Evaluation of the asphalt mix performance under repeated freeze-thaw cycles and application of Geosynthetics in cold regions

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Abstract
Geotechnical-related structures such as pavements have been widely used in cold-weather regions like most part of Canada. Due to the effect of global warming, pavements in cold regions will be thaw earlier and the number of freeze-thaw cycles are increasing each year. In addition to typical design considerations at normal temperatures, a pavement design must also take into account the unique issues related to freeze-thaw cycles, such as degradation of material properties. In this regard, Geosynthetics have been employed in cold regions to stabilize pavement system during construction and mitigate potential problems during their service at low temperature. This paper starts with the evaluation of the effect of environmental freeze-thaw (F-T) condition on the mechanical behavior of the base asphalt mix (GB20) according to the specifications of the MTQ in the LCMB (Le Laboratoire sur les chausséesetmatériauxbitumineux) laboratory at the École de TechnologieSupérieure (ÉTS) and further discusses past studies and their key findings on the application of geosynthetics to enhance the performance pavements in cold regions. The results reveal that geosynthetics at low temperature shows higher tensile strength and stiffness and reduced elongation before failure which can considerably upgrade the pavement behaviour in cold regions.

Keywords: Asphalt mix; Freeze-thaw cycles; Pavement in cold region; Geosynthetics.
Introduction

Canada is located in the northern hemisphere where it experiences different climatic conditions throughout a year [1]. The harsh fluctuations of temperature along with daily freeze-thaw cycles decrease the performance of Hot Mix Asphalt (HMA) [2,3]. Previous studies on the effect of HMA after freeze-thaw cycles show that using appropriate type of fibers and proper compaction can reduce the impact of freeze-thaw cycles and low-temperature on HMA [4,5].

At present, the impact of regional freeze-thaw cycles on bottom up fatigue cracking have not been considered in any design methods in cold regions, this results difference in pavement life between the design and actual pavements. On the other hand, there is lack of studies on fatigue characteristics of asphalt mixtures after repeated freeze-thaw cycles in the literature.

This research is aimed to focus on the effect of environmental freeze-thaw (FT) condition on the mechanical behavior of the base asphalt mix (GB20). The durability and performance of asphalt base mixtures subjected to repeated daily freeze-thaw cycles have not been studied yet. One of the main benefits of this research program is the fact that you will understand how the bituminous base materials in the pavement, behaves during freeze-thaw cycles, and the impact of those cycles on the evolution of the pavement condition and on the pavement life. With a complete Mechanical-Empirical pavement design method modification, the pavement would last longer, which will result in economy and in a smaller environmental impact.

Methodology

Specimen preparations and mix design tests have been conducted in accordance with the specifications of the MTQ in the LCMB (Le Laboratoire sur les chausséesetmatériauxbitumineux) laboratory at the École de TechnologieSupérieure (ÉTS). After the saturation process, each conditioned specimens were submitted to rapid freeze-thaw cycles as set forth in ASTM standard. For each freeze-thaw cycle, two
different temperature level were targeted which are -18 and 6 °C. Figure 1 shows cabinet temperature programing for freeze thaw cycles.

In this project, complex modulus tests were performed before and after conducting the rapid freeze-thaw cycles by using the Direct Tension-Compression (DTC) test on cylindrical samples. An MTS press was used over a range of eight different temperatures and six frequencies. The target applied strain was fixed at 50 μ-strain, and measured with three extensometers placed around the sample. The results of complex modulus have been analyzed by 2S2P1D rheological model.

Fatigue tests were carried out having four different levels of strain amplitude for the reference and conditioned mixes. It is based on the standard of DGCB at ENTPE. All the fatigue tests were performed under the same frequency and temperature conditions.

The tensile characteristics of asphalt mixtures were evaluated by loading the Marshall specimen along a diametric plane with a compressive load at a constant rate acting parallel to and along the vertical diametrical plane of the specimen through two opposite loading strips. The static indirect tensile strength of a specimen was determined using the procedure outlined in ASTM D 6931.

![Figure 1. Cabinet temperature programing for freeze thaw cycles](image_url)
Results

Performance of the MEPDG fatigue and dynamic modulus predictive models

The current MEPDG uses the Witczak model developed in 1999 for dynamic modulus ($E^*$) estimation. This model predicts $E^*$ values of asphalt mixtures from 8 input parameters that characterize aggregate gradation, asphalt binder behaviour, binder–aggregate interaction, air void content and loading condition.

Moduli $|E^*|$ that were experimentally determined from the laboratory can be compared with values obtained by Witczak model. The comparison of the laboratory-measured versus predicted is based on eight temperatures, seven frequencies and four different percentages of air voids, before and after 150, and 300 rapid freeze-thaw cycles.

The results from the (figure 2) showed that the performance investigated before and after freeze-thaw cycles varied based on number of freeze-thaw cycles. The accuracy will be enhanced by introducing a local calibration factor.

Figure 2. Predicted values versus measured values of $E^*$ on a log-log scale: before freeze-thaw cycles (Blue line); After 150 freeze-thaw cycles (Green line); C: After 300 freeze-thaw cycles (Red line)
Analysis of the fatigue life

Fatigue test results are usually expressed as the Wöhler curve. Wöhler curve represents the fatigue life versus the amplitude of the applied strain in logarithmic axes. Figure 3 indicates the comparison of parameter of $\varepsilon_6$ for the reference samples and after the environmental freeze-thaw cycles based on two different fatigue failure criteria. $\varepsilon_6$ value corresponds to the strain amplitude for a failure at 1,000,000 cycles. The reference mixture has much better performances regarding resistance to fatigue cracking than the mix after repeated freeze-thaw cycles.

