Performance of a Road Surface Condition Sensor

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Abstract

A new feature has been added to a commercial surface condition sensor to enhance the measurement of water layer thickness and salt concentration. Laboratory and field test results of the new sensor are presented. An accuracy of 0.1 mm up to 1.0 mm is reachable for water layer thickness in laboratory measurements and about 1 °C for salt concentration when expressed in depression of freezing point for values less than 10 °C. The performance suggests increased reliability and justifies applying the sensor within certain traffic control applications such as variable message signs and automatic weather controlled speed limit systems.

Introduction

Most commercial road surface condition sensors are based on qualitative detection of the presence of water or ice. However, from the point of view of actual driving grip the amount of frozen substance is essential. Laboratory testing [1] has shown that the grip between a tire and asphalt dangerously reduces already when the layer of ice gets thicker than about 50 micrometers. Although the actual grip depends appreciably on the condition of the tire and on the roughness of the asphalt, this result suggests that quite a small amount of ice is enough to cause a slippery condition. During a typical intensity 1 mm/h of freezing rain, it takes only a few minutes to reach this amount of ice.

Another important factor affecting tire friction is the concentration of salt or other de-icing compounds in the frozen water. In contradiction to a common assumption, it turns out that a solution of water and a de-icer compound does not freeze at one temperature [2]. Actually there is no freezing point, but a temperature at which freezing will start in a solution and the

This temperature is usually expressed as the depression of freezing point. The reason, why freezing cannot happen at one temperature, is that, while the freezing starts, the accumulated ice does not contain de-icer, whereas the concentration in the solution must increase and ice formation will stop unless the temperature does not decrease further. Consequently, a salty surface will become slippery only gradually as a function of temperature.

Since the thickness of ice and concentration of salt are essential in determining slippery conditions, it is obvious that we should be able to measure both these quantities fairly reliably. In this paper we present test results of a commercial road surface sensor supplied with an optical detector capable to measure water layer thickness. The sensor can also directly detect the presence of snow or frost, which are frequently causing slippery conditions. The sensor is manufactured by Vaisala Oyj and is available labeled as DRS511.

Measurement of water layer thickness

The optical detector of the sensor is based on reflection of light from the top surface of water layer on the sensor. In a sense it is a modified version of a typical optical distance sensor installed in the road flush with the surface. With water layer thicknesses of 4.0 mm or below the response is strongly dependent on the distance of the upper surface of water layer.

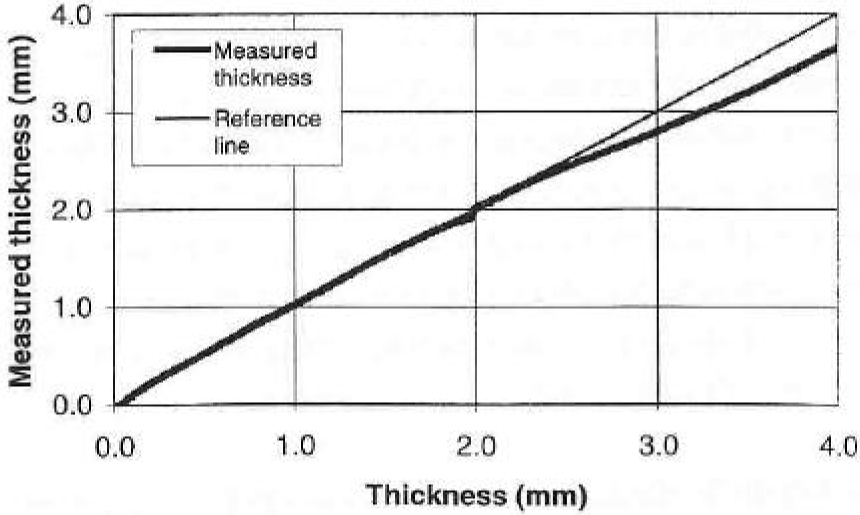

Figure 1 *Water layer thickness on the sensor in a laboratory measurement*

In Figure 1 we show the response of the sensor as a function of actual thickness. The data is measured in laboratory conditions by allowing an initial thickness to slowly evaporate out while recording the actual thickness by use of a microscope. We can conclude that in ideal conditions the sensor is capable of reaching a measurement range up to 4 mm and an accuracy of 0.1 mm in the range of 0.0 to 1.0 mm.

