Cold Regions Science and Technology 141 (2017) 8–15

Contents lists available at ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Degradation of asphalt mixtures with glass aggregates subjected to freeze-thaw cycles

Éric Lachance-Tremblay[a,*], Daniel Perraton[a], Michel Vaillancourt[a], Hervé Di Benedetto[b]

[a] École de Technologie Supérieure (ÉTS), Department of Construction Engineering, 1100 Notre-Dame Ouest, Montréal, Québec H3C 1K3, Canada
[b] Université de Lyon – École Nationale des Travaux Publics de l'État (ENTPE), LGCB, LTDS (CNRS 5513), Rue Maurice-Audin, 69518 Vaulx-en-Velin, France

ARTICLE INFO

Keywords:
Glass asphalt
Water
Freeze-thaw cycles
Moisture susceptibility
Complex modulus
Stiffness

ABSTRACT

Pavements in cold regions undergo extreme weather conditions such as prolonged exposure to water and repeated freeze-thaw cycles (FT). The objective of this paper was to evaluate the moisture susceptibility and degradation due to FT of asphalt mixture with glass aggregates. This was done using a new method based on complex modulus measurements. Samples were tested in dry condition and then saturated with water prior to various conditioning such as hot water soaking and multiple FT. The 2S2P1D rheological model was used to simulate the materials behaviour and evaluate the evolution of linear viscoelastic properties. Results showed that the presence of water in the mixture voids increased the mixture stiffness at temperature below freezing point. Also, repeated FT damaged the samples, glass asphalt mixture was damaged faster than the reference mixture. However, both mixtures reached equivalent damage after 10 FT cycles.

1. Introduction

Nowadays, the use of recycled materials and industrial byproducts in pavement structure, specifically in hot mix asphalt (HMA), is strongly favoured because of its economic and environmental advantages. Recycled glass can be crushed and used in HMA. Its use in HMA as a replacement of conventional aggregate or as a filler has recently been studied (Androjić and Dimter, 2016; Arabani et al., 2016; Lachance-Tremblay et al., 2016a; Lachance-Tremblay et al., 2016b; Shafabakhsh and Sajed, 2014; Bachand et al., 2016). Main advantage from both economic and environmental point of view is that the volume of binder absorbed by the glass aggregate decrease compared with conventional aggregate, which means that the optimal binder content decrease (Lachance-Tremblay et al., 2016a). However, glass aggregate is known to be responsible for an increase in moisture susceptibility (Airey et al., 2004; Maupin, 1998; Lachance-Tremblay et al., 2016a).

Asphalt pavements prolonged exposure to water can lead to stripping of the binder from the aggregate surfaces. Moisture damage in HMA is known as a physico-chemical phenomenon and can cause degradation of the mixture mechanical properties due to a loss of adhesion between binder aggregates (known as stripping) and/or a weakening of the cohesive resistance of the binder mastic (Kakade et al., 2016). Evaluation of the moisture susceptibility of HMA is normally conducted on loose aggregate coated with binder or on HMA compacted samples, both methods having their respective disadvantages. Tests conducted on loose aggregate, such as rolling bottle tests, have poor reproducibility mainly because the results are based on visual interpretation (Porot et al., 2016). Tests conducted on compacted samples, most common being AASHTO T-283 (TSR) and the Hamburg wheel track test, are often used for their simplicity. However, those tests are empirical, fail to relate with pavement field performances and are susceptible to give misinterpretation of moisture susceptibility (Buss et al., 2016; Vargas-Nordcbeck et al., 2016).

In cold climate, asphalt mixture used in pavement structure undergo extreme weather conditions such as rain, melting snow and freeze-thaw cycles which can lead to premature damage (Lamothe et al., 2015). When temperatures are below freezing point, the water in the asphalt mixture voids can lead to premature damage due to water expansion when freezing. In fact, freeze-thaw damage is considered as one of the major causes of degradation of asphalt pavement in cold regions such as Canada (El-Hakim and Tighe, 2014). It is well known that repeated freeze-thaw cycle leads to an increase of asphalt mixture voids content (Feng et al., 2010; Özgan and Serin, 2013; Xu et al., 2015; Xu et al., 2016; Yan et al., 2015). As a consequence, water can move more easily through the asphalt voids (Xu et al., 2016). In some region such as Quebec, pavement structures are exposed to multiple freeze-thaw cycles per winter (often over 40) (Lamothe et al., 2017).

The objective of this paper is to evaluate the moisture susceptibility

* Corresponding author.
E-mail addresses: eric.lachance-tremblay.1@ens.etsmtl.ca (É. Lachance-Tremblay), daniel.perraton@etsmtl.ca (D. Perraton), michel.vaillancourt@etsmtl.ca (M. Vaillancourt), herve.dibenedetto@entpe.fr (H. Di Benedetto).

http://dx.doi.org/10.1016/j.coldregions.2017.05.003
Received 16 March 2017; Received in revised form 1 May 2017; Accepted 20 May 2017
Available online 21 May 2017
0165-232X/

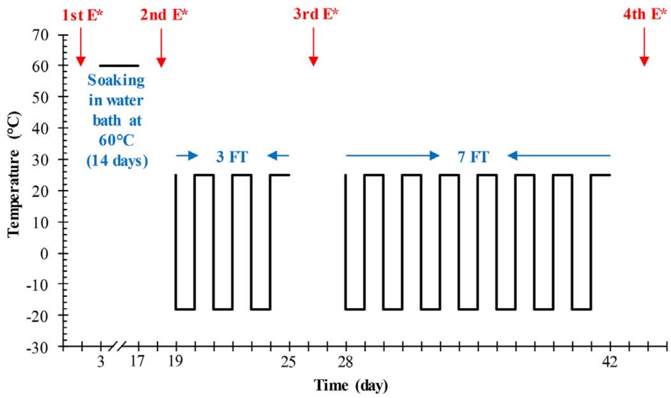

Fig. 1. Testing and conditioning procedure: Four complex modulus (E*) tests were performed for each sample after various conditioning.

