre-reinforced asphalt concrete (FRAC); however, the study only focused on the optimum fibre length that is suitable for shear bond strengths and fibre distribution in the FRAC. This application for shear bond strengths is also studied in other works [11-14]. Similarly, a study by Saleh et al. [15] defined an optimum dosage of aramid fibre that is 38mm in length to be 0.0065% by total weight of the mix which gave significant improvement in the cracking resistance, but the length was also based on the multiple-fibre pullout test at a cold temperature of −18°C [16]. In addition, a laboratory research by Cheng [17] on optimum fibre content in stone mastic asphalt (SMA) mixture looked at different additions of lignin but the entire study focused on high temperature performance. The study found that the optimum high-temperature deformation resistance of SMA mixtures increased initially which peaked at a dosage of 0.33% of fibre before decreasing with increasing fibre content. A similar study focusing mostly on high temperature and water resistance attempted to determine optimum asphalt content of basalt fibres using the methods of Marshall stability [18]; however, the study does not reflect advances in asphalt performance tests. In the study by Mirbaha, et al. [19], the determination of the optimum percentage of fibre additives was also limited to Marshal tests (stability, flow, etc) with very simple evaluation such as the effect on unit weight of the modified asphalt mixtures. There was no consideration of any set criteria, practicality (e.g. compactibility) or application of the asphalt concrete mixtures (high vs. low temperature climates).

The significance of this present study lies in determining optimum fibre content based on road construction practical considerations and laboratory performance tests that reflect field functionality. Therefore, according to the above, the main objective of this paper is to investigate the effect of PET fibre dosage on workability and mechanics of high-performance mixes in low temperature: namely compactibility; dynamic modulus as well as tensile strength and fracture energy.

2. OBJECTIVE AND SCOPE

The main objective of this study is to create a practical framework for determining optimum PET fibre dosage in high-performance asphalt concrete base course for low-temperature applications through various laboratory tests. The scope of fibre addition considered in this study include fibres used for strength and crack resistance applications. This framework is represented in an accept-reject criteria-based flow chart to reach the optimum fibre content. For this purpose, different criteria are analyzed, including compactibility [20-22], dynamic modulus [23, 24], as well as indirect tensile strength at low temperature [25].

Having said that, this framework can be adjusted for consideration of any other asphalt concrete layer in the pavement system and any mixture modified with fibres other than high performance asphalt concrete. Moreover, the framework can be adjusted to add or omit other performance tests that are most suitable for the project location and climate in question. For example, for fibre modification of high-performance asphalt concrete for high temperature applications, the framework can be modified to replace the indirect tensile strength test at low temperature [25] with the Hamburg wheel tracking test at high temperature [26].

3. THE FRAMEWORK FOR DETERMINING OPTIMUM FIBRE CONTENT

This study adds different percentages of PET to prepare samples with asphaltenes-modified binders. In order to determine which PET percentage gives the optimum result, different criteria are analyzed, including compactibility, dynamic modulus, as well as indirect tensile strength and fracture energy.

Compactibility is essential in obtaining the required smoothness and density in a compacted pavement. High voids in the pavements that are not compacted properly create significant performance issues. The chances are high that a pavement may experience permeability problems and oxidative aging of the binder if it is under-compacted, which eventually reduces the life of the pavement [27]. In this study, all samples must have an air void content of less than 6%, compacted using 80 gyrations by a Superpave gyratory compactor, to be considered compactible enough, which was the criterion adopted in this study according to Leiva-Villacorta, et al. [28]. In addition, considering that this study aims to enhance high modulus asphalt for cold climate applications, dynamic modulus is another fundamental criterion which was selected that can be used as a performance indicator since it correlates well with fatigue cracking and moderately with thermal cracking [29]. Dynamic modulus (i.e. stiffness) of high performance asphalt concrete mixes should be greater than 14 GPa at a temperature of 15˚C and a loading frequency of 10 Hz. Finally, since the created mixes should resist low temperature cracking, the low-temperature behavior of the asphalt mixtures is mainly described by creep compliance and indirect tensile strength [30], which is adopted as the third and final criterion for deciding on the optimum PET percentage. To increase the pavement's lifespan, the mixtures must be prone to minimal thermal cracking at low temperatures. The criterion for this test is an optimum combination of highest fracture energy and indirect tensile strength. To begin the evaluation process, the criteria were first applied to mixtures consisting of five different percentages of PET specifically, 0.05%, 0.10%, 0.15%, 0.20%, and 0.30% by weight of the total mixture, that were mixed with a modified crude oil binder and 6mm-long PET fibers. The entire process in shown in Figure 1.