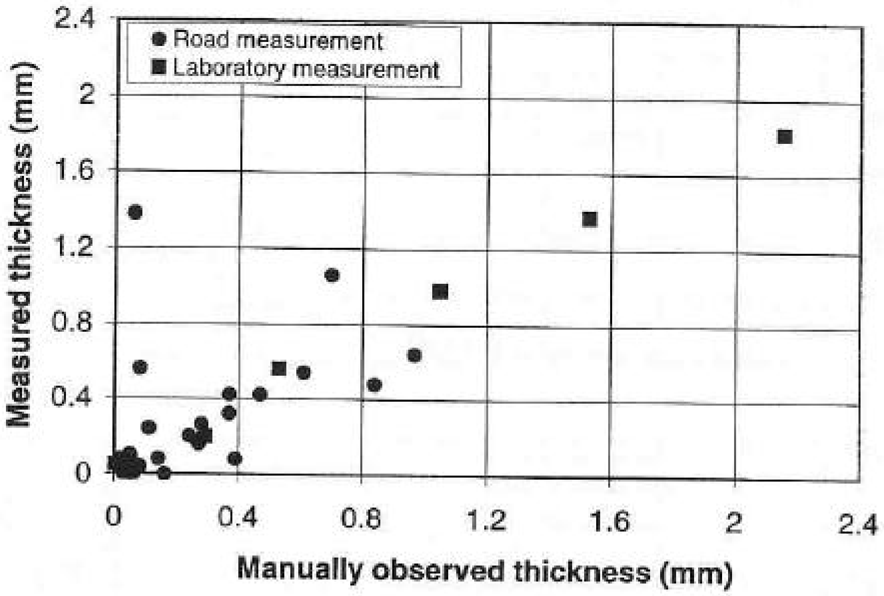

Figure 2 *Separate water layer thickness measurement results from laboratory conditions and from a sensor which is installed into a roadway.*

In Figure 2 we have collected separate thickness measurements. The circle points are values observed on sensors which were installed into a real road and exposed to normal traffic. The reference values have been taken by sucking water to filter paper and measuring the increase in weight per surface area. The square points are from laboratory measurements where water layers were applied onto the sensor and the thicknesses were observed by a calibrated microscope.

Obviously the accuracy is lower in road measurements because of traffic, sensor position, and water impurities. However, on the average the observed and measured values seem to match well. This is clear because the instant thicknesses on the sensor by nature vary considerably due to traffic and rain, but the average measurement values seem to follow the average thickness. The two very high measured values on the left represent a situation when there occasionally were impurities on the sensor. This kind of situations can be distinguished when the thickness is compared with other data of the sensor.

