A RAPID AND EFFECTIVE DE-ICING AGENT FOR

OPEN-GRADED ROAD SURFACINGS

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1 Abstract

The use of porous (e.g. porous asphalt) or open-textured (e.g. stone mastic asphalt) surfacings is spreading in a good many countries for reasons of safety (high skid resistance, no rutting, reduced splash and spray) and comfort (low rolling noise levels, reduction of light reflections). Unfortunately, under winter conditions these surfacings do not behave like conventional closed surfacings, for various reasons:

1. Moisture is entrapped almost permanently in their pores in winter and may in some cases lead to solid condensation at the road surface.
2. Their high porosity prevents salts spread for anti-icing or de-icing purposes from staying active on the surface.
3. Their lower thermal conductivity (or insulating nature) causes their surface temperature to drop more sharply and severely under certain climatic conditions.

As a result, larger amounts of conventional de-icing salts have to be spread and winter maintenance gangs have to turn out sooner. Hence the need to look for de-icing salts that are more appropriate on open-graded road surfacings.

One solution may be to use a mixture of 1/3 of calcium chloride ($CaCl_2$) flakes and 2/3 of coarse sodium chloride (NaCl) grains up to 5 mm in size.

This paper discusses the observations made in the laboratory and on site with this new mixture, which has been commercially available in Belgium since 1995.

2 Belgium: some information about the country, the road network and the climate

2.1 The country

Belgium is a country small in size (30,500 km²) but densely populated (10.2 million), situated at the heart of Europe. The country occupies a privileged position in between the Netherlands, France, Germany and Great Britain, and borders on the North Sea, the busiest sea route on the globe. Brussels, the national capital, is also the capital of the European Union.

The country's flourishing economy is largely directed to export (2/3 of production is exported). The prospects and prosperity of Belgium depend to a large extent on its transport infrastructure. The motorway and railway networks are consequently among the densest in the world.

Belgium is a federal state with three regions: Flanders in the north (5.9 million), Brussels at the centre (0.95 million) and Wallonia in the south (3.35 million). These three regions have autonomy in several branches, including the construction, management and maintenance of the motorways and main roads on their territories.

Flanders is a flat region (0 to 100 m), whereas Wallonia contains the Ardennes, a group of plateaus some 400 to 500 m in altitude – with the highest point rising nearly 700 m above sea level.

2.2 The road network

The road network comprises 1,700 km of motorways, 13,000 km of regional main roads and 131,000 km of local roads, amounting to a total of 145,000 km of paved roads. The national fleet of 5.5 million vehicles includes 4.5 million passenger cars each travelling an average distance of 15,000 km a year. There is also busy traffic, particularly commercial traffic, during the night.

Road transport accounts for 71 % of total freight transport. The economic importance of roads can, therefore, not be denied, even in winter. As a result, one of the tasks of the road authorities is to keep the road networks serviceable at all times, among other things by setting up a full organization for winter maintenance. The winter season lasts from November to March.

2.3 The climate

The country has a temperate maritime climate characterized by a relatively high number of rainy days (one in three) giving an annual rainfall of 700 (in Flanders) to 1,500 mm (at certain points in the Ardennes). The number of days of snow varies considerably from one point of the territory to another: from 14 days/year on the coast to 63 days/year on the Ardennes plateaus. The number of days of frost in Brussels remains acceptable: 59 per year. What characterizes the winters, at least in Flanders and Brussels, is the existence of numerous daily cycles of frost and thaw. The further we move towards the Ardennes plateaus, the more temperature falls and the number of freezing days increases – to a mean value of 115 per year.

This means that Belgian road managers are faced with a wide variety of "climates". In fact, the Ardennes plateau is the first steep spur of higher land encountered by the moisture-laden winds from the north-northwest (the North Sea squeezed up between Great Britain and Scandinavia). The change in altitude is sudden: from 47 to nearly 700 m above sea level in less than 40 km. It should be realized that temperature drops by 1 °C per 100 m of altitude; given the patchwork of road surfacings to be found in any given district, this is bound to create a puzzling complexity of situations. East winds are less disturbing; they bring very cold but dry weather in winter, with "continental" temperatures ranging between -10 and -20 °C.

