# Winter Maintenance on Porous Asphalt

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In 1986, porous asphalt (drain asphalt or open-graded asphalt) was introduced in the Netherlands. By 1997, approximately 40 percent of all highways in the Netherlands had been paved with this open asphalt. The main reason for the use of porous asphalt is its ability to reduce traffic noise and improve traffic safety. The increase in the use of open porous asphalt in the last couple of years has shown that its winter behavior deviates from that of normal dense asphalt. The main causes of the different behavior of porous asphalt, compared with dense asphalt, are its responses to temperature, humidity, and salt on the road surface. Discussed here is the maintenance required by the three principal forms of slipperiness: that caused by freezing of wet road sections, that caused by a small amount of moisture (condensation, sublimation, and freezing fog), and that caused by precipitation such as snow and freezing rain. Under "normal" Dutch winter conditions (in which slipperiness is caused mainly by the freezing of the wet road surface), winter maintenance of porous asphalt roads will not cause significant problems for the highway authority, requiring only a high consumption of salt to keep the road safe. However, in the case of freezing rain, the difference in friction between porous asphalt and dense asphalt is considerable. In highly intense freezing rain, a layer of ice will swiftly form on porous asphalt and cause a subsequent loss of friction.

In 1986, porous asphalt (drain asphalt or open-graded asphalt) was introduced in the Netherlands on a large scale because of its ability to reduce traffic noise and improve traffic safety. Porous asphalt is believed to increase traffic safety because it can minimize splash and spray and hydroplaning. An inquiry also made it clear that drivers appreciated the comfort of porous asphalt roads. By 1997 about 40 percent of the Dutch main road network had been improved with porous asphalt. Aside from the positive qualities, porous asphalt roads have some disadvantages, including high construction costs and a reduction in friction preceding construction. Recently it became clear that, immediately after construction, the friction of porous asphalt roads is insufficient.

Since the introduction of porous asphalt in the 1970s, highway departments have had to combat adverse conditions associated with the asphalt and wintry conditions. During the winter of 1978–1979, it became clear that winter behavior of the open porous asphalt strongly differs from that of a normal dense upper layer. Because of the relatively short sections of porous asphalt on the road and lack of experience, road authorities were not aware of the different treatment needed for this new layer. It was thought that more experience with open asphalt would help to solve the problems.

The first winters following large-scale construction gave no reasons to change this conclusion. An adaptive treatment for different types of slipperiness gave good results. Insight into the mechanism of slipperiness on porous asphalt made it clear that freezing rain on a road surface that was below the freezing point could cause a large reduction in friction. Because of a lack of freezing rain through the early 1990s, different views could not be examined. Laboratory tests, carried out by the Onderzoek Centrum voor de Wegenbouw (*1*), indicated the opposite of the theory that porous asphalt reduced friction. During these laboratory tests with simulated freezing rain, it was shown that porous asphalt, without any gritted salt, provided better friction than an upper layer of dense road surface. This may have been caused by breakage of the ice on porous asphalt.

This study deals with the properties of porous asphalt and the mechanisms that change them. By finding these mechanisms, which are caused mainly by different types of precipitation, slipperiness of porous asphalt upper layers can be combated.

## Behavior of Porous Asphalt

The main advantages of porous asphalt are thought to be the following:

- Traffic noise reduction,
- Traffic safety,
- Road capacity,
- Absence of splash and spray,
- Absence of hydroplaning,
- Absence of reflection from the road surface,
- Visible road marks, and
- Lack of ruts in the road surface.

A recent study completed by the Netherlands Ministry of Transport shows that there is no difference in traffic safety between road surfaces of dense and porous asphalt. Driver comfort is the main advantage of porous asphalt.

The main disadvantages of porous asphalt are

- Lifetime cost,
- Dirt build-up,
- Recycling,
- Mechanical damage, and
- Winter maintenance.

Maintenance of porous asphalt is the main problem for the road authority.

A ministry of transport survey shows that in the following situations porous asphalt requires close monitoring in winter conditions:

- Roads with low traffic volume,
- Roads on an incline,
- Roads with a limited superelevation,
- Hard shoulders,
- Changes from cold to warm temperatures,
- Snow remaining on the road surface,
- Slipperiness caused by condensation,
- Slipperiness caused by freezing rain, and
- Changeovers from porous asphalt to dense asphalt concrete.