Measurement of salt concentration

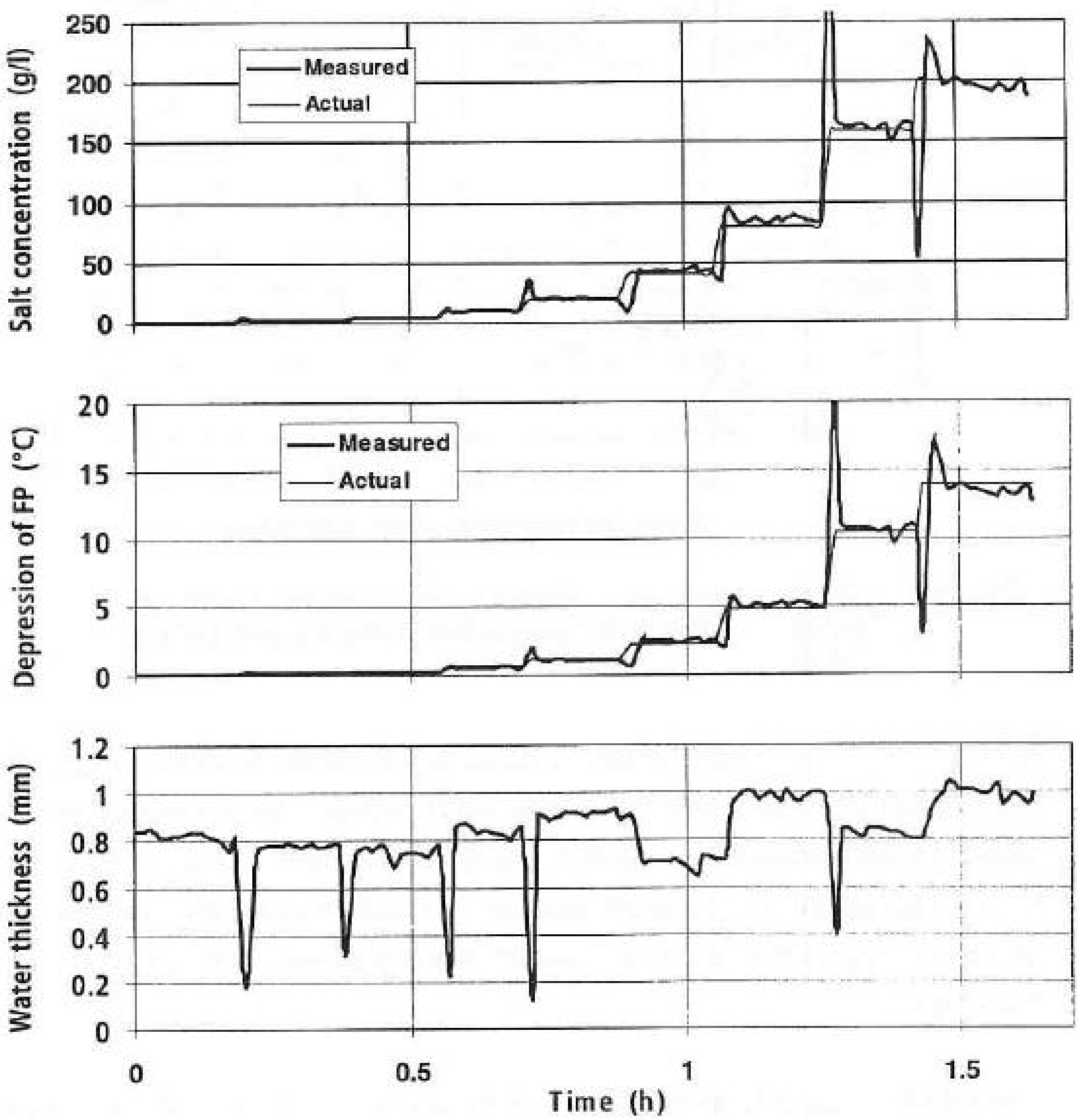

Figure 3 *Salt concentration, depression of freezing point, and water layer thickness as a function of time in a laboratory experiment measured at 0 °C.*

The amount of salt on a wet road surface turns out to be fairly proportional to the electrical salt on the surface in units of g/m^2. The salt concentration is obtained by dividing the amount of salt with the thickness of the water layer. There is a known relationship between the salt concentration and the depression of freezing point. Consequently, by measuring the salt amount and the water layer thickness it is possible to arrive into a reliable measure of the freezing properties of the road surface.

In Figure 3 we show the results for salt concentration, depression of freezing point, and water layer thickness of a laboratory measurement conducted at 0 °C. Water solutions of NaCl having concentrations of 0.0, 2.5, 5.0, 10, 20, 40, 80, 160, and 200 g/l were applied sequentially on the sensor. We can conclude from the data that an accuracy of better than 10 % is reachable for salt concentration and depression of freezing point with a calibrarated sensor.