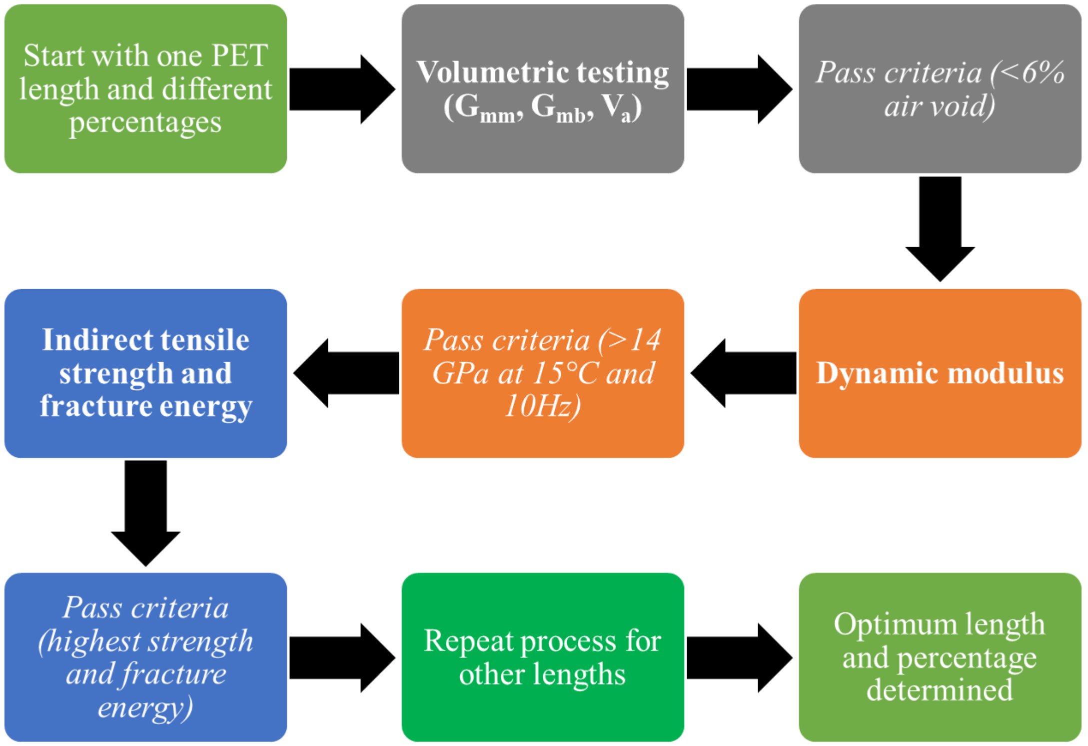

Figure 1: Flowchart of the framework for determining optimum fibre content

4. MATERIALS AND MIX DESIGN

4.1 Material additives

4.1.1 Asphaltenes

Asphaltenes are a no-value waste material with minimal applications and a relatively high production rate in oil refineries. The asphaltenes material used in this study was derived as a by-product of the solvent deasphalting process of Alberta oil-sand bitumen and was received in chunk form. These chunks were turned into powder (Figure 2) and then sieved using a No. 100 sieve, with a mesh size of 150 µm, to make them easier to uniformly disperse and mix with an asphalt binder. According to the saturate, aromatic, resin and asphaltene (SARA) analysis carried out, the asphaltenes content was found to be 79.6%, while saturates, aromatics, and resins are 6.9%, 9.7%, and 3.8%, respectively.

Figure 2: Asphaltenes in chunk form (left), and processed powder form (right)

4.1.2 Polyethylene terephthalate fibres

Polyethylene terephthalate (PET) is the most used thermoplastic polymer resin of the polyester family that can be found in the municipal solid waste [31]. PET is known for its durability, strength, low gas permeability as well as thermal and chemical stability [32]. The PET fibres employed in this research project were received as original PET post-processed with a length of 6mm and an average hairline diameter of 20 µm (Figure 3).

Figure 3: PET fibres processed to a length of 6mm

4.2 Mixture design

4.2.1 Aggregate gradation

After consulting different standard specifications and literature for high performance asphalt concrete with a high stiffness, from France, South Africa, the United Kingdom and Australia [6, 33-35], a final gradation envelope was selected for the mixture design procedure. The selected optimum gradation has a nominal maximum aggregate size (NMAS) of 19mm. For this study, European specification is adopted, and the minimum specifications for dynamic modulus of high performance mixes is 14,000 MPa at a temperature of 15°C and under a 10 Hz loading frequency [28, 34]. Figure 4 displays the target gradation, the maximum density curves and as shown, the target gradation is bounded within the French envelopes.