As noted in a report on winter maintenance of porous asphalt (2), the main causes of the different behavior of porous asphalt relative to that of dense asphalt concrete are temperature, humidity, and salt on the road surface.

### Temperature Behavior

Since the construction of the National Ice Warning System in the Netherlands, the temperature behavior of porous asphalt has become clear. Many useful measurements were obtained by using this system, especially from roads with one lane of porous asphalt and the other lane of dense asphalt concrete. The road temperature data (winter of 1986–1987) from the ice warning system confirmed that, on average, the porous asphalt drops below freezing sooner, and as the air temperature rises, the temperature of the porous asphalt stays below freezing longer than that of a comparable road section of dense asphalt (Figure 1). The data also show that the maximum temperatures of porous asphalt are often lower than the maximum temperatures of dense asphalt. The measurements also indicate that the minimum temperatures of porous asphalt are often a little higher than those of dense asphalt.

In addition, when the air temperature rises after a cold period, the temperature behavior of porous asphalt causes a colder road surface than that of a comparative road section of dense asphalt. When the air temperature remains at or a little above freezing, and cold weather has been prolonged, porous asphalt sections remain below freezing considerably longer than do comparable dense asphalt road sections (Figure 2).

### Humidity Behavior

Voids in porous asphalt ensure that precipitation is slowly drained to the shoulder as a result of the superelevation of the road. Some of the precipitation remains behind in the pores (Figure 3). In the winter roads dry slowly because traffic brings moisture back to the surface of the road. The transport of moisture is caused by the air pumping effect of vehicle tires.

Remaining moisture combined with the average lower temperature of a porous asphalt section suggests that this open asphalt is more sensitive to freezing on wet road sections. If an ice warning system is present, this slipperiness will be indicated by a warning to the road authority. The sensors of the ice warning system signal slipperiness in time to prevent dangerous situations.

### Behavior with Regard to Salt on Road Surface

When a frozen wet road section is forecast (because of falling temperatures), preventive spreading operations should take place before a layer of ice adheres to the road. In these conditions the prewetted salt technique is used to spread the salt onto the road. The mixture used consists of dry sodium chloride (NaCl) grains and a sodium chloride or calcium chloride ($CaCl_2$) solution