3 Winter behaviour of porous asphalt

3.1 What is porous asphalt?

Porous asphalt mixes are an interesting development in hot-laid bituminous materials for wearing courses. They are rich in stone (80 to 85 %) and poor in fines (4 to 6 %) and bitumen (4 to 5 %). Layer thickness is generally between 25 and 40 mm. The main characteristic of this type of surfacing is its high voids content (initially 19 to 25 %), which is responsible for creating a network of channels in the bulk of the mix. This network acts both as a buffer store capable of absorbing considerable amounts of water and as a draining course enabling the water to be drained off to the shoulders (figure 1). In rainy weather, this results in the absence of aquaplaning, increased skid resistance, and reduced splash and spray behind vehicles. Porous asphalt also has other advantages such as a reduction in rolling noise level, light reflection and rolling resistance. On impervious underlying structures with a high bearing capacity, the material stands up well to trafficking owing to its very strong "skeleton" of stones. When designing a porous asphalt pavement, account should be taken of the need for effective drainage of the water that has penetrated the layer to the lateral collection devices or the shoulders. The underlying layer must be absolutely impervious to avoid any infiltration of water into the base.

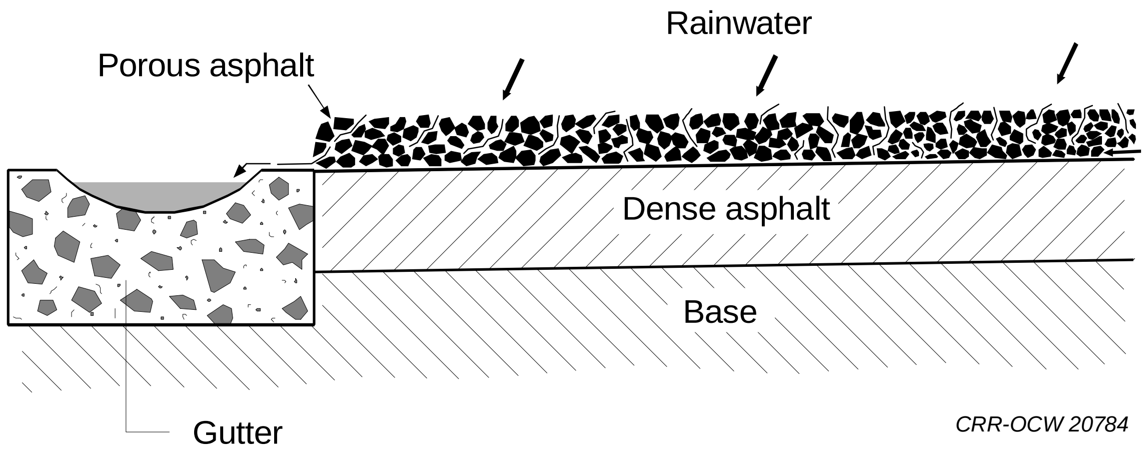

Figure 1 – Subsurface water drainage within a porous asphalt wearing course

The first experiment in Belgium dates back to 1979. Since then, numerous applications have taken place both on low-volume roads and on major roads, motorways, urban roads, tunnel roads and even airfield runways.

The use of porous asphalt or open-textured surfacings (e.g. stone mastic asphalt) is spreading in Belgium for reasons of safety (high skid resistance, no rutting, reduced splash and spray) and comfort (low rolling noise levels, reduced light reflections).

3.2 Winter behaviour of porous asphalt

Under winter conditions, porous asphalt (and to a lesser extent open-textured surfacings such as stone mastic asphalt) do not behave like conventional dense surfacings, for three main reasons:

1. Moisture is entrapped almost permanently in their pores in winter and may in some cases lead to solid condensation at the road surface.
2. Salt spread for anti-icing (precautionary) purposes tends to drain away relatively soon into the numerous pores. As a result, it can be active only for a short time. Under sufficient volumes of traffic a limited portion of it may, however, regain the surface through the sucking and pumping effect of tyres of passing vehicles.
3. Their lower thermal conductivity (or insulating nature) causes their surface temperature to drop more sharply and severely under certain climatic conditions. In Belgium, thermal mapping has enabled road network inspectors to conclude that temperature at the surface of porous surfacings takes on average half an hour less to drop below 0 °C than it does on dense asphalt surfacings. This observation also applies to the reverse process of rising above the freezing point, the duration of which may depend on the duration and intensity of freezing (accumulation of cold in the pavement). Consequently, it may take a porous asphalt surfacing up to one hour longer to unfreeze than a conventional wearing course, that is, twice as much time to return to the normal "blacktop" condition (figure 2).

