EFFECT OF HYDRATED LIME ON THE RESISTANCE OF ASPHALT MIXTURES TO WINTER-RELATED DAMAGE: MOISTURE, FREEZE-THAW AND DEICING SALTS

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ABSTRACT

The recent severe winter episodes all over Europe have shown that asphalt mixtures are vulnerable to winter climate and sollicitations: The usual damaging effect of moisture is enhanced when associated to freeze-thaw cycles. Also, the presence of deicing salts can modify these effects.

In this context, this study focuses on different ways to evaluate the resistance of asphalt mixtures to winter damage. The effect of aggregate origin (two having poor bitumen-aggregate adhesion and one having good adhesion) and of hydrated lime was assessed with the same bitumen source.

First, bitumen dewetting potential of the coarse 6/10 aggregate was quantified using a modified XP T 66-043 protocol (passive adhesion), with or without salts. This confirmed the strong stripping potential of two of the aggregate sources. Also, deicing salts increased the dewetting of all aggregates.

Then, moisture resistance of AC 10 mixtures was quantified using EN 12697-12 method B, with the usual conditioning of 7 days at 18°C but also with a conditioning of 3 days at 40°C, with or without salts. Salts were seen not to affect the results. The 3 days 40°C protocol was seen to be more severe than 7 days at 18°C.

Finally, freeze-thaw cycles were applied to the mixtures following a protocol adapted from the Lottman test (AASHTO T283).

As a result, the different testing methods give a different and somewhat divergent view of the stripping potential. In all cases, hydrated lime can successfully improve the resistance of asphalt mixtures to winter damage.

Keywords: hydrated lime, moisture, freeze-thaw, adhesion, deicing salt

1 INTRODUCTION

The recent severe winter episodes all over Europe have generated numerous damage to the road network, including premature formation of potholes in asphalt mixtures. This irreversible damage is generally favoured by the repetition of freeze-thaw cycles in the presence of moisture[1]. Mixture type, aggregate nature, binder choice and the presence or not of additives are the principal elements governing the resistance of the asphalt mixture to winter damage. More precisely, when cold temperature are intertwinned with rain falls, the water accumulating inside the pavement undergoes freeze-thaw cycles that can lead to the mixture failure and pothole formation. The failure occurs because of the volume expansion of the water turning into ice, which can damage the bitumen-aggregate bond. A study by Mauduit et al. [2] clearly demonstrated the damaging effect of ice formation as a function of moisture saturation for asphalt mixtures submitted to freeze-thaw cycles (Duriez size specimens).

Additives can be used to limit these damages. In a Japanese study by Hao and Hachiya [3], several solutions were tested including liquid antistrips, hydrated lime and cement. Hydrated lime was seen to be one of the most effective solution in order to improve the resistance of asphalt mixtures to freeze-thaw cycles. Similarly, Sebaaly [4] quantified that this improvement in the resistance to freeze-thaw cycles leads to a 38% longer durability. Finally, Huang et al.[5]confirmed this improved resistance to freeze-thaw cycles for asphalt mixtures containing hydrated lime.

Hydrated lime has been known as an additive for asphalt mixtures from their very beginning [6,7,8]. It experienced a strong interest during the 1970s in the USA, partly as a consequence of a general decrease in bitumen quality due to the petroleum crisis of 1973, when moisture damage and frost became some of the most pressing pavement failure modes of the time. Hydrated lime was observed to be the most effective additive [9] and as a consequence, it is now specified in many States. It is estimated that 10% of the asphalt mixtures produced in the USA now hold hydrated lime [10,11]. Similar observations led the Netherlands to specify hydrated lime in porous asphalt [11,12], a type of mix that now covers 70% of the highways in the country. As a result, hydrated lime is being increasingly used in asphalt mixtures in most European countries, in particular Austria, France, the Netherlands, the United Kingdom and Switzerland.

The effects of hydrated lime on asphalt mixtures have been thoroughly studied [8,13] showing an overall increased durability coming from improved resistances to moisture-damage, fatigue and rutting together with a reduction in bitumen chemical ageing.

In this paper, we present experimental results on the effect of freeze-thaw cycles on several asphalt mixtures, made out of different aggregate origins, with or without hydrated lime and in the presence or not of de-icing salts. This study's goal is to compare and to optimize also the method of laboratory to estimate the water resistance and the freeze-thaw resistance of asphalt.

2 EXPERIMENTAL

We compared the mechanical performance of asphalt mixtures made from three different aggregate, known for their good or not-so-good adhesion with bitumen.

The study was performed in three steps:

- Validate the good or not-so-good adhesion through passive adhesion test on the basic components (bitumen / aggregate or mastic / aggregate),
- Moisture damage on asphalt mixtures made out of the three aggregate origins, with or without hydrated lime, in the presence or not of de-icing salts, using standard tests, sometimes slightly modified in terms of time and type of conditioning,
- Influence of freeze-thaw cycles following a specific test protocol.

The mechanical properties were measured in a destructive way (i.e. compressive strength) and the study therefore necessitated a large amount of specimens.

2.1 Materials

Three aggregates coming from French quarries were used:

- G1, a rhyolite known for its not-so-good adhesion with bitumen,
- G2, a crushed river gravel known for its not-so-good adhesion with bitumen,
- G3, a microdiorite known for its good adhesion with bitumen.