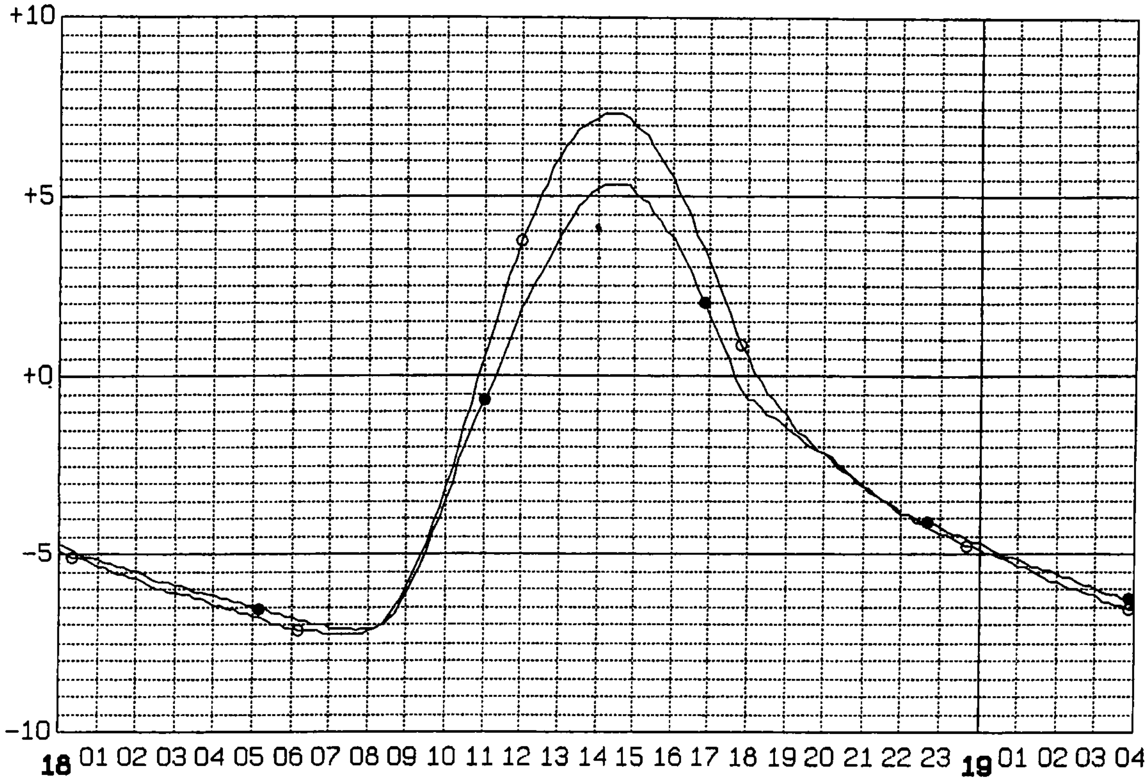


FIGURE 1 Characteristic path of porous asphalt temperature (●) compared with dense asphalt (○) concrete. Porous asphalt remains below freezing longer.

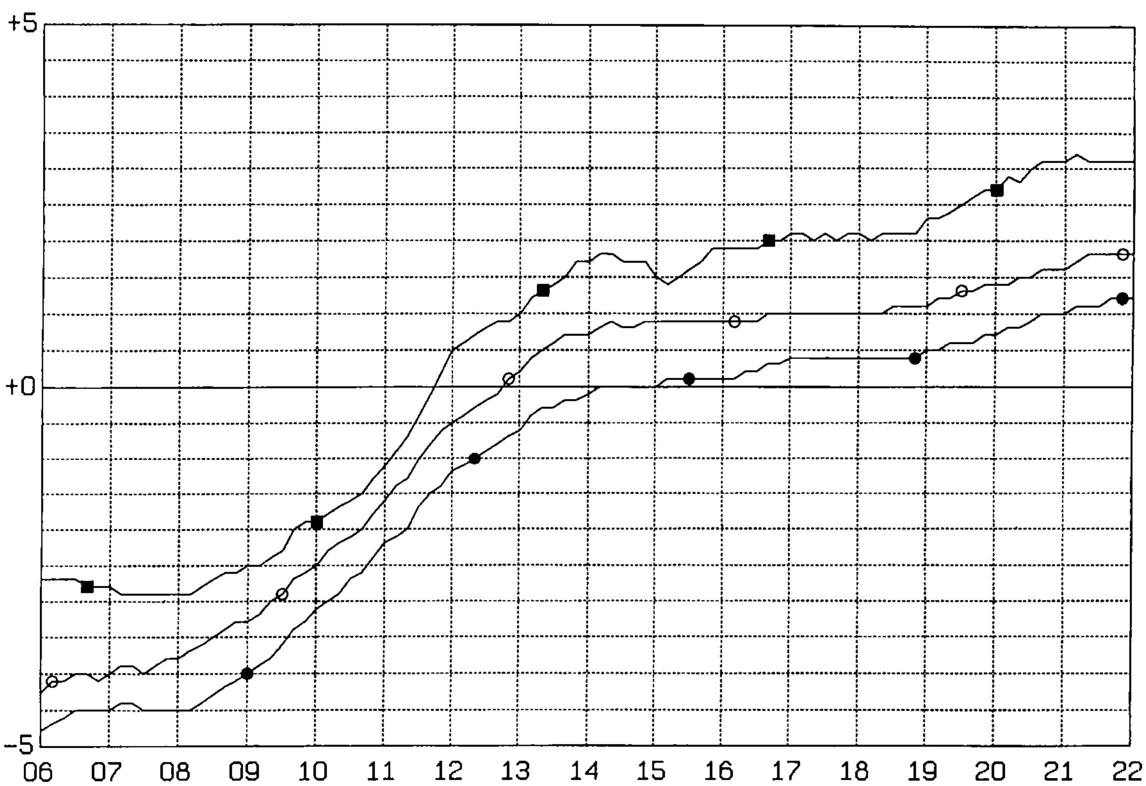


FIGURE 2 Temperature path of porous asphalt road section (●) versus temperature path of dense asphalt road section (○), and air temperature (■), following cold period.