In periods with spells of frost, a porous asphalt surfacing may, therefore, be icy while another surfacing in dense asphalt is not. When this happens, areas of transition between dense and porous surfacings may treacherously surprise road users.

That is why larger amounts of conventional de-icing salts have to be spread and winter maintenance gangs have to turn out sooner on porous asphalt.

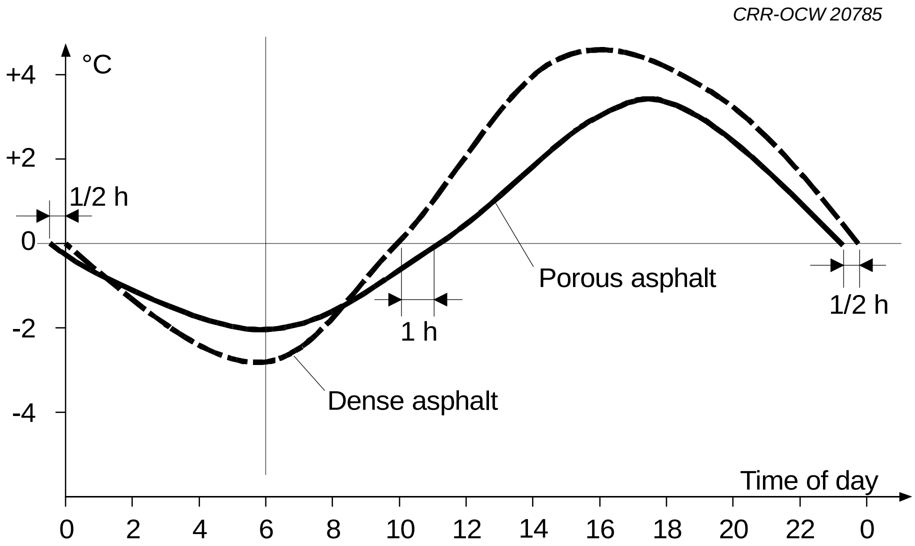

Figure 2 – Winter behaviour of porous asphalt in comparison with dense asphalt

4 De-icing agents

Ideally, a de-icing agent should meet all of the following seven criteria:

1. Acts rapidly and even when spread in small quantities.
2. Is inexpensive and readily available.
3. Is easy to store and to spread.
4. Is guaranteed to keep for several years.
5. Has as few and little side effects (e.g. corrosion) as possible.
6. Has minimum harmful effects on plants and wildlife.
7. Leaves a minimum residue after use.

Besides NaCl and $CaCl_2$, many other de-icing agents have been tested in Belgium: KCl, $MgCl_2$, urea, phosphates, alcohols, glycols, calcium magnesium acetate (CMA), etc. They are markedly inferior to NaCl and $CaCl_2$ in meeting one or several of the above criteria and have, therefore, never gained acceptance. Only alcohols and glycols are used for anti-icing on airfield runways.

Research has shown that under certain atmospheric conditions (relative humidity and air temperature, temperature of the road surface and of the de-icing agent) $CaCl_2$ in flakes appears to be most effective, followed by NaCl. At equal rate of application (by mass), $CaCl_2$ in the form of flakes (better than the powdered and the liquid forms) proves to perform best in the first thirty minutes or so after spreading, and is then caught up by NaCl in its melting action.

The choice between these two chemicals in Belgium is generally made in consideration of temperature. NaCl only works down to -7 °C, whereas $CaCl_2$ remains effective at temperatures between -7 and -15 °C.

In comparison with NaCl, the main disadvantages of $CaCl_2$ are its higher price (in Belgium it is four times as expensive as NaCl), the extra precautions to be taken to prevent lumping during storage and the risk of hexahydrate formation ($CaCl_2 \cdot 6H_2O$), which makes the road very slippery.