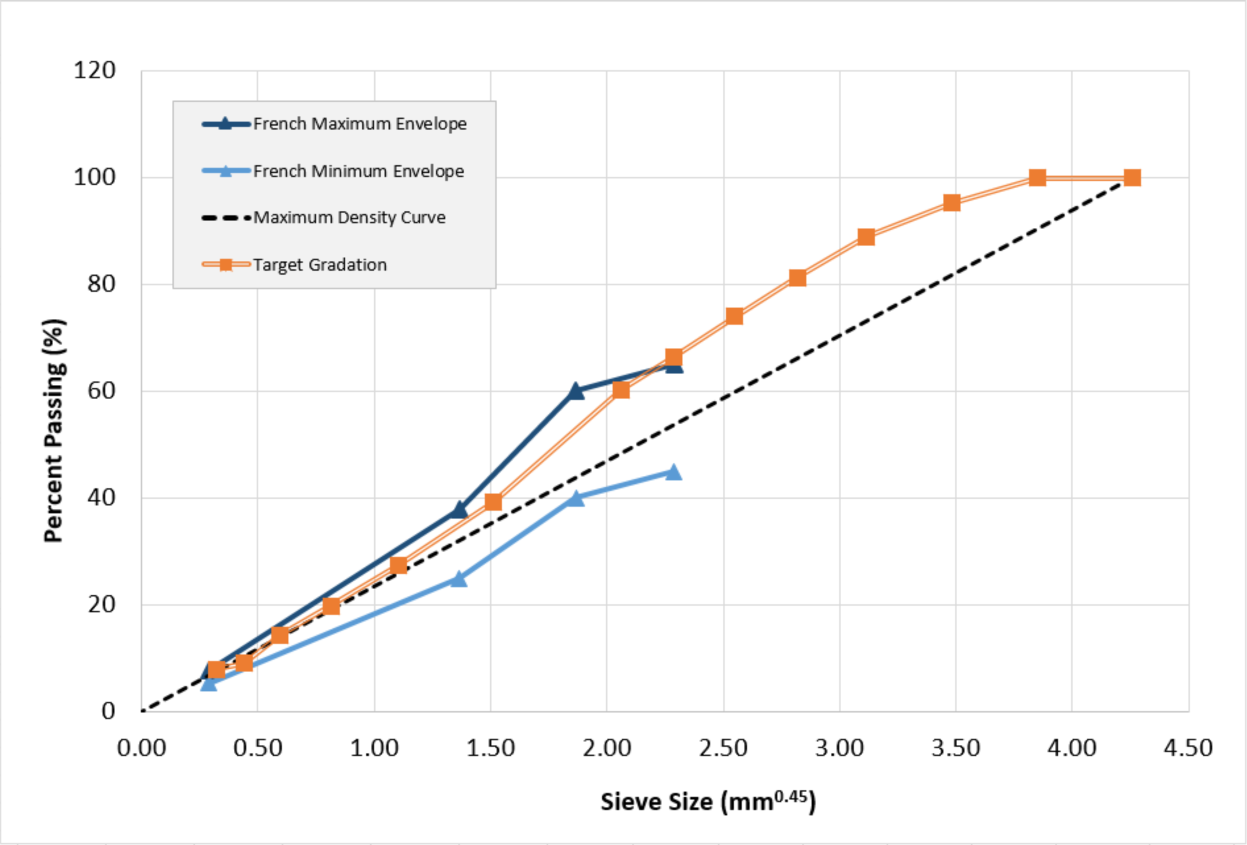

Figure 4: Selected aggregate grain size distribution for high performance asphalt concrete

4.2.2 Mixture volumetric properties

The volumetric properties are shown in Table 1, which consist of binder grade, design air void, voids in the mineral aggregate (VMA), voids filled with asphalt (VFA), and effective binder content by volume. The values provided below are the requirements for a high modulus asphalt base course [28].

Table 1: Volumetric properties of HPAC mixes with NMAS of 19mm

Property	Value
Binder grade	PG82-16
Design air void (%)	1.5±0.5
Voids in the mineral aggregate (VMA) (%)	15
Voids filled with asphalt (VFA) (%)	90
Effective binder content by volume (%)	13.5±0.5

4.2.3 Aggregate properties

Three tests were used to determine the aggregate properties. These are specific gravity of coarse and fine aggregates, water absorption and Los Angeles abrasion tests. The specifications for high modulus asphalt preparation are met according to the results displayed in Table 2. The table shows that coarse and fine aggregates meet all the requirements, and the coarse aggregates' Los Angeles abrasion value lies within the specified range.

Table 2: Aggregate properties

1. Specific gravity test results				
	Aggregate portion (%)	Bulk specific gravity	Bulk specific gravity (SSD*)	Apparent specific gravity
Coarse aggregate ($\geq$ 4.75mm)	39.7	2.618	2.652	2.666
Fine aggregate ($<$ 4.75mm)	60.3	2.502	2.600	2.617
2. Water absorption test results				
	Water absorption (%)		Criterion[1]	
Coarse aggregate ($\geq$ 4.75mm)	0.3		≤1.0	
Fine aggregate ($<$ 4.75mm)	0.4		≤1.5	
3. Los Angeles abrasion test results				
	Value obtained (%)		Standard range (%)[2]	
Coarse aggregate ($\geq$ 9.5mm)	23		10 - 45	

[1] Denneman, et al. [34]

[2] ASTM [36]

**SSD: Saturated surface dry*

4.2.4 Binder content

The binder used in this study to reach the high temperature requirement was a crude oil binder that is readily available in the market with a base performance grade of PG70-22. The binder was modified with asphaltenes to produce a performance grade of PG82-16. Denneman, et al. [34] constructed an outline to calculate the binder content for high modulus asphalt concrete. This outline utilizes the richness modulus *K* and the type of aggregate gradation selected to calculate the binder content specifically for the mixture design. Richness modulus *K* represents the binder film thickness coated on the surface area of aggregates [28]. The optimum binder content for this work was calculated to be 5.6% by weight of the total binder, aggregates, and fibre mixture.