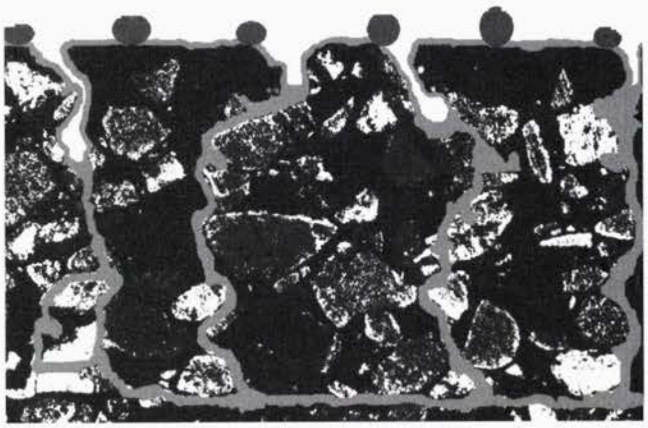

**FIGURE 3 Distribution of water in voids of porous asphalt. Only a thin layer of water and salt grains is present on surface.**

(16 percent). The mixture is made on a spreading sheet and is immediately on the road (Figure 4).

On road sections of dense asphalt this salt mixes with the moisture on the surface. The resulting salt solution freezes only when the temperature falls below the freezing point of the mixture, which is substantially lower than the freezing point of water. Small amounts of falling precipitation are neutralized, and the wet road section is not slippery. In addition, traffic considerably accelerates the mixing process and distributes the salt on the road.

The amount of salt for spreading operations is doubled (11 g/m$^2$) on porous asphalt because it contains more moisture. On porous asphalt, the salt is distributed evenly on the road, and only a small amount of the salt disappears into the voids. As on dense asphalt, the air pumping effect of tires accelerates the mixing process, even within voids of the porous asphalt. Conversely, nearly all the salt applied to dense asphalt remains on the road surface. The amount of the salt solution slowly decreases, because the crown of the road causes moisture to flow away from the road. The salt solution can also be blown away or transported by traffic.

**FIGURE 4 Prewetted salt is spread on surface before ice layer forms.**

Although more spreading operations are needed on porous asphalt, the amount of salt solution on the surface of the porous road is less than that on dense asphalt concrete. The distributed salt mixes with the moisture inside the voids of porous asphalt (because of the air pumping effect), the salt dissolves, and the resulting salt solution prevents moisture from freezing. Also, little salt solution remains on the surface of porous asphalt because of the material's draining properties. The largest amount of salt solution is in the voids (Figure 5). Through the air pumping effect of tires, fresh salt solution is transported continuously to the road surface (Figure 6). The salt solution stored in the voids is available for thawing the road surface. In general, a driver does not notice any difference between porous asphalt and dense asphalt concrete as long as sufficient traffic is on the road.

If moisture (precipitation, condensation, or fog) is not added to the road surface, the salt solution becomes concentrated through evaporation. Ultimately, small salt crystals surface, which on dense asphalt concrete are evident in a whitening of the road surfaces as the salt dries. On dense asphalt concrete, the small white salt crystals slowly disappear over time. This disappearance is influenced by traffic. On porous asphalt the salt remains for a considerably longer period, mainly in the voids of the asphalt. A survey of different types of slipperiness may show the properties of porous asphalt during other, more critical circumstances.

## Slipperiness

Slipperiness may be divided into three principal forms:

- Slipperiness caused by freezing of wet road sections; the available moisture on the road surface causes slipperiness as temperatures fall.