![Comparison of parameter of $\varepsilon_6$ for the reference samples and after the environmental freeze-thaw cycles](image)

**Figure 3.** Comparison of parameter of $\varepsilon_6$ for the reference samples and after the environmental freeze-thaw cycles

Indirect Tensile Strength (ITS) Test Results

The value of ITS is corresponding to the cracking resistance of mix. Figure 4 compares the results of tensile strength before and after the freeze-thaw cycles. Specimens have different trend after the effect of F-T cycles compare to the reference specimen. Increasing the number of cycles lead to decrease the tensile strength of the material.
Application of Geosynthetics in cold regions

It is well documented that fine-grained soils are susceptible to freeze-thaw cycles which in turn can change strength, compressibility, and permeability of soils. Regehr et al. [6] indicated that normal issues in cold regions often stem from scattered ice lenses and unfrozen ground, temperature gradient within the unfrozen soil layer, freeze-thaw cycles, and existence of ice and water in subgrade. Despite there have been innumerable studies in geotechnical related structures in cold regions, long-term performance of these structures in such regions have not been always meet the purpose [6]. It is obvious that during warmer weather, subgrade experience weakness and pavements are more vulnerable to rutting and fatigue cracking. Polymer-based Geosynthetics have been widely applied to address this issue.

Geosynthetic is defined by ASTM as a planar product manufactured from a polymeric material that is used with soil, rock, or other geotechnical-related material as an integral part of civil engineering projects [7].

Geosynthetics because of their pertaining benefits to economics, construction expediency, and functional superiority (lightness, durability, ease of installation, resistant
to corrosion, etc.) have been commonly employed for geotechnical-related structures like pavements and other applications.

Among other features (e.g. drainage, separation, reinforcement, fluid barrier, and protection), reinforcement function can play an important role to lessen the negative effect of freeze-thaw cycles on pavement bearing capacity.

Reinforcement provided by geosynthetics has three main attributes:

- To increase the structural capacity of a pavement system over a weak subgrade;
- To increase the service life of the pavement;
- To reduce pavement thickness with the same performance.

It should be noted that the effectiveness of geosynthetics materials to obtain above mentioned benefits depends on the geosynthetic fibers stiffness, tensile strength, its position and interfacial bonding strength in the pavement structure [8]. Furthermore, for reinforcement to be effective, it is essential that it is placed in a zone under tension during traffic and environmental loading applications because it allows to geogrid carrying tensile loads through tension membrane action.

The reinforcement function is provided through three mechanisms [9]:

**Lateral confinement** through interfacial friction and interlock between aggregate, soil and the geosynthetic as figure 1. When a loaded area is applied over an aggregate layer, the layer hastendency to move laterally. In case of application a geosynthetic layer, the movement can be restrained by transferring shear stresses induced by traffic loads to tensile stresses in the geosynthetic [10]. Therefore, frictional characteristics between the soil and geosynthetic are required to specify this mechanism.
Enhanced bearing capacity by extending the plane of shear failure in the soil, as figure 2. Based on this mechanism the failure model of subgrade soil may change from punching failure to general failure by inclusion of geogrid in pavement.

Membrane support of the wheel loads, as figure 3. This mechanism only develops under heavy loads which cause rutting in the subgrade. In this case, vertical components of tension stresses developed in the geosynthetic layer cause to support the applied loads. It should be noted that the tension membrane force is not vertical, but its vertical component decreases the vertical pressure applied on the subgrade soil.
Regehr et al. [6] proposed four main alternatives to mitigate the possibility of sungrade degradation in roadways located in cold regions: (1) controlling roadbed thawing, (2) cooling roadbed, (3) insulating roadbed, and (4) reducing roadbed fill weight. Allen et al. [12] and Henry and Holtz [13] took advantage of geotextiles and geocomposites to lessen frost heave in soils by making capillary barriers. The study conducted by Zhang and Presler [14] demonstrated that the use of wicking fabrics to reduce moisture in roadways to mitigate frost boils. Henry and Stormont [15] suggested the application of the Geocomposite Capillary Barrier Drain (GCBD) to reduce frost damage in pavement structures. The GCBD made of a capillary barrier as the core encompassed by a geotextile separator at the bottom and a geotextile at the top. The capillary barrier has relatively coarse openings to hinder upward or downward unsaturated flow. The applied geotextile was a heavy woven, multifilament material with a relatively large thickness (mass per unit area = 2,370 g/m², thickness = 3.2 mm, and O₉₅ = 0.075 mm. Geotextiles have also been employed to avoid erosion in cold regions [16].

Han and Jiang [17] indicated that geosynthetics at low temperature have enhanced tensile strength and stiffness, lower creep rate, and lower elongation at failure. It was also shown that the inclusion of geosynthetics in soil structure provides drainage to water flow, retains mechanical properties, and reduces frost heave during and after freeze-thaw cycles.

Figure 7. Membrane support mechanism [11]
which provide higher engineering performance for pavement in low-temperature condition.

**Conclusion**

The aim of this research is to improve the current MEPDG methods for fatigue and dynamic modulus predictive models take into account the effect of freeze-thaw cycles. So far, it is found that the effect of freeze-thaw cycles is important to consider during the design life of asphalt pavement. The results indicate that the air voids content do affect the complex modulus value, and that that freeze-thaw cycles do decrease the value of the modulus. Regarding resistance to the performance tests (fatigue and ITS), the reference mixture has much better performances than the conditioned mix.

Furthermore, geosynthetic-reinforced pavement can be viewed as a reliable option to enhance pavement performance in terms of higher stiffness and lower deformation before failure.

**References**