5. EXPERIMENTAL AND TESTING PROCEDURE

5.1 Preparation of specimens

The asphalt mixtures were prepared using a laboratory bucket mixer and then divided into appropriate specimen sizes as per the recommendation of AASHTO R 47 [37]. The split hot-mix asphalt (HMA) was collected in flat-bottom trays and spread evenly to approximately 50mm in thickness. In addition, the design compaction temperature was set to 160°C as per the equiviscous temperatures obtained from the viscosity-temperature relationship. Test specimens were prepared using a Superpave gyratory compactor (SGC), with a ram pressure of 600 kPa, an average external angle of 1.25° and 30 gyrations per minute throughout compaction. The moulds and other necessary equipment used in the process of compacting specimens were heated at the compaction temperature, and the mould was charged with the mix, avoiding segregation of the mixture.

For samples prepared for volumetric testing, the mix was conditioned at the compaction temperature of 160°C for two hours to simulate the short-term aging of asphalt mixes [38]. A similar compaction effort using an SGC represented in a constant number of gyrations (N_{des}) of 80 was used to obtain the target design air void of 1.5% and to keep air void content less than 6%. On the other hand, for samples prepared for performance testing, the mix was short-term conditioned (for mixture mechanical property testing) in an oven at a temperature of 135°C for four hours before being brought to a compaction temperature of 160°C over a period of 30 minutes [38].

A common problem in prepared fibre-modified asphalt mixes is clustering and balling; this is indicative of incomplete dispersion of the fibres in the mix. During the mix preparation, no fibre clustering was observed. One reason why this was achieved could be attributed to the small length used in this study (6mm) and the additional mixing time of 1-2 minutes adopted to eliminate or reduce these clusters.

5.2 Volumetrics testing

Proper HMA compaction assists in ensuring good performance during the life span of the road [39]. Different parameters were used to calculate the total work done during compaction, which included the density data, the change in the height of the sample during compaction, the size of the sample, and the pressure used to compact the sample. The compactibility of the mixtures was calculated by plotting the air void (estimated from height change during SGC compaction) against the number of gyrations. To do that, each unique mixture (with and without asphaltene-modified binder and PET fibre including different dosages) was first tested for the theoretical maximum specific gravity (G_{mm}), as per AASHTO T 209 [20].

5.3 Dynamic modulus

The asphalt mix is a viscoelastic material, and the modulus value is impacted by the loading time and the ambient temperature. Moreover, for a sinusoidal loading, a phase lag (δ) exists between stress and strain because of the viscous properties of the asphalt mixes [40]. In this study, the dynamic modulus test was conducted using a universal testing machine (UTM) according to AASHTO T 342 and AASHTO 378 [23, 24]. The gyratory compacted samples were cored and cut to create cylindrical specimens with an average diameter of 100mm and an average height of 150mm using a core bore.

The ends of the test specimens were ground using an end grinder for a smooth surface and to make it perpendicular to the axis of the specimen. For dynamic modulus testing, the design air void was 1.5%. A sinusoidal repetitive axial compressive stress with various loading frequencies (0.01, 0.1, 0.5, 1, 5, and 10 Hz) was applied to the specimen at specific temperatures (-10, 4, 15, 21, 37 and 54˚C) while the test was in progress (Figure 5). Linear variable differential transformer (LVDT) sensors were used to measure the vertical deformation of the test specimen. A software system was used to continuously measure the resulting strain response of the specimen due to the applied stress.

Figure 5: Dynamic modulus test setup showing LVDTs attached to the sample

5.4 Indirect tensile strength at low temperatures

The current standard method to evaluate tensile strength of asphalt mixtures at low temperature is the creep compliance and the indirect tensile (IDT) strength test [30]. This test is used to depict the low-temperature behavior of the asphalt mixtures and thermally induced cracking in asphalt pavements during their life spans. It is a destructive test that was carried out in this study using a UTM, see Figure 6, according to AASHTO T 322 [25]. Three cylindrically shaped specimens with a diameter of 100mm and an average thickness of 40mm were prepared for each mix using the SGC. Then, the samples were inserted into the chamber, and the test was conducted at three temperatures of -20°C, -10°C, and 0°C. Vertical and horizontal deformations were recorded during the loading period and the tensile strength was determined by applying a load to fracture to the specimen at a rate of 12 mm/min.

Figure 6: IDT strength test setup

The fracture energy (G_f) for three replicates of each asphalt mix was determined using the area under the load-displacement graph as per Equation 1 [41], and the indirect tensile strength (S_t) was calculated as per Equation 2 [25].

$$G_f = \frac{W_f}{D \times t} \times 10^6 \tag{1}$$

where

G_f = failure energy (Joules/m^2),

W_f = work of failure (Joules), which is simply the area under the load-displacement curve,

D = specimen diameter (mm), and

t = specimen thickness (mm).

$$S_t = \frac{2000 \times P}{\pi \times t \times D} \tag{2}$$

where

S_t = indirect tensile strength (kPa), and

P = maximum load (N).