In some instances, a limestone filler was used.
A Total 35/50 bitumen and a calcic hydrated lime Asphacal® H100 from the Dugny plant of Lhoist, conforming to CL 90 S according to NF EN 459-1 (CL for calcic lime, 90, for 90 % of CaO + MgO, S for “slaked”) were used throughout the study. Class A sodium chloride de-icing salts from the City of Paris were used in the work.

The tested asphalt mixtures were AC 10 surf 35/50 mixtures according to NF EN 13108-1 (Béton Bitumineux Semi-Grenu BBSG 0/10 in the former French nomenclature), manufactured in a BBMax25 (MLPC) mixer following NF EN 12697-35 [14]. The binder content was fixed according to the density of aggregates and our experiences on asphalts with these materials.

Table 1: Composition of the tested asphalt mixtures.

		G1	G1 + hydrated lime	G2	G2 + hydrated lime	G3	G3 + hydrated lime
% passing	12.5 mm	100.0	100.0	100.0	100.0	99.9	99.9
	10 mm	95.2	95.2	91.1	91.1	93.3	93.3
	6.3 mm	60.6	60.6	56.3	56.3	58.0	58.0
	4 mm	50.1	50.1	47.6	47.6	47.5	47.5
	2 mm	33.2	33.2	28.7	28.7	35.1	35.1
	1 mm	21.7	21.7	24.2	24.2	23.9	23.9
	63 µm	7.3	7.3	6.4	6.4	6.6	6.6
% limestone filler		2	1	3	2	2	1
% hydrated lime		0	1	0	1	0	1
binder content (% based on aggregate)		6.0	6.0	5.8	5.8	5.3	5.3
air voids (*)(%)		15.9	15.1	12.0	10.8	10.8	10.8

(*) : geometrical determination

2.2 Passive Adhesion Test

Passive adhesion test according to XP T 66-043 [15], allows to visualize the dewetting of the bitumen from the aggregate in presence of water. It is very simple and only necessitate small amounts of materials. However, its quantification remains difficult because it consists in a visual estimate of the quality of coating expressed in % of covered surface. Also, it is measured only on the 6/10 aggregate fraction and not on the asphalt mixture. Still, it clearly differentiates between materials.

In our case, three objectives were assigned to the testing:

- Confirm the choice of aggregate (especially the good / not-so-good adhesion),
- Estimate the effect of de-icing salts,
- Modify the protocol in order to assess the effect of hydrated lime.

Practically, 100 g of a 6/10 aggregate are dried at 110°C during at least 12 hours in a ventilated oven. They are manually mixed with 5 g of a 35/50 bitumen at 150°C. The coated aggregate is left to cool down at room temperature in a beaker for 30 min. Then, 300 ml of water at 60°C are poored onto the coated aggregate. The filled beaker is placed for 16 hours in an oven at 60°C and a visual estimate of the coating extent after the conditioning is performed (% of covered surface).

The same protocol was also applied with water containing 2 wt.% of de-icing salts.

When mastics were used, 1 g of filler was added to the 5 g of bitumen prior to mixing with the aggregate. Note that this filler / bitumen ratio was similar to the hydrated lime / bitumen ratio in the asphalt mixture (Table 1).

In all cases, the final result was expressed in terms of % of aggregate surface covered with the bitumen after the conditioning. The result was obtained as a mean of 5 measures from 5 different trained operators. As defined in the standard, each operator gave a mark chosen between 100, 90, 50, <50 or 0 %.

2.3 Asphalt mixtures specimens conditioning

Several parameters were maintained constant in all cases:

- Manufacturing specimens following the standard Duriez procedure :compaction of sample under a static 60kN load during 300s (NF EN 12697-12 method B [16]),
- Moisture saturation of the specimens conditioned in water between 55 and 80% (Lottman procedure [17]),
- Compressive strength at a loading rate of 1mm/s,
- 3hours annealing at ambient testing temperature after conditioning in water (in order to have the same good thermal homogeneity of the specimens)
- 18 Duriez samples for each asphalt from a same manufacturing (3 specimens for each condition) .

2.4 Moisture damage testing

Moisture damage was studied using two different protocols, adapted from the following methods:

- European standard for moisture damage (NF EN 12697-12 method B [16]): compressive strength after conditioning 7 days at 18°C in air (C) or in a water bath (i), to determine i/C,
- European standard for moisture damage (NF EN 12697-12 method A [16]): indirect tensile strength (ITS) after conditioning 72 hours at room temperature in air (ITS dry) or at 40°C in a water bath (ITS wet),
- American standard (Lottman test –[17]) : indirect tensile strength (ITS) after conditioning at room temperature in air (ITS dry) or following a freeze-thaw cycle consisting in 16 hours à -18°C and 24 hours at 60°C.

In order to limit the number of parameters, we decided to measure strength always in the compressive mode.

Three conditioning temperatures were tested : 18°C (classical Duriez), 40°C et 60°C (only performed on mixes based on G1 aggregate)

Saturation degree was checked by weighing each specimen after compaction and after water saturation.