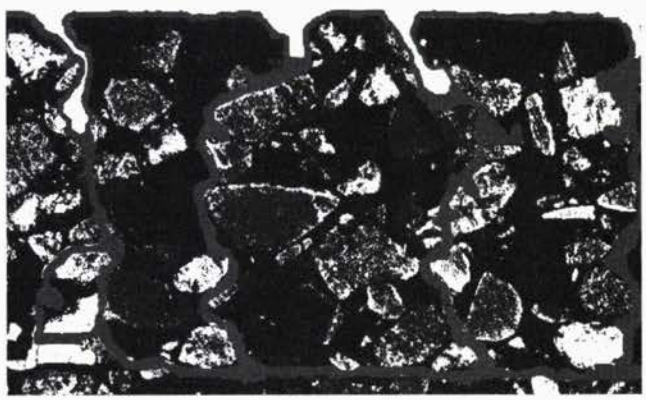

**FIGURE 5 Distribution of salt on road surface and in voids of porous asphalt. Only a small amount of salt remains on surface.**

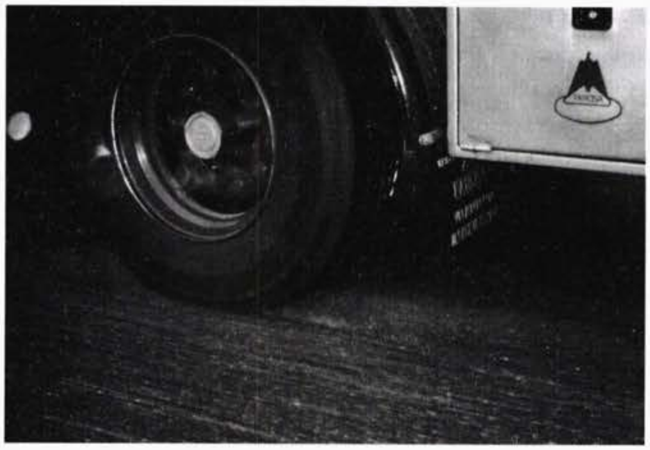

FIGURE 6 Air pumping effect of tires. Moisture visible behind tire has been sucked out of voids of porous asphalt. This effect transports thawing agent to surface and allows surface to remain wet.

FIGURE 7 If balance between salt solution in voids and on road surface is disturbed, a small amount of precipitation may be sufficient to reduce surface friction.

- Slipperiness caused by a small amount of moisture (condensation, sublimation, and freezing fog).
- Slipperiness caused by precipitation. All types of precipitation, including hail, snow, ice rain, and freezing rain, can cause slipperiness.

## Freezing of Wet Sections

When wet road sections freeze, no differences distinguish porous asphalt from dense asphalt concrete after preventive spreading operations. In these cases, the amount of moisture on the road surface must be monitored. If a large amount of moisture is present, more salt must be distributed to reach the intended lower freezing point. In comparison with dense asphalt concrete, a double quantity of salt is needed to neutralize the moisture in the voids of porous asphalt.

## Small Amount of Moisture

A difference between porous asphalt and dense asphalt concrete is evident when the road surface temperature is below freezing and a small amount of moisture falls on the road. A considerable difference in friction can arise on road surfaces if they are below freezing and spreading operations already have been carried out. This situation can occur if the balance of the salt solution in the voids is disturbed because of diminishing traffic intensity (Figure 7). A small amount of new moisture on the road surface of porous asphalt then reduces the friction of the road surface. On dense asphalt concrete this reduction of friction does not occur because the amount of salt on the surface is sufficient to prevent reduction.

Experience has shown that condensation or freezing fog on well-gritted porous asphalt, in combination with normal (or nightly) traffic intensity, does not cause a reduction in friction. In contrast, the less-traveled hard shoulder turns white, and friction may be reduced. Even so, during periods of fog and road surface temperatures below freezing, slipperiness must be monitored. Fog that changes into drizzling rain can greatly reduce friction.

At night porous asphalt is more sensitive to the lowering of friction because of the disturbed balance between the voids and the surface. A suitably instrumented ice warning system can warn road authorities of drizzling rain so that extra spreading operations may be implemented.

In the Netherlands, air temperatures at or just below freezing often occur and are likely to cause complications. Under these circumstances temperatures of the road surfaces of bridges (porous and dense) and viaducts often drop below freezing. Frozen bridges and viaducts are caused by a lack of warmth in their foundations. The adjacent road sections, which can consist of either porous asphalt or dense asphalt concrete, remain at or rise above freezing at the same time. In this case a large difference in friction can occur.

