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Effect of hydrated lime on linear viscoelastic properties of asphalt mixtures with glass aggregates subjected to freeze-thaw cycles

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HIGHLIGHTS

- Hydrated lime reduces the variation of LVE properties exposed to conditioning.
- Hydrated lime must be used with high glass aggregate content (60%).
- Master curves of the complex modulus norm superimpose in DRY and WET condition.

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ABSTRACT

This paper focuses on the effect of hydrated lime on the linear viscoelastic (LVE) properties of asphalt mixtures with glass aggregates subjected to conditioning: 1) 14 days in hot water and 2) repeated freeze-thaw cycles. Complex modulus test was used to evaluate LVE properties. Three glass aggregates (0%, 20%, 60%) and two hydrated lime (0%, 2%) content were studied. Results show LVE properties of samples with glass aggregates (0% hydrated lime) are greatly affected by conditioning. Adding hydrated lime to samples with glass aggregates significantly reduce the variation of LVE properties due to conditioning.

1. Introduction

In North America, glass recycling faces an important challenge [1]. Glass is a material that can be easily melted and reused to manufacture new glass products. To do so, the recycled glass must be exempt from any source of contamination such as paper, plastic or any other materials that can be collected during the recycling process [2]. Moreover, to reuse recycled glass to manufacture new glass products, collected glass must be separated and classified according to the type and color. However, most of the recycling sorting facilities in North America doesn't have the equipment required to produce a recycled glass quality that meets the needs of the recycling companies [1]. As an example, in 2015 in Quebec province, 86 000 tons of glass was sent to the landfills, which is an increase of 120% compared with 2012 [3]. Some research projects are trying to find alternatives to disposal in landfills for recycled glass.

The use of recycled glass in pavement structures, especially in asphalt mixtures, is the subject of some recent research publications [4–6]. However, asphalt mixtures with glass aggregates might have a higher moisture susceptibility compared with conventional asphalt mixture. Silica (SiO_2) is the main chemical component of glass. Aggregates with high content of SiO_2 are classified as siliceous aggregates and are typically considered hydrophilic (high attracting power with water) [7]. It is well known in the literature that siliceous aggregates have poor adhesion properties with bituminous binder (in comparison with limestone aggregates) which result in poorer adhesion thus increasing the stripping potential [7–11]. General explanation suggests that the acids of siliceous aggregates counteract with the acids of the asphalt binder (repulsive forces) which make it very difficult to obtain a good aggregate-binder bond [12]. To improve the adhesion between siliceous aggregates and therefore, improve the durability of asphalt mixtures, hydrated lime is often added as an

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anti-stripping agent [13–15]. Hydrated lime changes the aggregates surface by allowing precipitation of calcium ions on the aggregates surface. Those calcium ions bond with the acids from the bituminous binder therefore creating water-insoluble salts [16]. Therefore, there is an improvement of the adhesion between the binder and the aggregate surfaces and the tendency of the binder to be stripped from the surfaces of the aggregates is reduced [17]. Moreover, some authors consider that hydrated lime improves the durability to freeze-thaw cycles [18] and slows down the aging of the bituminous binder [13,15]. A recent research has shown that in the case of asphalt mixture with glass aggregate, hydrated lime significantly improve the mixture resistance to stripping [19].

This paper presents an evaluation of the effect of hydrated lime on asphalt mixtures with glass aggregates subjected to hot water conditioning and freeze-thaw cycles. To do so, the linear viscoelastic (LVE) properties were evaluated using complex modulus (E^*) test at different state of conditioning. First, a description of the experimental program and the 2S2P1D LVE model is presented. Then, the experimental results are presented, and the evolution of parameters linked with LVE properties (2S2P1D modelling parameters, experimental shift factors) is discussed.

Table 1
PG 70-28 Binder Characteristics.

Specific gravity	1.022
Viscosity at 135 °C (Pa·s)	1.097
Viscosity at 165 °C (Pa·s)	0.312
T_L (°C)	−32.8
T_H (°C)	73.8
Ring & Ball temperature (°C)	58.2
Penetration at 25 °C (10^{-1} mm)	131
Elastic Recovery (%) at 10 °C[1]	75

[1] ASTM D6084-13.