In Belgium, NaCl and $CaCl_2$ were spread dry in the early days, but practice has gradually changed over to spreading brine (a solution containing 25 % of NaCl or 33 % of $CaCl_2$) and, since the nineties, to the wet salt method.

5 Performance of de-icing agents on porous asphalt

5.1 Field observations

In our latitudes, experience has shown that in 90 to 95 % of winter treatments of porous asphalt salts (NaCl) with an average (continuous) grading between 0 and 3 mm or vacuum salts (grading between 0 and 1 mm) are adequate to clear rime ice and certain types of black ice. The know-how and experience of the road manager are obviously called upon here. Preventive or precurative action involving an increased number of passes of salt spreader (and higher rates of application of NaCl if required) makes it possible to use conventional de-icing agents.

The above treatments are only for ice film thicknesses of a few tens of microns. Sheets of black ice several millimetres thick are dealt with by other means. Use is made of mechanical tools of the wet salt spreader type (wet salt being a de-icing chemical wetted with a brine of salt). Other means are required to clear thick ice, supercooled rain or surface-compacted snow. This paper seeks to define better answers to the unpleasantness caused by the conditions described above.

5.2 Importance of particle size

The particle size of a de-icing agent plays a not inconsiderable part in ice control on porous asphalt surfacings. Specialist authors agree that fine salts disappear too soon into pores in the road surface after spreading and are consequently poorly effective in places where their effect is rightly expected. Remanence on the road surface can be improved by using medium-graded salts (3 to 5 mm in particle size).

5.3 Melting action of a mixture of 2/3 of NaCl and 1/3 of $CaCl_2$

As a result of technical refinement and implementation since 1995, snow and ice control has developed from the use of a single agent into the spreading of a mixture of 2/3 of 3 to 5 mm-sized NaCl grains and 1/3 of $CaCl_2$ flakes. The similarity in grading between the two components helps to avoid segregation. Their maximum particle size should be limited to 5 or 6 mm, to prevent the salt crystals from becoming real projectiles – especially under the tyres of vehicles travelling at high speeds.

The NaCl salt component reacts endothermically with moisture from its ambient environment. By its internal structure, porous asphalt offers ideal conditions for water storage to trigger the physical reaction of heating.

The two components have complementary physicochemical properties. Hygroscopicity, deliquescence and speed of action are due to the calcium chloride, while the sodium chloride brings in remanence (durability of action). In addition, the product is not subject to the disadvantages of its individual components under extreme conditions, namely the undercooling of sodium chloride and the formation of calcium chloride hexahydrate. The cost of the mix is about three times that of NaCl.

The $CaCl_2$ flakes are the real accelerators of the melting process, while the coarse NaCl is the melting reserve that removes the last traces of slipperiness. This is shown in figure 3.

It appears from this figure that the mixture of 2/3 of NaCl and 1/3 $CaCl_2$ puts road users safe for at least an additional quarter of an hour before the road surface ices up completely, thereby leaving more time for intervention. Ice control is, indeed, most often a matter of working against the clock.

Technicians who literally "bend their heads" over porous asphalt have reported the formation of ice cones on the tops of surface aggregates in porous asphalt surfacings. The same observers have pointed out that this phenomenon can be counteracted with tangible results by combining an appropriate preventive treatment with a reinforced curative treatment (adapted rates of application of de-icing agent) using a mixture of 2/3 of NaCl crystals and 1/3 of $CaCl_2$ flakes. The presence of medium-sized NaCl grains ensures the remanence of a reserve of salt to generate the indispensable melting heat at the road surface.