If spreading operations are followed by a dry period, the salt distributed on dense asphalt concrete slowly disappears from the effects of traffic. A porous asphalt road section also dries out under these circumstances. The salt, however, does not disappear—small crystals remain in the voids of porous asphalt. These salt crystals dissolve again if new precipitation occurs, even as road surface temperatures drop below freezing. Traffic transports this solution to the surface of the road, and the salt buffer helps to make the porous asphalt passable. As the action of traffic transports this solution to the surface of the road, the salt barrier allows the porous asphalt to remain passable and unfrozen.

## Precipitation

Different types of precipitation can cause slippery roads. The following comments on different types of precipitation apply to both porous asphalt and dense asphalt concrete.

### *Snow*

In the Netherlands, snow may occur when road surface temperatures are above or below freezing. When road surface temperatures are above freezing, a slippery road surface may occur briefly on both porous asphalt and dense asphalt concrete. Afterward, the heat in the road surface melts the snow, which results in normal friction along the road surface. In general, porous asphalt is colder, so snowfall on this asphalt can cover the road surface earlier than on dense asphalt surface (Figure 8).

When snow falls during a period of below-freezing surface temperatures, all types of asphalt need preventive spreading treatment. Spreading before initial snowfall is the only way to prevent icing of the road. If roads are left untreated, snow crushed by traffic becomes ice. During snowfall, the behavior of porous asphalt differs from that of dense asphalt concrete. The performance of the porous asphalt road varies and is dependent on traffic intensity and the salt buffer present in the voids of the asphalt. If spreading operations are not carried out before initial snowfall, a porous asphalt road is more passable than a dense asphalt concrete road because of the salt buffer. During periods of high traffic intensity and snowfall, the performance of a porous asphalt road section, in general, does not differ from that of dense asphalt concrete. During periods of low traffic intensity, it becomes more difficult to maintain the quality of the road. For example, less-traveled porous asphalt exit ramps become slippery faster than do exit ramps of dense asphalt concrete (Figure 9).

**FIGURE 8 Hard shoulder of porous asphalt next to dense asphalt concrete road surface. Shoulder is fully covered with snow because without traffic action, salt remains in voids rather than transferring to surface.**

### *Hail*

When precipitation is hail, the temperature of the road is nearly always above freezing. Both dense asphalt concrete and porous asphalt are affected, although the slipperiness is temporary because the heat of the road quickly melts the hail.

### *Freezing Rain*

In freezing rain, the friction levels of the two road surfaces differ considerably. In addition to friction, recognition of black ice by road users is important in freezing-rain circumstances. During periods of snowfall, road users can easily detect visually differences in friction between porous asphalt and dense asphalt concrete. During freezing rain, road users cannot usually perceive the difference.

Whether precipitation reaches the ground in the form of snow or freezing rain depends on the temperature of the upper layers of air. The colder upper layer of air is responsible for the condensation of water to ice crystals (snow). If snow falls through layers of below-freezing air temperatures, the snow keeps its original form. If the snow passes through layers with air temperatures above freezing, the snow crystals melt. When this occurs, the precipitation can remain in liquid form or freeze, depending on atmospheric conditions of the lowest layers. If the ground or the air right above the surface is below freezing, the rain freezes on contact; otherwise it falls as unfrozen rain (Figure 10). Almost immediately after the supercooled drop reaches the road surface, it congeals. Salt melts the first freezing rain, as is the case with snow. After this solution is transported to the voids (as a result of gravity), the amount of salt on

**FIGURE 9 Evident difference in behavior of main road and shoulder (porous asphalt) and exit ramp (dense asphalt).**

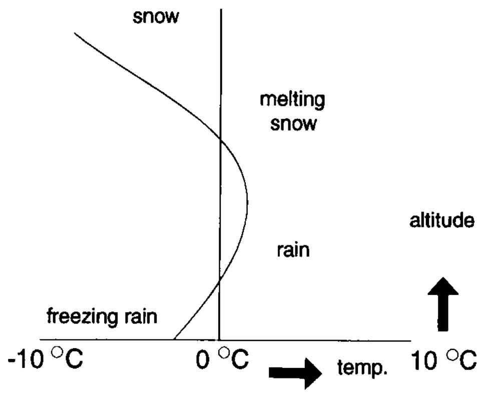


FIGURE 10 Form of precipitation at ground level depends on temperature of upper layers of air.

the surface of porous asphalt has decreased considerably. The continuing freezing rain quickly forms a layer of ice, which is caused by a lack of salt. Average higher intensity of precipitation on the road surface and higher density of freezing rain (1 cm snow equals 0.1 cm water) influence the balance between the thawing agent in the voids and the thawing agent on the road surface.