2.5 Freeze-thaw testing

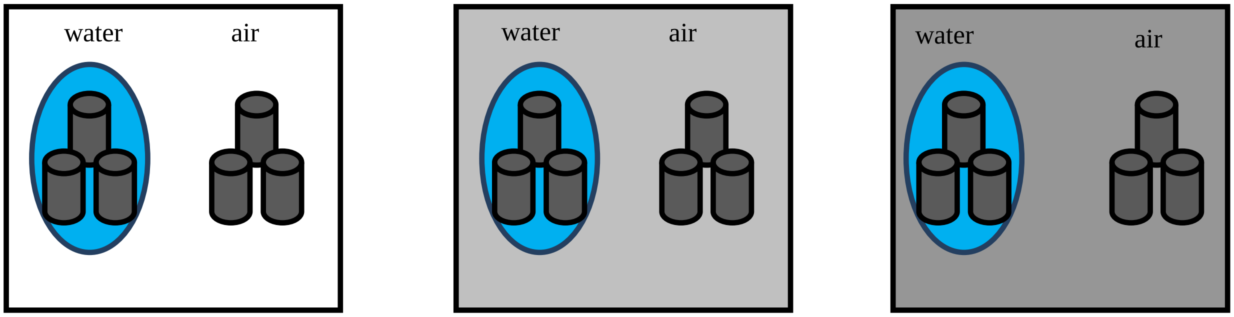
Freeze-thaw damage was studied a protocol adapted from the following method:

- American standard (Lottman test –[17]) : indirect tensile strength (ITS) after conditioning at room temperature in air (ITS dry) or following a freeze-thaw cycle consisting in 15 hours à -18°C and 24 hours at 60°C in water.

This procedure is sometimes repeated [4,5].

Again, and in order to limit the number of parameters and make tests easier to compare, some of the parameters were kept constant (see section 2.3). In particular, strength was again measured in the compressive mode.

Practically, 18 Duriez specimens were separated into 3 sets of 6 samples each (Figure 1). Each set was used for a certain number of freeze-thaw cycles. Each set is divided in two subsets of 3 samples each: one subset being moisture-saturated, the other being kept dry. Both subsets experience the same temperature conditioning. For practical reasons, the freezing cycles lasted 20 hours à -18°C and the thawing cycles 52 hours at 40°C (hence 72 hours in total or 3 days), a slight deviation from the strict Lottman protocol [17].



1 cycle **2 or 3 cycles** **3 or 5 cycles**

Figure 1: Schematic of the repartition of specimens for freeze-thaw testing: Three sets of 6 samples were obtained, each set divided into subsets, one moisture-saturated and the other dry. All subsets experienced the same temperature conditioning.

3 PRELIMINARY TESTS

3.1 Effect of conditioning temperature on the compressive strength of dry specimens

In a first step, we studied the effect of the temperature of the dry conditioning on the compressive strength at room temperature of the materials:

- 3 or 7 days at 20°C for the dry conditioning as required in the standard NF EN 12697-12 method B,
- 3 or 7 days at 40°C for the dry conditioning.

This step was necessary in order to assess whether the possible differences in retained compressive strengths between a water conditioning at 18°C (Duriez) or at 40°C (ITSR), could come from differences in the thermal history instead of adhesion related problems. Results are given in Table 2 below.

Table 2: Compressive strength at room temperature of the dry specimens after various (dry) thermal histories: 3 or 7 days at 20 or 40°C (mean of three specimens for each condition)

		3 days				**7 days**			
		Air (40°C)		Air (20°C)		Air (40°C)		Air (20°C)	
		Compressive strength (MPa)	Standard deviation	Compressive strength (MPa)	Standard deviation	Compressive strength (MPa)	Standard deviation	Compressive strength (MPa)	Standard deviation
G1	Without lime	9.17	0.17	10.15	0.29	9.17	0.09	10.10	0.70
	With lime	9.97	0.62	10.87	0.50	9.67	0.09	10.00	0.59
G2	Without lime	10.45	0.04	11.37	0.31	8.77	0.21	10.40	0.36
	With lime	10.27	0.19	10.37	0.29	10.7	0.25	11.17	0.33
G3	Without lime	11.60	0.64	11.50	0.92	12.58	0.37	12.70	0.65
	With lime	12.63	0.54	13.90	0.71	11.5	0.90	12.13	0.05
Standard deviation mean		0.435				0.383			

As a result, compressive strengths tend to be systematically lower after the 40°C conditioning than after the 20°C conditioning whathever the nature of aggregates and bitumen content. This could be a systematic effect due to a slight heterogeneous thermal state of the samples coming from 40°C, which could have a somewhat softer core not fully cooled to room temperature (annealing time was 3 hours for 1kg specimens).

These results could be completed with a study on air void content ‘s influence.

In all cases, and given the measured standard deviation on compressive strength, the differences are barely significative. Still, we considered that the thermal history effect could be present and therefore mimicked the wet thermal history for the dry specimen. In other words, dry specimens used to calculate the i/C ratio for a wet conditioning at 40 or 60°C, were also stored at the same dry temperature before testing.

3.2 Effect of a wet conditioning temperature of 60°C as compared to 40°C

Given that the Lottman test considers a conditioning at 60°C (thawing cycle) whereas the European standard method A considers a wet conditioning at 40°C (ITSR), we tried to evaluate the impact of 60°C versus 40°C on one of the water-sensitive materials (G1). Specimens were tested after conditioning in air (to obtain C) or in water (to obtain i) at 40°C or 60°C. Results are given in Figure 2.