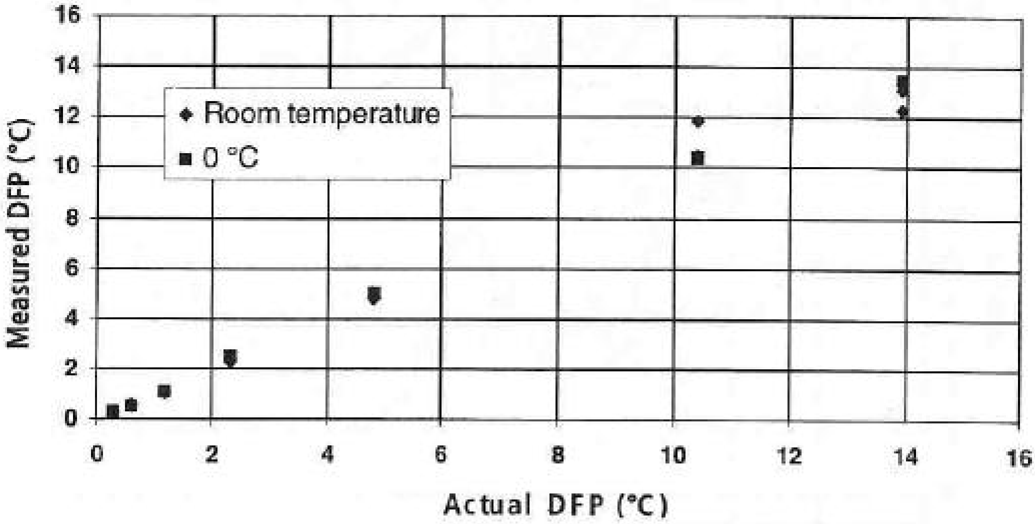

Figure 4 *Measured depression of freezing point as a function of actual DFP in °C. The values include the data of Figure 3 and two sets of data measured at room temperature.*

Figure 4 shows the measured depression of freezing point as a function of the actual data. The values at 0 °C are the same as in Figure 3. There are two different measurements taken at room temperature to reveal repeatability. We may conclude that an accuracy of better than 10 % is reachable for depression of freezing point less than 8 °C and about 15 % at higher concentrations.

Obviously the accuracy of DFP attainable in laboratory conditions cannot be reached in a road environment. Overdriving traffic will cause additional noise in the measurements. Also uneven local distribution of salt especially across the road and just after spreading will cause ambiguity as compared to an average of a larger area of road surface. Nevertheless, accurate local measurement will certainly help in assessing potential slipperiness in a given section of road.