6. RESULTS AND DISCUSSION

6.1 Results of volumetrics testing

The asphalt mix must have the workability to facilitate placement and compaction without being fragile. Maximum specific gravity (G_{mm}), bulk specific gravity (G_{mb}) and air void (V_a) are the three parameters that can give an idea of the compactibility of the test specimens. All the obtained results are based on a design number of gyrations (N_{des}) of 80 for all mixes and are presented in Table 3.

Table 3: Compactibility results of control and fibre-modified mixes

Mix	PET content, %	Maximum specific gravity, G_{mm}	Bulk specific gravity, G_{mb}	Air void, V_a, at N_{des}
Control Mix	0	2.434	2.398	1.49%
PET-modified mix	0.05	2.432	2.396	1.49%
	0.10	2.425	2.390	1.44%
	0.15	2.423	2.388	1.46%
	0.20	2.419	2.391	1.17%

It can be observed that both the maximum specific gravity and bulk specific gravity values are decreasing as the addition of PET increases. However, the results also show that the compactibility of the different mixes is similar and is not highly affected by the addition of PET. Furthermore, the air void values are below 6%, which is within the required value, according to Leiva-Villacorta, et al. [28] and as shown in Figure 7.

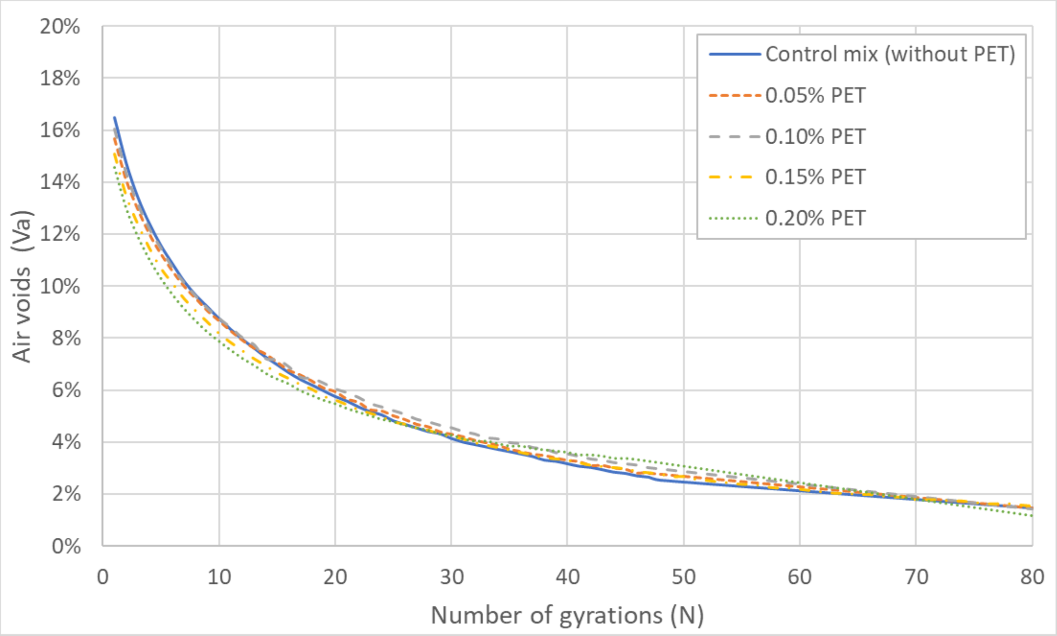

Figure 7: Compactibility of control and PET-incorporated asphalt mixes

6.2 Results of dynamic modulus test

The results of the dynamic modulus for control and PET-incorporated HPAC samples at a temperature of 15˚C and a loading frequency of 10 Hz are displayed in Figure 8. It should be noted that the error bars in the figure are based on the standard deviation of the dynamic modulus value of the two tested samples for each type of mix.