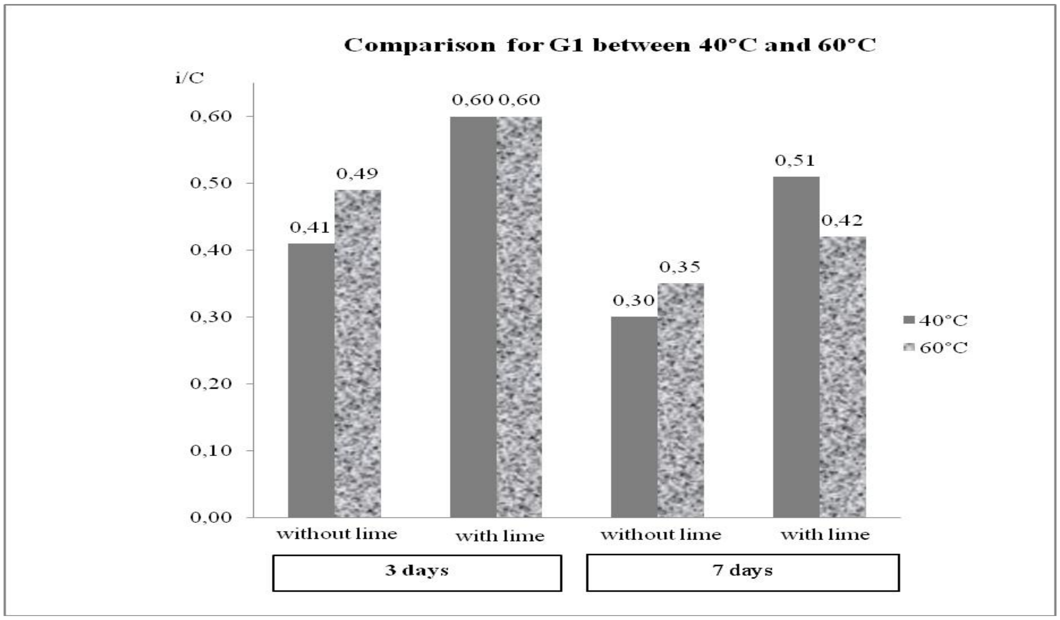


Figure 2: i/C ratio for asphalt mixtures based on G1 aggregate after 3 or 7 days conditioning at 40 or 60°C.

Given the repeatability of the test, we did not observe significant differences between the two conditioning temperatures. These tests are made only on one material but with a bad adhesion characteristic.

Therefore, we considered that 40°C would be enough to highlight differences that would not otherwise be captured by the normal Duriez conditioning (7 days at 18°C).

3.3 Effect of de-icing salts in the water bath

We tried to assess the effect of the presence or not of de-icing salts in the conditioning of the samples. In order to do so, we compared the i/C ratio for specimens after conditioning 7 days at 18°C (standard Duriez procedure – NF EN 12697-12 method B) or 3 days at 40°C (standard ITSR procedure – NF EN 12697-12 method A) in the presence or no of 2% de-icing salts in the water bath. Results are given in Table 3.

Table 3: i/C ratios for asphalt mixtures based on G1 or G3 aggregate after conditioning 7 days at 18°C (standard Duriez procedure – NF EN 12697-12 method B) or 3 days at 40°C (standard ITSR procedure – NF EN 12697-12 method A). Conditioning was done in normal or salted (2% NaCl) water.

		Duriez 18°C / 7 days	I/C 40°C / 3 days
G1 rhyolite	normal water	0.91	0.51
	salted water	0.94	0.50
G3 microdiorite	normal water	-	0.74
	salted water	0.95	0.70

Nota: Note that compressive strength was measured at 0.15 mm/min for all conditions instead of 1 mm/min.

Interestingly, i/C ratios were identical with or without de-icing salts. Thus, the detrimental effect of de-icing salts observed with the passive adhesion test (see section 4.1) was not seen in a Duriez or ITSR test. In all cases, note that the i/C for 40°C conditioning (ITSR) were always lower than for 18°C (Duriez).

4 RESULTS

4.1 Passive Adhesion

Results for the different aggregate in normal or salted water are shown in Figure 3 below. A clear difference could be seen between G3, known for its good adhesion and the other two aggregate, known for their not-so-good adhesion with bitumen. Interestingly, bitumen dewetting was always more intense in salted water than in normal water. Also, the presence of de-icing salts favoured the dissolution of some of the bitumen compounds in the presence of aggregates G1 and G2.

	G1 **6/10 rhyolite**	**G2** **6/10 river gravel**	**G3** **6/10 microdiorite**
In Water			
Coverage	**77%**	**50%**	**100%**
Comments	Very light traces of bitumen in water and some bitumen at the bottom of the beaker.	Clear water but some bitumen at the bottom of the beaker.	
In Salted Water		 <	
Coverage	**50%**	**< 50%**	**90%**
Comments	Light traces of bitumen in water	Bitumen-coloured water	

Figure 3: Results of the passive adhesion test for all three aggregates in the presence or not of de-icing salts (2% NaCl).

The same test was repeated with mastics instead of neat bitumen (Table 4).