During periods of snow, the action of traffic maintains a good balance between the salt in the voids and the salt on the road surface. The melting process of snow (as a result of the weight of the vehicles and the balance in transport of salt to the road surface by the air pumping effect) prevents a strong reduction in friction.

During periods of steady freezing rain, the balance between the salt solution in the voids and the salt solution on the road surface of porous asphalt is disturbed. This disturbed balance is caused by quicker succession of freezing raindrops, higher density, quicker transport of the thawing agent, and a layer of ice, which forms immediately. In the case of high intensity of freezing rain, the layer of ice forms swiftly and causes a subsequent loss of friction.

## Solutions for Slipperiness Caused by Freezing Rain

With sufficient traffic intensity, porous asphalt and dense asphalt behave more or less the same. However, freezing rain negatively influences the performance of porous asphalt. Especially at changeovers between porous asphalt and dense asphalt, the road user becomes aware of the difference in slipperiness. At these changeovers, the friction of dense asphalt concrete is often sufficient, whereas the friction of porous asphalt is often greatly reduced.

A variety of techniques can be used to reduce slipperiness caused by freezing rain. Often a combination of these techniques is used. On many main roads in the Netherlands, displays have been installed that indicate reduced speed limits because of road conditions. In addition, these displays force traffic to use one lane, which optimizes the air pumping effect of tires. At some locations without displays, traffic is forced to proceed in a column. Positive results have been obtained by this method. Portable signal boards located at changeovers between dense and porous asphalt are also used to warn road users. During periods of freezing rain, the media also frequently warn road users of the dangers associated with porous asphalt. Since the 1996–1997 winter, the Dutch government has distributed information about the properties of porous asphalt at border crossings.

If the road surface is covered with a layer of ice during periods of freezing rain, sodium chloride is spread to remove this layer. If the layer of ice is thin, the operation often succeeds, and the road surface is temporarily ice free. With continuous freezing rain, a new layer of ice forms. Although spreading operations temporarily improve the friction of the road surface considerably, they also have negative effects. When salt melts the layer of ice, an endothermic reaction (heat depletion) takes place. During this reaction heat is drawn from the environment. Since the air contains little heat, the reaction takes heat from the road surface. Thus, as a result of the spreading (melting) operation, the road surface temperature can fall between 1 and 2°C.

In the case of slowly rising temperatures, the porous asphalt remains critical for a longer period than does dense asphalt (Figure 11). Slipperiness occurs for a considerably longer period on porous asphalt. An improvement can be obtained by adding solid $CaCl_2$ to sodium chloride. The hygroscopic character of $CaCl_2$ brings about an exothermic (heat-producing) reaction when the solution is mixed with water or ice. This hastens the thawing process. A mixture of $CaCl_2$ with sodium chloride (40/60) is expected to give the best result. The first tests with this mixture were carried out during the 1996–1997 winter. During this test, the layer of ice melted quickly. However, it could not be concluded that the heat from the $CaCl_2$ reaction abolished the cooling effect caused by the endothermic reaction of sodium chloride. Moreover, during periods with steady freezing rain, this thawing agent is transported into the voids, and the road surface becomes slippery again. More tests are needed because the mixture of $CaCl_2$ and NaCl also has practical disadvantages associated, for example, with storage and handling.

Distributing sand to reduce the slipperiness caused by freezing rain is not advisable. Sand is covered by new freezing rain, or it is transported into the voids, if enough moisture is available on the road. Only when freezing rain stops does sand improve the friction of the road. Meanwhile, the sand changes the structure of the