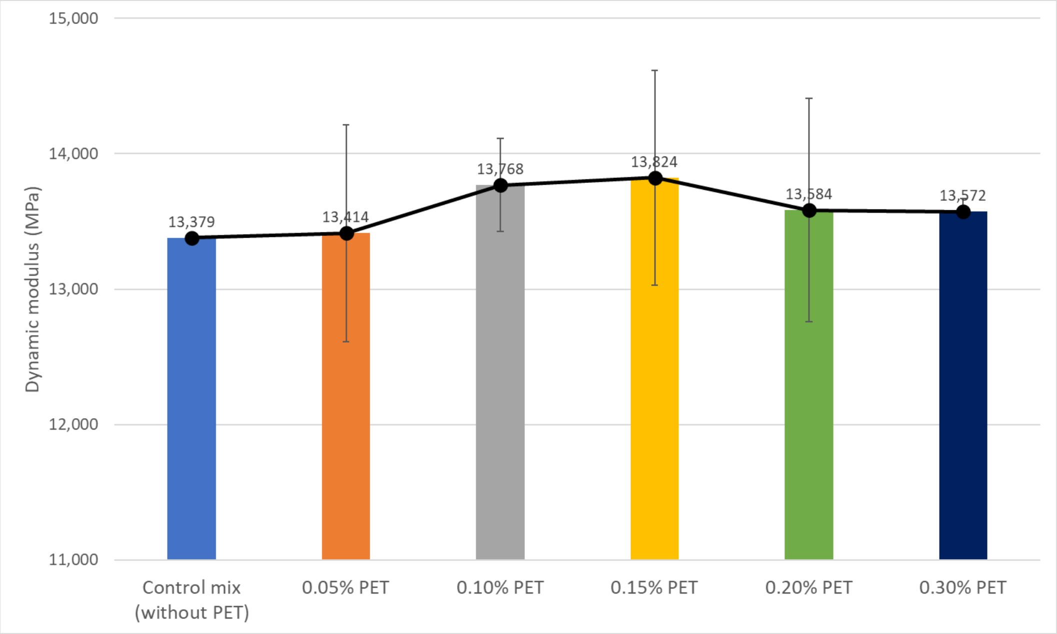

Figure 8: Results of dynamic modulus at 15˚C and 10 Hz

The dynamic modulus master curve for all mixes at a reference temperature of 15°C was developed and is displayed in Figure 9. The master curve shows that the trend for all mixes is almost the same in which the dynamic modulus value increases with increasing frequency (representing lower temperatures), a behavior that reflects the viscoelasticity of asphalt mixtures. This similarity in trend reflects no negative impact of PET on the anticipated response of HPAC mixes.

With reference to the master curve, even though all mixes miss the target minimum 14 GPa at 10 Hz loading frequency by a small amount (a percentage difference ranging from 4% for control to 1% for 0.15% PET samples), there is a slight increase in the mix stiffness as a result of addition of the PET fibres. This improvement is as high as 3.3% using the percentage of PET of 0.15%. For this reason, in determining the optimum PET content for the 6mm long fibres, it was decided to accept all results obtained for all types of mixes as meeting the stiffness criteria, up to the achieved peak value. As such, the choice of optimum PET content will be decided based on the most superior performance in the IDT strength test.

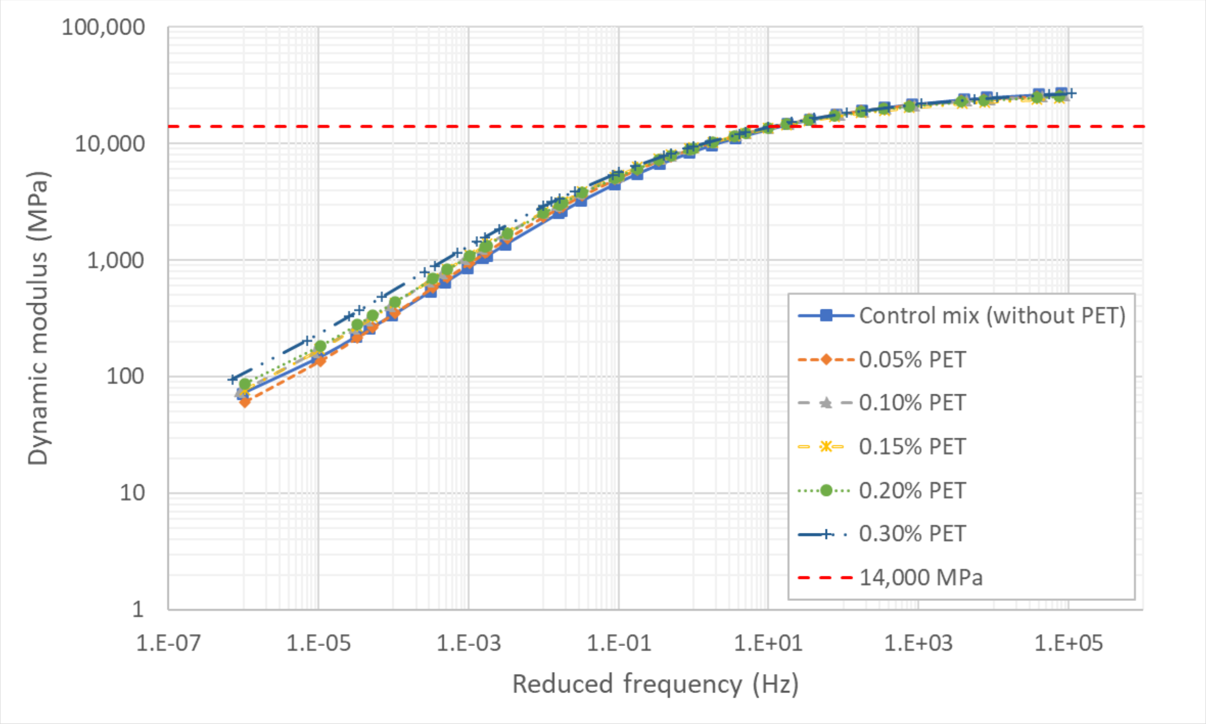

Figure 9: Dynamic modulus master curve at a reference temperature of 15°C

6.3 Results of indirect tensile strength test

Figure 10 shows the fracture energy results at the test's low temperatures of -20°C, -10°C, and 0°C. A general trend observed is that the fracture energy increases with increasing fibre dosage. The improvement in the fracture energy is as high as 19% at -20°C, 22% at -10°C and 32% at 0°C from the same mix, namely 0.15% PET. This result implies that the cracking potential of the PET fibre modified mix is much lower.