In all cases, the negative effect of de-icing salts was again clearly observed. Also, aggregate G3 showed again a superior adhesion than the other two materials. The beneficial effect of hydrated lime could be clearly seen with G1(on aggregates and mastic) and G3 (only on aggregates). It was however less evident with aggregate G2 at the tested lime content. Note that the viscosifying effect of the mastic makes it more difficult to fully coat the aggregate prior to water immersion than with the neat bitumen. This effect was even more pronounced with lime-based mastics, as could be anticipated from the higher viscosifying effect of hydrated lime as compared to mineral filler [8].

Table 4: Results of the passive adhesion test for all three aggregates in the presence or not of de-icing salts (2% NaCl) for the mastics made at 20wt.% in the bitumen of either hydrated lime or the filler from the tested aggregate or limestone filler.

Aggregates	**G1 6/10 rhyolite**		**G2 6/10 river gravel**		**G3 6/10 microdiorite**	
Filler in mastic	G1	hydrated lime	G2	hydrated lime	limestone	hydrated lime
Coverage in Water	65%	70%	< 20%	40%	> 80%	> 80%
Coverage in Salted Water	50%	70%	< 20%	< 20%	> 80%	> 80%

Note: for G1 and G2 aggregates, we made mastic with the filler extracted from G1 or G2 sand to have the same nature. For G3, we use a classic limestone filler.

4.2 Moisture damage

4.2.1 Comparing Duriez (18°C, 7 days) and ITSR (40°C, 3 days) conditioning

All materials were tested after a conditioning of 7 days at 18°C or 3 days at 40°C (ITSR). Results are given in Table 5.

Table 5: i/C ratios for asphalt mixtures based on G1, G2 or G3 aggregate, with or without hydrated lime, after conditioning 7 days at 18°C (Duriez procedure – NF EN 12697-12 method B) and 3 days at 40°C (standard ITSR procedure – NF EN 12697-12 method A).

Aggregate in mixture	**G1 rhyolite**		**G2 river gravel**		**G3 microdiorite**	
	no lime	hydrated lime	no lime	hydrated lime	no lime	hydrated lime
Duriez (7 days 18°C)	-	-	0.88	0.99	0.93	0.97
ITSR (3 days 40°C)	0.41	0.60	0.60	0.64	0.70	0.91

Interestingly, results with the Duriez procedure give always pretty high values of the i/C ratio, whatever the tested material. For example, the difference between G2, with a not-so-good adhesion, and G3, with a good adhesion, is almost not significant. With the ITSR conditioning, differences become more significant.

In all cases, the beneficial effect of hydrated lime is always reflected by a higher i/C ratio, regardless of aggregate origin.

4.2.2 Effect of conditioning time at 40°C on the i/C ratio

All materials were also tested after a conditioning of 3 or 7 days at 40°C. Results are given in Table 6 and Figure 4.

Table 6: i/C ratios for asphalt mixtures based on G1, G2 or G3 aggregate, with or without hydrated lime, after conditioning 3 days at 40°C (standard ITSR procedure – NF EN 12697-12 method A) or 7 days at 40°C.

		i/C (Air-40°C)	
		3 days	7 days
G1	Without lime	0.41	0.35
	With lime	0.60	0.51
G2	Without lime	0.60	0.56
	With lime	0.64	0.66
G3	Without lime	0.70	0.76
	With lime	0.91	0.84

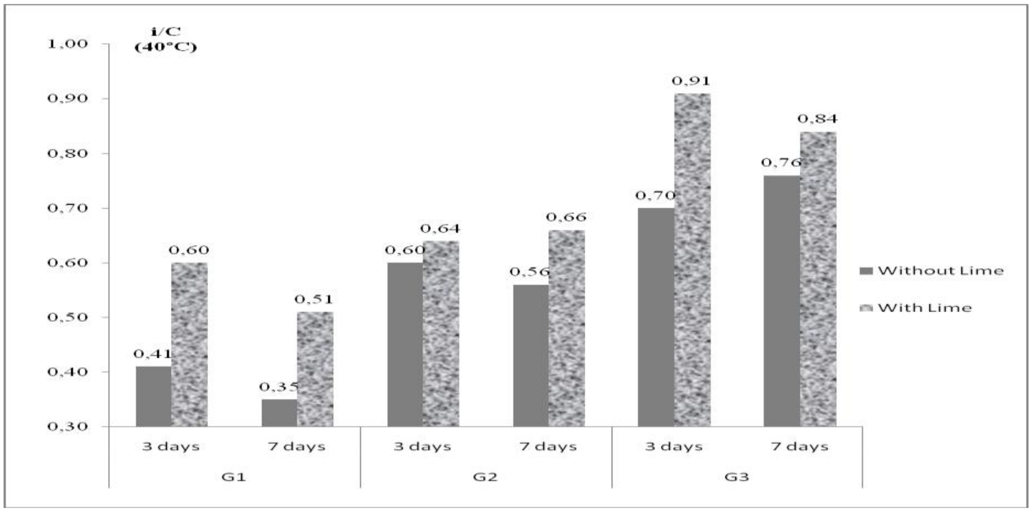


Figure 4: i/C ratios for asphalt mixtures based on G1, G2 or G3 aggregate, with or without hydrated lime, after conditioning 3 days at 40°C (standard ITSR procedure – NF EN 12697-12 method A) or 7 days at 40°C.

The different behaviour towards adhesion of aggregate G3, as compared to G1 and G2, is clear from the results without hydrated lime: i/C is superior to 0 .7 for G3 when it ranges from 0.35 to 0.6 for the other materials.