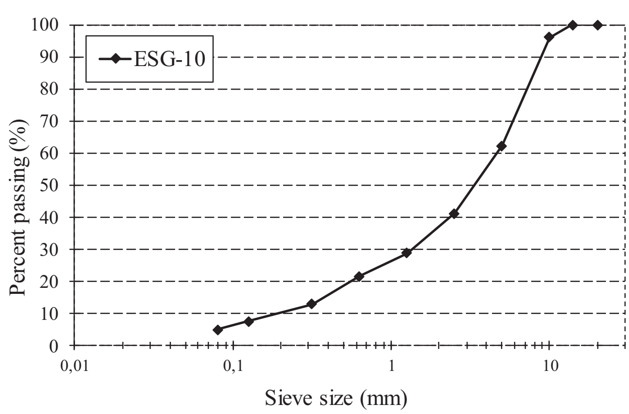

Fig. 1. ESG-10 reference mixture gradation curve.

2. Experimental program

2.1. Tested materials

One type of asphalt mixture with a nominal aggregate size of 0/10 mm (ESG-10, ESG: *Enrobé semi-grenu*) with a polymer modified binder PG70-28 (Table 1) was used. Fig. 1 shows the gradation curve for the ESG-10 reference mixture. Three different glass contents (0% identified as reference, 20% and 60% by volume of the aggregates) and two hydrated lime content (0% and 2% by mass of the aggregates) were studied (Table 2). The glass aggregates proportions (sizes from 0 mm to 5 mm, presented in Table 2) were chosen to keep as constant the gradation curve shown in Fig. 1. Hydrated lime was used as an anti-stripping agent in replacement of a conventional limestone filler.

2.2. Samples preparation and conditioning

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 limestone filler or hydrated lime for homogenization and then with the binder for 60 to 90 s. After mixing, loose HMA samples were cured in a covered pan at 160 °C in a ventilated oven for a minimum of 30 min, but no >2 h. After curing, HMA samples were compacted using a shear gyratory compactor (SGC) mould with 150 mm diameter. The mass of HMA placed in the SGC mould was chosen to get a 170 mm sample height at a target void content of 5.5 ± 1 percent. The complex modulus testing samples were cored/sawed from SGC compacted samples at 75 mm diameter and 150 mm length.

The complex modulus (E^*) tests performed are presented in Table 3. The testing temperatures and frequencies used for the E^* tests are presented in Table 4. The first E^* test was done in dry condition (DRY), which gave the initial Linear Viscoelastic (LVE) properties of the sample (referenced as «dry state»). The sample was then saturated with water to a level of saturation between 70% and 80%. To introduce water in the sample voids network, a saturation process under vacuum was used. Once the level of saturation was reached, the sample was placed on a sand bed in a water bath at 60 °C for 14 days of conditioning. The sand bed

Table 2
Voids content of the specimen and proportions of the different aggregates used.

Asphalt mixture		REF	REF-HL	20G	20-HL	60G	60G-HL
Glass content (% by volume of the aggregates)		0	0	20	20	60	60
Hydrated lime content (% by mass of the aggregates)		0	2	0	2	0	2
Specimen voids content (%)		5.4	5.7	5.7	5.1	5.0	4.7
Proportion of the different aggregates used (% by mass)	Limestone 5–10 mm	39	39.0	40.6	39.7	42.8	42.8
	Limestone 0–5 mm	35.6	35.5	32.2	31.5	0	0
	Limestone 0–5 mm washed	14.8	14.7	8.7	8.4	0	0
	Sand 0–1.25 mm	8.9	8.8	0	0	0	0
	Limestone filler	1.7	0	0	0	0	0
	Hydrated lime	0	2.0	0	2.0	0	2.0
	Glass 1.25–5 mm	0	0	0	0	30.5	30.4
	Glass 1.25–2.5 mm	0	0	5.5	5.5	0	0
	Glass 0.630–1.25 mm	0	0	0	0	6.6	6.6
	Glass 0.160–0.630 mm	0	0	6.5	6.5	7.8	10.2
	Glass 0–0.630 mm	0	0	6.5	6.5	12.3	8.0