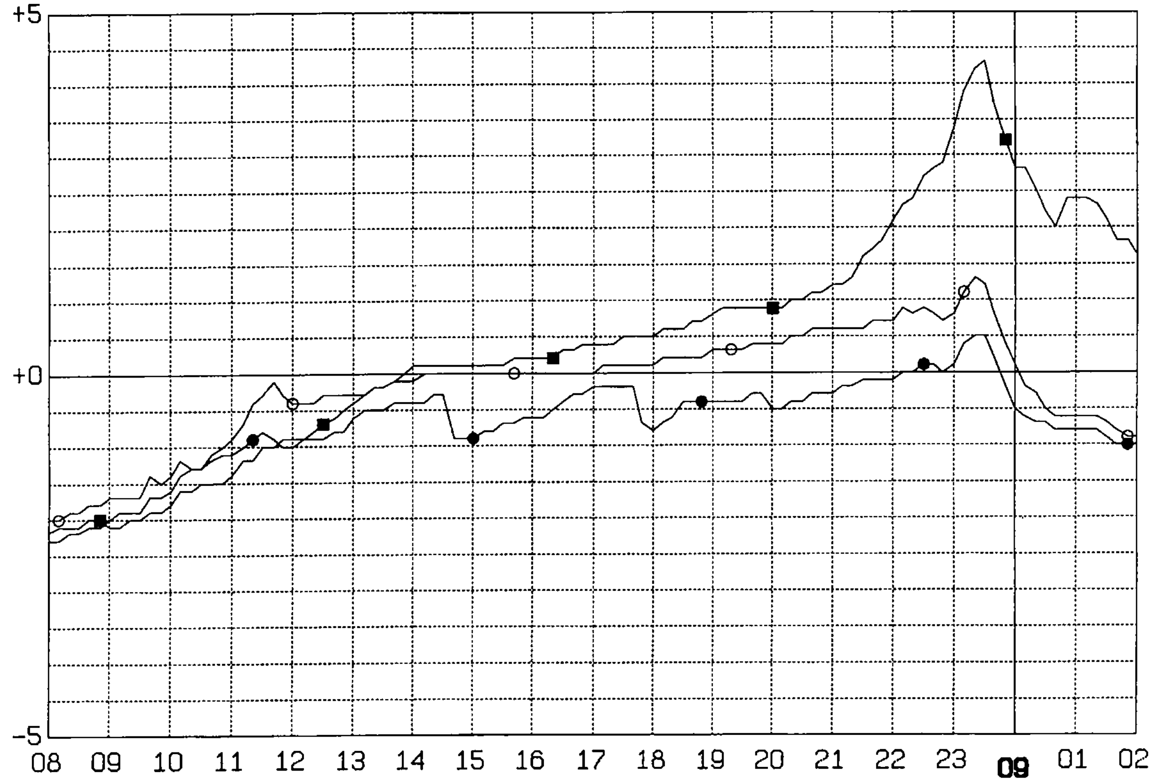


**FIGURE 11 Road surface temperature of porous asphalt (●) and dense asphalt (○), January 8, 1996. Fall in temperature of porous asphalt at 14:30, 17:40, and 20:00 is caused by gritting operations. Also shown is air temperature (■).**

porous asphalt. The voids are filled with sand, and the desirable transport of water is disturbed after a period of freezing rain. It is doubtful whether it is possible to remove the sand by using cleaning techniques.

Perhaps temporary elimination of the porous asphalt structure is a solution. Some material that is poorly soluble in water can be used to close the voids of porous asphalt temporarily. After a while rain should open the voids again. As such an option, calcium sulfate ($CaSO_4$) must be explored as the spreading agent. $CaSO_4$ is easily obtained and relatively inexpensive. The material is poorly soluble in water (0.2 wt%) and would not cause many problems for the environment or for road authorities.

## Conclusion

Dutch winters are characterized by unsettled weather. Temperatures can pass the freezing point several times, often in one day. Long cold periods with a great deal of precipitation are rare. Because of their nondense structure and their temperature and humidity behaviors, roads made of porous asphalt require greater attention from the highway authority than do comparable roads made of dense asphalt concrete. Winter maintenance of porous asphalt roads does not cause the highway authority many worries under normal Dutch winter conditions, in which slipperiness is caused mainly by the freezing of wet road surfaces. Only in the case of freezing rain does the driving quality of porous asphalt become considerably less than that of comparable dense asphalt concrete.

## References

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2. Noort, M. *Winter Maintenance on Porous Asphalt.* Ministry of Transport, Delft, The Netherlands, 1991.