Asphalt mixtures with G1 without lime experienced a loss of adhesion of 15% when the conditioning was performed for 7 days instead of 3. Asphalt mixtures with G2 without lime experienced a lower loss of adhesion (7%) when the conditioning was performed for 7 days instead of 3. The difference between G1 and G2 in the extent of adhesion loss due to longer conditioning time could come in part from the differences in air voids (15% for G1 as compared to 11% for G2 – see Table 1). The higher density of G2 could make it somewhat less sensitive to longer conditioning times. In the mean time, asphalt mixtures with G3, known for its good adhesion, were not sensitive to an increase in conditioning time.

G1 and G2, both with a not-so-good adhesion, were similarly improved by lime addition. The presence of hydrated lime in asphalt mixture G1 improved the adhesion by more than 46% regardless of conditioning time. In asphalt mixture G2, it improved the adhesion by 6 to 15% depending on conditioning time. Even the aggregate with good adhesion (G3) was improved by adding hydrated lime.

4.3 Freeze-Thaw Cycles

As previsouly described, the i/C ratio were measured after multiple freeze-thaw cycles according the procedure described in 2.5 : for each number of cycles (1,3 or 5)

- one subset of 3 samples kept dry at 20°C, (to obtain C)
- one subset of 3 samples being moisture-saturated, then the freezing cycles during 20 hours à -18°C and the thawing cycles 52 hours at 40°C (hence 72 hours in total or 3 days), (to obtain i)

As a reference, we used the compressive strength for the dry specimen (C) stored 3 days at 20°C and wet specimen stored 3 days at 40°C in water bath (i), that is, without freeze-thaw cycle.

Results are given in Table 7 below (compresive strengths) and
Figure ***5*** (G1), Figure 6 (G2) and Figure 7 (G3) show the corresponding i/C ratios for all materials.

Table 7: Compressive strengths of the asphalt mixtures based on G1, G2 or G3 aggregate, with or without hydrated lime, stored in dry (C) or wet (i) conditions, after 1, 3 or 5 freeze-thaw cycles. The data after 3 days at 40°C (standard ITSR conditioning – NF EN 12697-12 method A), without freeze-thaw cycle, are taken as reference (0 cycle).

		Reference		1 cycle		3 cycles		5 cycles	
	Hydrated Lime(%)	C (MPa)	i (MPa)	C (MPa)	i (MPa)	C (MPa)	i (MPa)	C (MPa)	i (MPa)
G1 rhyolite	0	10.15	3.73	7.37	4.77	7.70	4.10	8.50	3.40
	1	10.87	6.00	7.73	5.50	8.23	4.57	6.43	4.17
G2 river gravel	0	11.37	6.27	9.10	5.20	8.20	3.97	9.87	3.53
	1	10.37	6.60	9.53	6.50	9.80	6.43	9.47	6.30
G3 microdiorite	0	11.5	8.13	10.97	7.7	11.17	6.87	-	-
	1	13.9	11.43	10.7	6.53	11.00	6.4	10.77	5.93

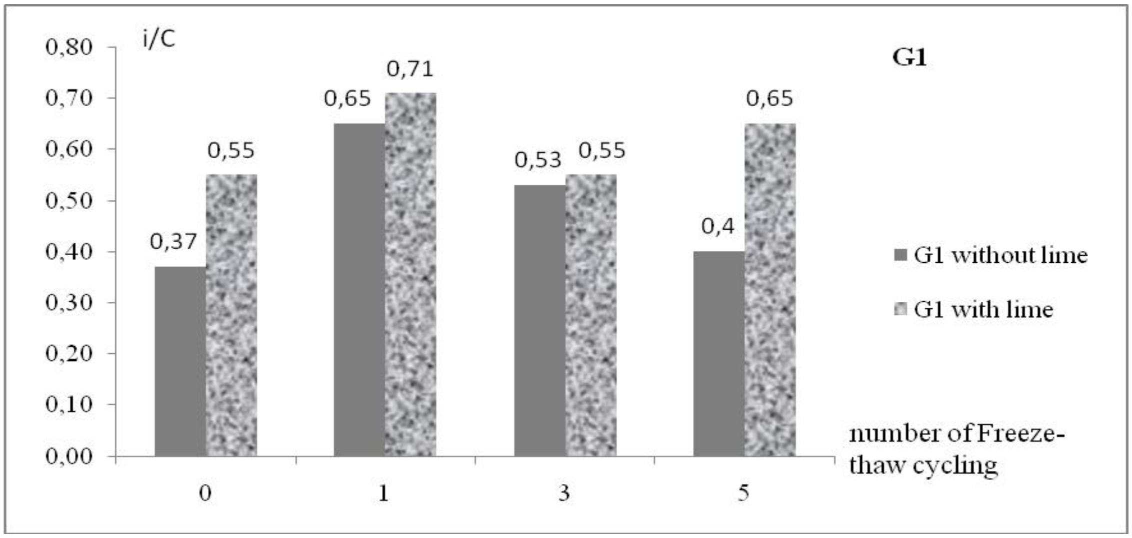


Figure 5: i/C ratios after 1, 3 or 5 freeze-thaw cycles for asphalt mixtures based on G1 aggregate, with or without hydrated lime. The data after 3 days at 40°C (standard ITSR conditioning – NF EN 12697-12 method A), without freeze-thaw cycle, are taken as reference (0 cycle).