Data from a highway

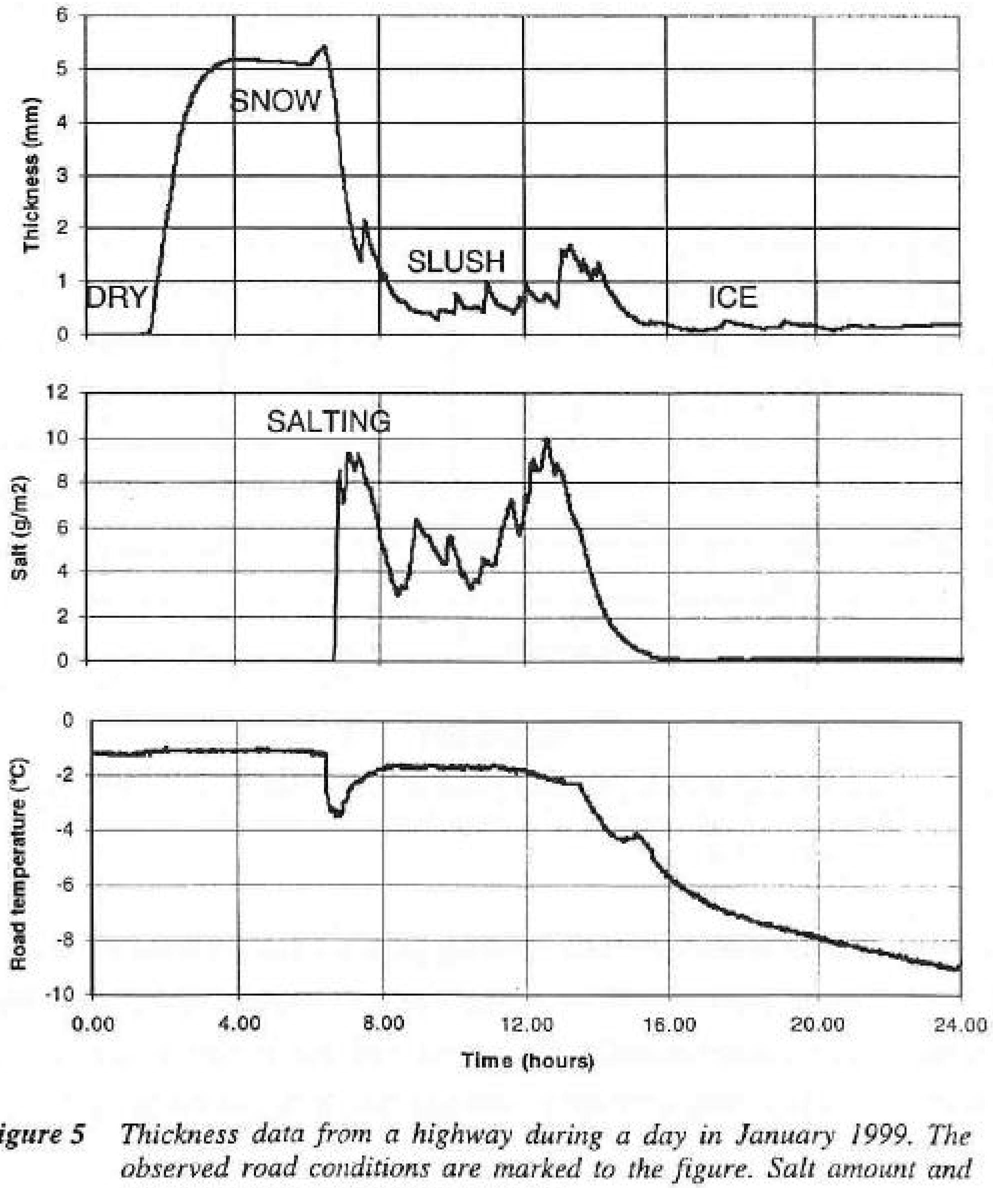

Figure 5 *Thickness data from a highway during a day in January 1999. The observed road conditions are marked to the figure. Salt amount and road temperature clarify the situation.*

From Figure 5 it is clear that the optical measurement indicates also snow, slush and ice. The data was recorded from a highway carrying moderate traffic in Southern Finland. The snow at 2:00 am caused a high and even peak to the thickness. Salting at 7:00 am changed snow to slush. As a result the thickness reduced and started to vary. Later on traffic still reduced the amount of slush and salt. Due to that and lower temperature the road finally froze, which produced a low and even thickness. We can conclude that not only the amount but also the variation of the thickness indicates the type of the material on the road.

The accuracy for snow and slush is lower than the accuracy for water thickness. This is because the value of the thickness also depends on the optical reflection properties of snow and slush. However, the thickness values give a very illustrative view of road surface condition. Moreover, the accuracy for ice and specially for clear ice is better because their optical properties are closer to the properties of water.

It is important to note that the sensor detects snow directly from the road surface. Hence it can be detected whether snow remains on the road when it is snowing.

By combining the thickness information to other measurement results of the sensor and the road weather station it is possible to analyse road surface condition more reliably than before. This kind of analysis model is implemented in Vaisala's Road weather station (ROSA) which has been under field testing in Southern Finland during the winter 1998-1999.

Summary and conclusion

Test results of a new road surface condition sensor are presented in this article. The sensor tests included measurements of water layer thickness, salt concentration, and depression of freezing point as well as the detection of snow, slush and ice. An accuracy of 0.1 mm in the range of 0.0 to 1.0 mm for water layer thickness was achieved in laboratory tests and an accuracy of about 1 °C for salt concentration when expressed in depression of freezing point. According to the measurements from a highway the sensor is capable of detecting snow, slush and ice.

The results suggest that the sensor is reliable enough to be used within certain traffic control systems. Supporting results have also been achieved in field tests which were carried out in the road weather station of Utti in Southern Finland during the winter 1998-99.

Acknowledgement

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References

1. Nicolas, Jean-Peter: Glättebildung durch Überfrierèn. Schwellwerte der Oberflächenfeuchte auf Fahrbahnen. Bast Heft V 36, 1996. 26 pages.

2. Turunen, Markus: Measuring salt and freezing temperature on roads. Meteorol. Appl. 4, pages 11-15, 1997