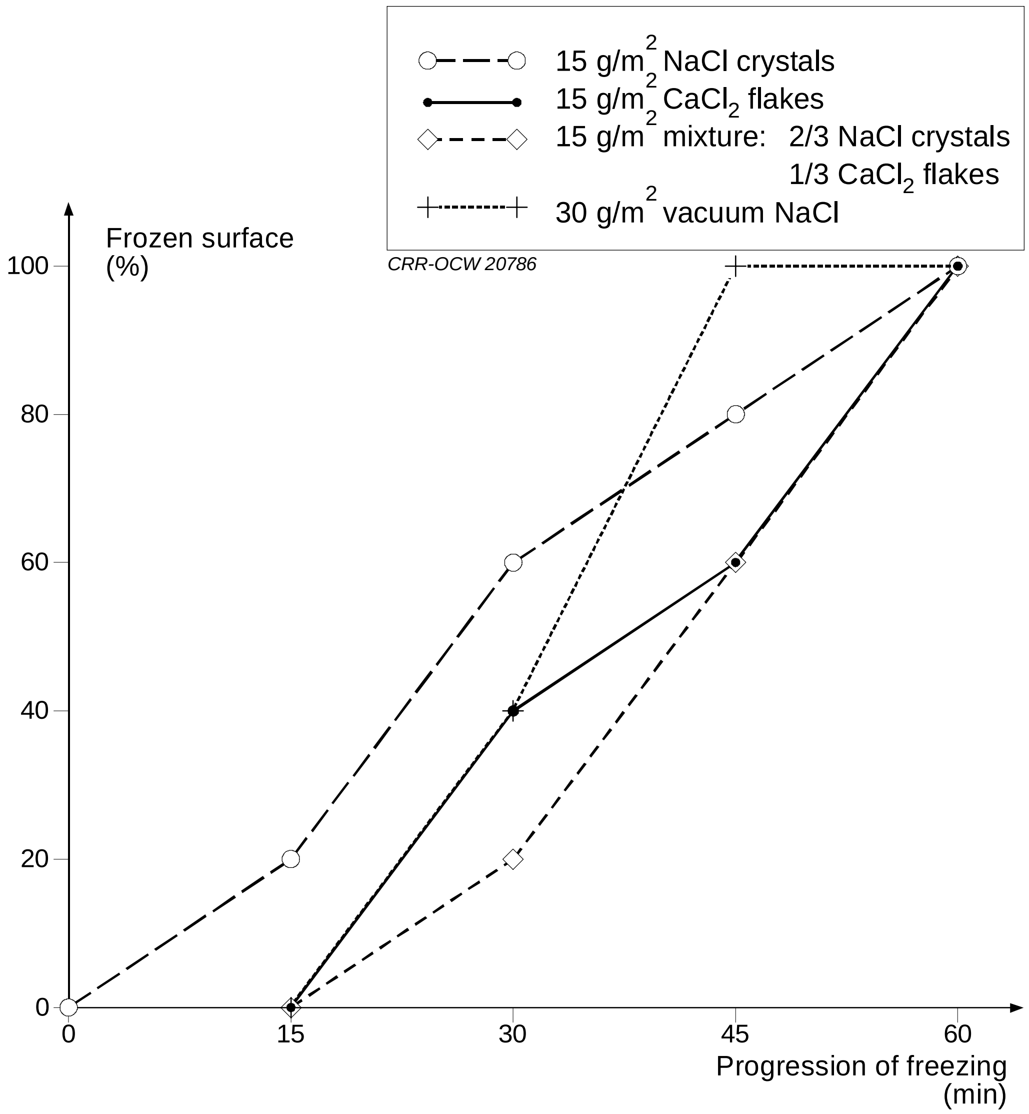

Figure 3 – Melting action of various types of de-icing agent

5.4 Remanence of the 2/3 NaCl + 1/3 $CaCl_2$ mixture

5.4.1 How to measure remanence?

Salt remanence on a dense road surfacing is easy to measure. SOBO is certainly the most suitable manual device to measure residual saltness. It cannot be operated, however, on porous asphalt, as the liquid used for the electrical readings immediately seeps into the open pores of the surfacing.

A Belgian company has developed a test for both dense and porous asphalt. The principle is based on the determination of chloride content by titration with $AgNO_3$ in the presence of an indicator (potassium chromate). These products are applied on the road surface by means of a spray gun.

The equivalence point from which it is possible to determine chloride content (quantitatively and qualitatively) is marked by the indicator changing colour from yellow to brick red. This red colour appears when the surplus silver nitrate (after the chlorides have been neutralized) reacts with the potassium chromate.