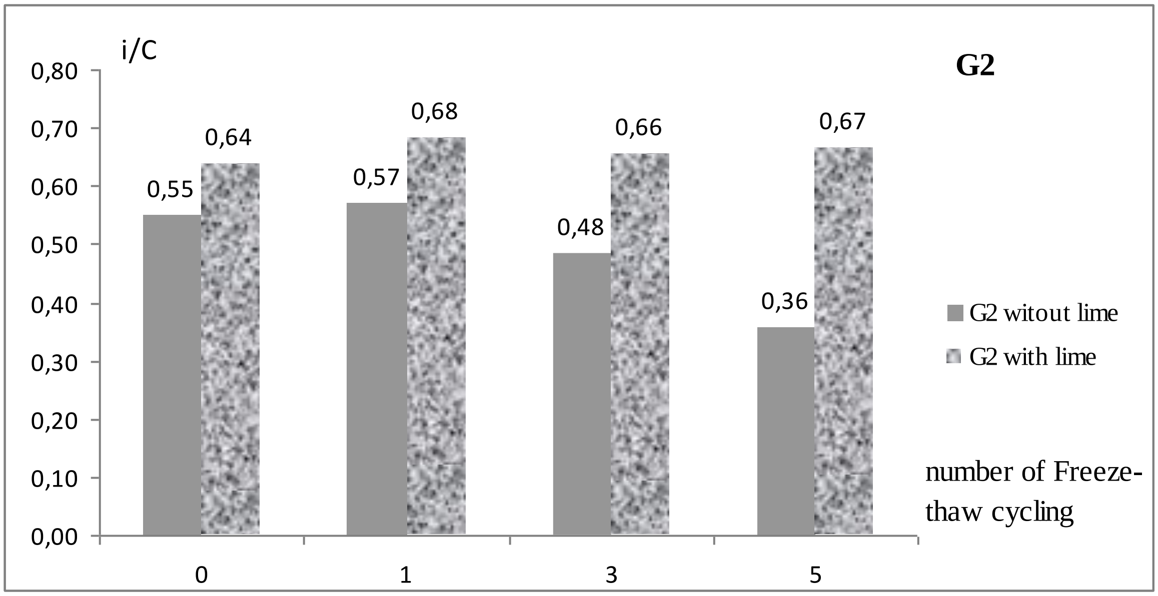


Figure 6: i/C ratios after 1, 3 or 5 freeze-thaw cycles for asphalt mixtures based on G2 aggregate, with or without hydrated lime. The data after 3 days at 40°C (standard ITSR conditioning – NF EN 12697-12 method A), without freeze-thaw cycle, are taken as reference (0 cycle).

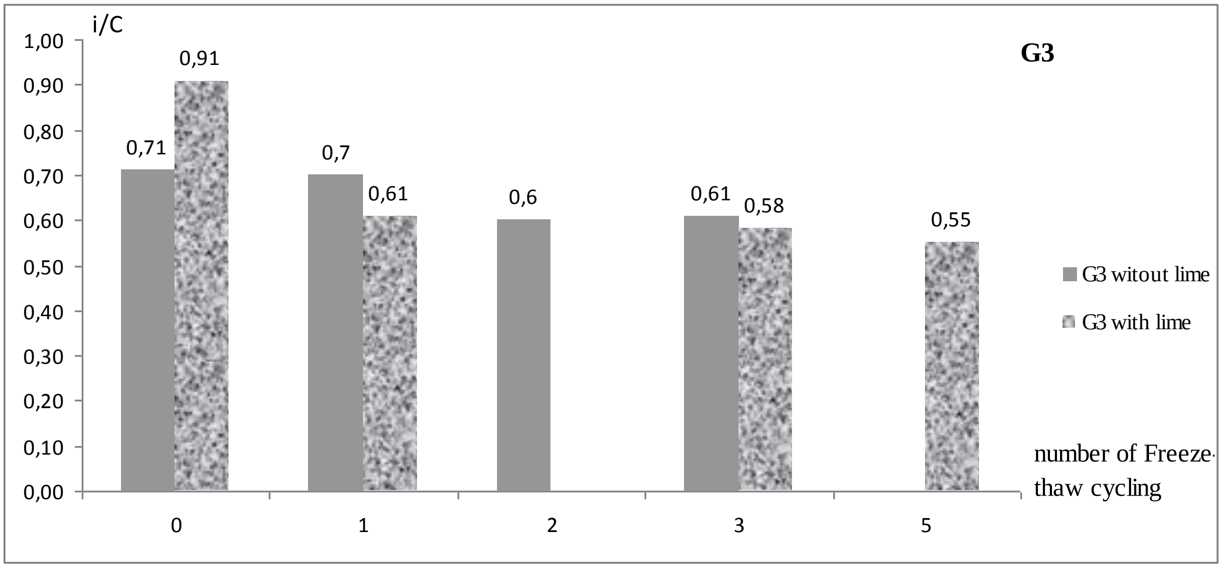


Figure 7: i/C ratios after 1, 3 or 5 freeze-thaw cycles for asphalt mixtures based on G3 aggregate, with or without hydrated lime. The data after 3 days at 40°C (standard ITSR conditioning – NF EN 12697-12 method A), without freeze-thaw cycle, are taken as reference (0 cycle).