Figure 11 shows the indirect tensile strength results at the three test temperatures. A similar general trend to the fracture energy is also observed in which the tensile strength increases with increasing fibre dosage for any one temperature. The improvement in the tensile strength is as high as 8% at -20°C and 13% at

0°C from the same mix, namely 0.15% PET. This result is very significant since the indirect tensile strength is not expected to increase with fibre addition, rather it's expected to essentially reduce cracking potential and inhibit crack propagation. At -10°C, even though there is a small fluctuation in the tensile strength values, both the decrease (in the 0.05% PET mix) and increase (in the other two fibre mixes) are insignificant.

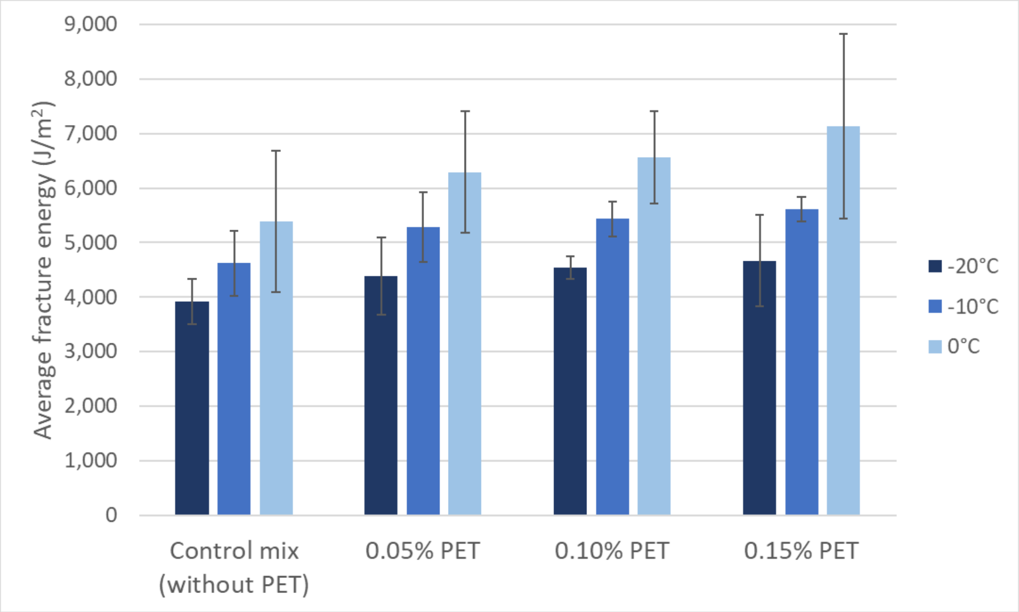

Figure 10: Fracture energy results at test temperatures of -20°C, -10°C and 0°C

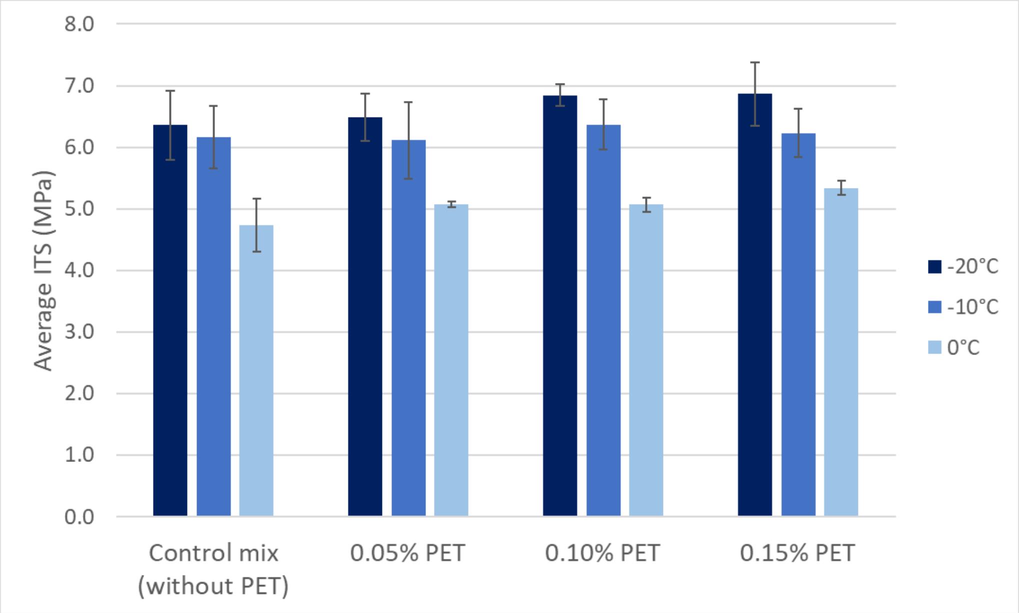

Figure 11: Indirect tensile strength results at test temperatures of -20°C, -10°C and 0°C

The summary test data of the average indirect tensile strength and average fracture energy is also provided in Table 4.