5.4.2 Observations

We compared the remanence on site of NaCl crystals with that of the mixture of 2/3 of 3 to 5 mm-sized NaCl grains and 1/3 of $CaCl_2$ flakes.

The two de-icing agents are very similar in chloride content (100 g of NaCl contains 60.7 g of chloride, while 100 g of "2/3-1/3 mixture" contains 61.7 g of chloride).

It should be noted that we made the comparisons on roads under traffic, while contrasting the observations on dense asphalt with those on porous asphalt.

Three threshold values were predefined for titration: 15, 10 and 5 g/m^2 of chloride, respectively, in accordance with the wishes of road network inspectors.

The colorimetric readings clearly showed that seven hours after spreading (under exactly the same climatic conditions) the 2/3 + 1/3 mixture could be credited with 25 % more remanence than conventional NaCl, both on dense and on porous asphalt.

The difference in remanence increased with time after the beginning of spreading. The objective of the 2/3 NaCl + 1/3 $CaCl_2$ concept was, therefore, clearly attained.

5.5 Skid resistance of the 2/3 NaCl + 1/3 $CaCl_2$ mixture

Any active de-icing agent melts ice crystals into a more or less concentrated solution ("brine"), which affects the grip of vehicle tyres on (or the skid resistance of) the road surface. Loss of skid resistance can be determined from comparative SRT (British pendulum tester) measurements performed on the salt solution and on a film of pure water. Figure 4 illustrates this comparison for three different brines.

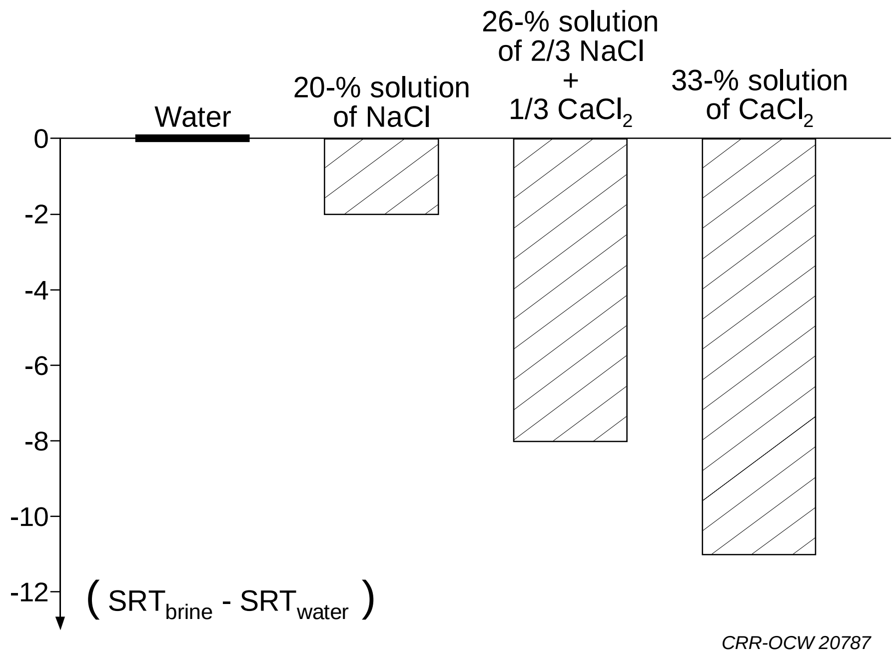

Figure 4 – Drop in SRT value due to the presence of brine

The value found with the 2/3 NaCl + 1/3 $CaCl_2$ mixture lies in between those recorded on the NaCl and the $CaCl_2$ solutions, as could be expected.

6 Conclusions

The sensitivity of porous asphalt to occasional winter weather conditions has prompted a study into the various de-icing agents available on the European market for this type of asphalt surfacing.

From the whole of results collected in the laboratory or in the field it can be concluded that not only for penetration into ice and for remanence to form a latent reserve of energy, but also for limitation of loss in skid resistance a mixture of 2/3 of NaCl and 1/3 of $CaCl_2$ currently performs best, under Belgian climatic conditions, in giving answers to the problems raised by the winter behaviour of porous asphalt road surfacings.

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