Asphalt mixtures made of aggregate G1 without hydrated lime experienced a 14% decrease in wet compressive strength from 1 to 3 cycles and a 29% from 1 to 5 cycles. In the presence of hydrated lime, the compressive strength still diminished, but the compressive strength always remained higher than without lime (Table 7 and
Figure ***5***). Repeating freeze-thaw cycles tended to increasing the difference between materials with and without lime.

A somewhat similar behaviour was observed with asphalt mixtures made of aggregate G2. A 32% drop in compressive strengths was observed from 1 to 5 cycles but almost no change was observed in the presence of hydrated lime (Table 7 and Figure 6).

Finally, asphalt mixtures made of aggregate G3 were relatively unaffected by the repetition of freeze-thaw cycles. In this latter, no significant difference could be highlighted between with or without lime.

5 CONCLUSIONS

By using different testing protocols, this study tried to evaluate the effect of de-icing salts, moisture damage and repeated freeze-thaw cycles on asphalt mixtures. Three different aggregate sources were used in a typical French Asphalt Concrete mix design.

In a first step, we highlighted the good or not-so-good adhesion behviour toward bitumen of the aggregates using passive adhesion tests. The detrimental effect of de-icing salts was clearly demonstrated and the positive effect of hydrated lime, especially with material G1 (rhyolite), was highlighted. However, this test allows to compare aggregate fractions 6/10 and not directly asphalt mixtures.

Different testing methods for moisture damage on the asphalt mixtures. A 3 days conditioning at 40°C, following the standard ITSR procedure (NF EN 12697-12 method A), was seen to be better than the Duriez procedure (7 days at 18°C - NF EN 12697-12 method A) at discriminating between materials. Further increasing conditioning time (7 instead of 3 days) or temperature (60°C instead of 40°C) did not seem to give additional information. In all cases, the beneficial effect of hydrated lime was evidenced by a strong improvement in i/C ratio.

As far as freeze-thaw cycles are concerned, hydrated lime could improve the i/C ratio up to 50% after 5 cycles. In terms of wet compressive strength, this amounts to a 44% increase. In the limit of the 5 freeze-thaw cycles that were studied, hydrated lime was seen to almost stop the damage coming from repeating freeze-thaw cycle for material G2, maybe as a consequence of its higher density. With aggregate G1, and at the tested hydrated lime content of 1%, hydrated lime limited the drop in performance but did not stop it. In all cases, untreated materials showed a strong decrease in mechanical properties after the first freeze-thaw cycle. This suggests that the damage is probably due to a combination of an initial damage occurring upon expansive ice formation during the first cycle, followed by a further decrease possibly due to more traditional moisture damage mechanisms upon thawing (time at 40°C).

Beyond the comparison between materials, treated or not, it appears that the Duriez procedure (NF EN 12697-12 method B) is not so effective in discriminating between materials. As a matter of fact, all tested materials, with or without lime, easily meet the current specifications (i/C > 80%). However, the passive adhesion test clearly detects the risk of using aggregates G1 or G2 without additives, a risk also validated by the field experience (these materials are always used with adhesion promoters).

In the mean time, the 3 days - 40°C ITSR conditioning (NF EN 12697-12 method A) was better suited in order to detect possible adhesion problems. In the limit of the tested materials (aggregate, bitumen and mix design), increasing conditioning time to 7 days or increasing the temperature to 60°C was not seen to be more severe.

From this study, it clearly appears that asphalt mixtures with a not-so-good adhesion are badly damaged by repeated freeze-thaw cycles. In the mean time, an asphalt mixture with a good adhesion is not seen to be badly damaged after 5 cycles. Studies with up to 20 cycles or more have been published [4,5], and it could be that increasing the number of freeze-thaw cycles would have made bigger differences. Still, the level of damage after one freeze-thaw cycle remains quite similar to the one obtained after ITSR conditioning only. This would mean that the freeze-thaw cycle is essentially “active” through its cumulated time at 40°C in the thawing period. This could be a consequence of not reaching the threshold water saturation level, from which expansive ice formation was seen to damage materials in the study by Mauduit et al. [2]. Note that asphalt mixtures in the field easily reach saturation levels close to 100 % [1,18]

Interestingly, de-icing salts have a detrimental effect on asphalt mixtures that is only captured by the passive adhesion test. The observation of bitumen compounds in the water clearly show that something is happening. Still, a Duriez-type or ITSR-type conditioning in salted water does not highlight any specific effect of de-icing salts. It is however likely that the solubilization of bituminous compounds in the field would be enhanced by the dynamic effects of water, the contact from the tires forcing the water under pressure inside the asphalt mixtures. In this context, the representativity of these tests and there ability to simulate real asphalt mixture behaviour must be questioned. Testing method that better simulate the dynamic water effects, such as the German rut tester under water (also known as the Hamburg wheel tracking device), could be better suited in order to reproduce the field behaviour of asphalt mixtures in the lab [19].

Finally, if the detrimental effect of moisture, de-icing salts and repeated freeze-thaw cycles could be clearly highlighted in this work, it remains very difficult to estimate their probability of occurence in the field from the current test methods. In this sense, the Duriez test seems to be a very poor tool. In all cases, the use of hydrated lime appears as a promising solution in order to formulate asphalt mixtures having an improved resistance to winter damage.

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