Table 4: Summary data of indirect tensile strength test

Test temperature	Mix ID	Average indirect tensile strength (MPa)	Average fracture energy (J/m^2)
-20°C	Control mix	6.4	3,917
	0.05% PET	6.5	4,389
	0.10% PET	6.8	4,542
	0.15% PET	6.9	4,669
-10°C	Control mix	6.2	4,619
	0.05% PET	6.1	5,283
	0.10% PET	6.4	5,432
	0.15% PET	6.2	5,613
0°C	Control mix	4.7	5,389
	0.05% PET	5.1	6,294
	0.10% PET	5.1	6,561
	0.15% PET	5.3	7,138

6.4 Determination of optimum fibre dosage

In order to determine the optimum content of the fibre (PET fibre in this study) for mechanical performance application, the framework discussed in Section 3 was followed. As seen in the compactibility test, the results showed that the compactibility of the different mixes is similar and is not affected by the addition of PET fibres. Since the air voids were below 6%, all fibre dosages were carried forward to the next test for the second step (dynamic modulus). From Figure 8, the dynamic modulus value at 15°C and 10 Hz increased to a peak of 13,824 MPa at a concentration of 0.15%, before dropping again at a concentration of 0.20%. Once again, as all mixes missed the target minimum of 14 GPa, in determining the optimum PET content for the 6mm long fibres, it was decided to accept all results obtained for all types of mixes as meeting the stiffness criteria up to the achieved peak value. For this reason, the IDT results included all percentages up to 0.15% but did not include 0.20% and 0.30% PET fibres. Thus far, it seemed that the addition of 0.15% PET fibres provided the best results. The final step was to analyze the IDT test results for optimum fibre percentage. As seen from the results, the mix with 0.15% PET showed the greatest improvement over all temperatures in the fracture energy (e.g. 32% at 0°C) and tensile strength (e.g. 13% at 0°C).

Thus, based on all the above, it can be concluded that, in this study's high-performance asphalt concrete mixes for low temperature applications, the optimum PET fibre is 0.15%. This is based on practical construction, highest stiffness, and the best low temperature response.

7. CONCLUSIONS AND RECOMMENDATIONS

The use of fibres to improve tensile strength of asphalt pavement and its cracking resistance so as to enhance low temperature performance is one proven solution. For best efficiency in mechanical performance, the optimum fibre content must be determined first because by exceeding this level, fibres cannot achieve the best effect. The traditional approach for determining the optimum dosage of any type of fibre for use in asphalt mixes includes trial and error, previous testing literature or tapping into existing agency knowledge and best practice. This study adopts a framework for determining optimum fibre content that employs asphalt volumetrics and performance tests. This framework is represented in an accept-reject criteria-based flow chart to reach the optimum fibre content for use in high-performance asphalt concrete (HPAC) applications in cold regions such as Canada. As such, the significance of this study lies in determining optimum fibre content based on road construction practical considerations and laboratory performance tests that reflect field functionality.

This study investigated the use of HPAC for base course applications. All samples included in this study were required to have an air void content of less than 6% to be considered compactible enough, using 80 gyrations by a Superpave gyratory compactor. In addition, considering that this study aimed to enhance high performance asphalt for cold climate applications, the dynamic modulus criterion was chosen as a minimum of 14 GPa at a temperature of 15˚C and a loading frequency of 10 Hz. Finally, since the asphalt mixes should resist low temperature cracking, the criterion was an optimum combination of highest fracture energy and indirect tensile strength. These criteria were started with for mixtures containing five percentages of PET namely 0.05%, 0.10%, 0.15%, 0.20% and 0.30% with a length of 6mm.

Results of the volumetrics testing showed that the compactibility of the different fibre mixes was similar and was not affected by the addition of PET. As such, the air void criterion of maximum 6% was met for all mixes. Results of the dynamic modulus test showed that a fibre dosage of 0.15% gave the greatest increase (3.3%) in the mix stiffness as a result of addition of the PET fibres, before dipping at a concentration of 0.20% and further at 0.30% indicating an optimum dosage for stiffness measurement. Finally, results of IDT strength showed that the fibre content of 0.15% yielded the best combined effect of fracture energy (highest improvement of 32% at 0°C) and tensile strength (largest improvement 13% at 0°C).

It is recommended that this framework be adjusted for consideration of any other asphalt concrete layer in the pavement system, any mixture modified with fibres other than HPAC, and any other practical aspects. Moreover, the framework can be customised to add or omit other performance tests that are most suitable for the project location and climate in question. For other consideration such as cost of fibres in a project, it is recommended that cost analysis (such as lifecycle cost analysis or cost-benefit analysis) is included in the framework to support strategic planning, decision making and cost reduction.

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