and degradation due to freeze-thaw cycles of glass asphalt samples tested using a new method based on complex modulus (E*) measurements (Lamothe et al., 2017; Perraton et al., 2016). Then, the glass asphalt mixture performances are compared with a reference mixture. The use of recycled glass as an aggregate in cold regions pavement structure is currently being studied at the *Laboratoire des Chaussées et Matériaux Bitumineux* (Pavements and Bituminous Materials Laboratory) of *École de Technologie Supérieure* in Montreal, Quebec, Canada.

2. Experimental program

For this paper, two samples were used for complex modulus test, one for the reference mixture and one for the glass asphalt mixture. For each sample, four complex modulus tests were done: 1) in dry condition, 2) after 14 days in hot water bath (60 °C), 3) after 3 freeze-thaw cycles and 4) after 10 freeze-thaw cycles. Fig. 1 shows the detailed sequence of testing and conditioning. For the second E* test (WET), the sample was tested only at temperatures over freezing point. The goal was to quantify the effect of water soaking (i.e. stripping) on linear viscoelastic properties without the degradation due to freeze-thaw cycles. This was done in order to assess the moisture susceptibility. For the third and fourth E* test (3 FT and 10 FT), the goal was to quantify the degradation due to freeze-thaw cycles in order to assess the durability.

3. Material and samples preparation

3.1. Materials

An asphalt mixture with a nominal aggregate size of 0/10 mm (ESG10, Quebec standard) with a polymer modified binder PG70-28 (Table 1) was used. This type of mixture is often used as a surface course in the Quebec region. Fig. 2 shows the granular curve as well as the specifications for ESG10 mixture (Québec, 2016). Both mixtures were prepared with the same effective volumetric binder content (V_{be}), which is a criterion in the Quebec standard (Québec, 2016). Mix design characteristics are found in Table 2. For the glass-asphalt mixture, 20% of the volume of limestone aggregates were replaced with glass aggregates of three different sizes: 1) 6% of glass 1.25–2.5 mm, 2) 7% of glass 0.630–1.25 mm and 3) 7% of glass 0.315–0.630 mm. Hydrated lime was used as an anti-stripping agent, 2% of the weight of aggregates, to improve the stripping resistance (Table 3). Also, hydrated lime is known to improve the freeze-thaw cycle resistance (Yan et al., 2015).

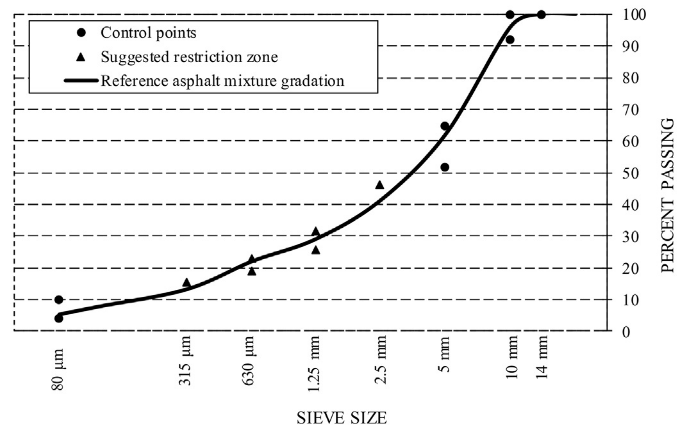

Fig. 2. ESG10 control mixture gradation curve with control points and suggested restriction zone (Québec, 2016).

Table 2
Mixture characteristics and volumetric properties.

Mixture	G_{mm}	b[a] (%)	V_{ba}[b] (%)	V_{be}[c] (%)	Limestone volume (%)	Glass volume (%)
Reference	2.536	5.4	1.3	12.2	100	0
Glass	2.498	5.3	0.8	12.2	80	20

[a] Binder content by mass.
[b] Volume of absorbed binder.
[c] Volume of effective binder.

3.2. Samples preparation

All samples used in this study were prepared in the laboratory. The limestone aggregates, glass aggregates and hydrated lime were heated to 180 °C, and the binder to 168 °C, with a tolerance of ± 2 °C prior to mixing. The heated aggregates were first mixed with the hydrated lime, and then mixed with the binder until a homogenous visual rendering was obtained. After mixing, samples were cured in a covered pan at 160 °C in a ventilated oven for a minimum of 30 min, but no > 2 h to prevent oxidation of the binder. The samples used for E* testing were cored from samples compacted using a gyratory compactor mould of 150 mm diameter and 170 mm height to a target void content of 5.5% ± 0.5%. The cored samples were 75 mm in diameter and 150 mm in length.

3.3. Samples conditioning

For each sample, four complex modulus E* test were done. The first E* test was done in dry condition to characterize the mixture initial

Table 1
PG70-28 binder characteristics.

Specific gravity	1.022
Viscosity at 135 °C (Pa·s)	1.097
Viscosity at 165 °C (Pa·s)	0.312
Ring & Ball temperature (°C)	58.2
Penetration at 25 °C (10^{-1} mm)	131
Elastic recovery (%) at 10 °C[a]	75

[a] ASTM D6084-13.

Table 3
Hydrated lime characteristics.

Specific gravity	2.24
Available CaO (%)	70.3
Available $Ca(OH)_2$ (%)	92.8