WINTER MAINTENANCE OF POROUS ASPHALT PAVEMENTS

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1. Abstract

The maintenance plan of any managing company of road infrastructures requires yearly high expenses for the operator teams which are in charge of salt or de-icing substance spreading on road surfaces. This is particularly onerous in regions where low temperatures or ice formation on road surfaces occur frequently. Such a compulsory spreading operation implies yearly a significant consumption of the above substances, and, hence, a cost which is strongly related, along to the type of substance used, to the geometric configuration of the road (longitudinal and transversal slope, effectiveness and disposition of draining and water collecting works).

The increasing diffusion of road pavements with draining and sound-absorbing macro-roughness, despite their high mechanical and performance characteristics (especially with respect to circulation safety) in comparison to traditional pavements, has produced in winter maintenance a significant increase of salt use. This has led to a consequent increase of costs, number of operations, as well as environmental damage.

In the light of the above, the present paper illustrates the results of an experimental investigation; a new anti-icing technique is being proposed, which consists in heating the draining surface by taking advantage of the Joule effect and using resistive metal elements energised by electric current.

This technique, besides being profitable, guarantees the expected mechanical performance of the asphalt mixture and can be adopted to reduce the amount of salts and number of operations during winter maintenance of porous bituminous mixtures.

The experimental investigation has made use of laboratory equipment in order to define and test the technical solutions proposed.

2. Introduction

By “anti-icing techniques” are termed all the operations necessary to avoid the formation and development of snow or ice, generally by spreading chemical agents which prevent the ice or snow from sticking to the road surface.

A winter maintenance plan of road pavements, to be really effective, must carefully consider this preventive phase, above all in relation to the road characteristics and the service expected.

A successful anti-icing programme involves the capability to take rapid and qualified decisions in the selection of the most suitable intervention to keep pavement conditions at an acceptable level.

The intervention shall start before or at the same time as the snowfall. Therefore one must be able to forecast with a certain probability when the snowfall will begin and how it will be.

For the time being, the intervention consists in spreading chemical substances on the road surface, these being, typically, duly concentrated watery saline solutions (FHWA, 1996).

Porous bituminous mixtures as those used in draining and noise-absorbing road pavements make anti-icing operations particularly delicate and expensive.

The mixtures’ porous structure, which helps draining the rain or melted snow, causes at the same time the quick draining away of the saline substances dissolved in it and forces the operator teams to intervene faster and more frequently, obviously at higher costs.

Generally speaking, approximately 30% more salt is used for draining mixtures compared with traditional pavements, although the selection of binary salts, i.e. $CaCl_2$ + NaCl, will make the treatment more effective (Camomilla et al., 1997).
Disregarding the economic factor, the exaggeratedly high amounts of saline solution used for this kind of surfaces increase the well-known environmental problems related to the removal of salty water from road pavements and with the water's aggressive action above all on structural elements made from reinforced concrete (Collepardi, 1991).
With respect to traffic safety, the consequences of a late anti-icing action in the case of porous bituminous mixtures are particularly serious: tyres can no longer roll on the pavement with sufficient adherence because the pores are clogged up with fresh snow, compacted by the vehicles passing by and forming an ice layer inside the pavement that is very difficult to remove, even when the weather conditions becomes milder.
An alternative anti-icing method consists in the installation, during road construction, of a heating system of the road surface based on the Joule effect.
This way, before and during the snowfall the road surface will be kept at a temperature systematically higher than the external one.
Through the laboratory investigation it was possible to determine the best types of resistive material, the optimum positioning criteria, as well as how the heating circuit should be fed in safety conditions.
Finally, the results achieved were evaluated (Figure 1).

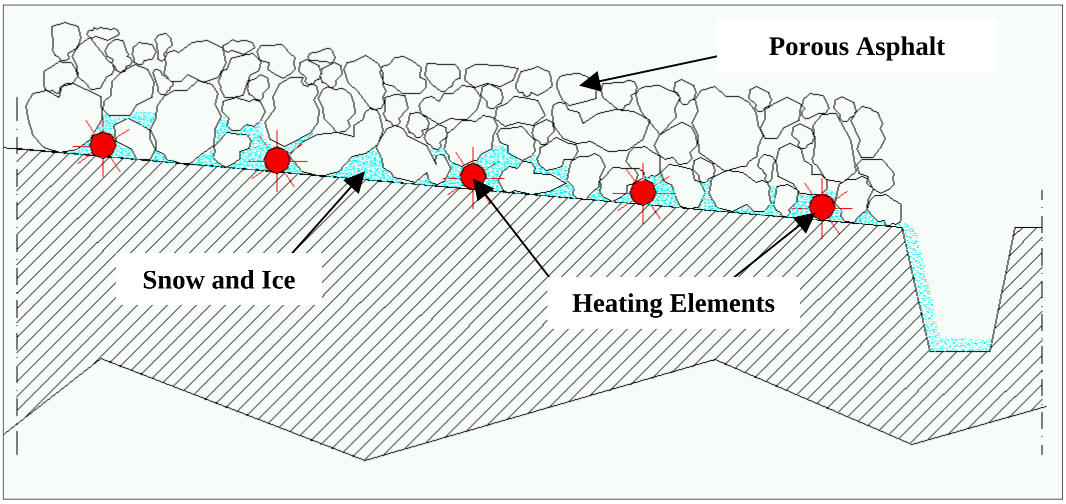

Figure 1 – Functional Diagram of a Heated Pavement

3. Technological System Selection

To avoid ice formation in draining pavements, an important preventive action can be carried out by taking advantage of a physical principle. Practically, the road surface is heated by a simple technology up to a temperature above the water freezing point or at least able to make the possible salt spreading action more effective. A resistive element is heated by electricity in compliance with the well-known Joule equation:

$$W = R \cdot I^2 \qquad (1)$$

where W is the power obtained in the form of heat, R is the element resistance and I is the electric current flowing through it.
Consequently, the selection of the heating element to be used is of the utmost importance.
In fact, a conductive material with a high electrical resistance will be required, able to permit the current flow but at the same time dissipating a lot of current in the form of heat.
In the literature, carbon and nicrome are indicated as the most suitable to the purpose thanks to their high resistance, approximately 100 μΩ·cm.

In this case, the optimum filament shall guarantee a very good heating at low current, a long time of operation, a low commercial cost and, last but not least, a very high mechanical strength. The latter will allow the filament to stand the stress to which he may be subject during laying and asphalt compaction.
An earlier investigation (Montepara and Giuliani, 2001) identified in the alkrothal alloy (15% Cr, 4.5% Al, 80.5% Fe) the most suitable filament.
In the experimental phase this filament, subjected to a certain voltage, almost immediately reached the foreseen and desired temperature with no delay due to the thermal inertia that generally precede normal operation. As to the flow of current passing through the pavement, the simple electric diagram shown in Figure 2 applies.

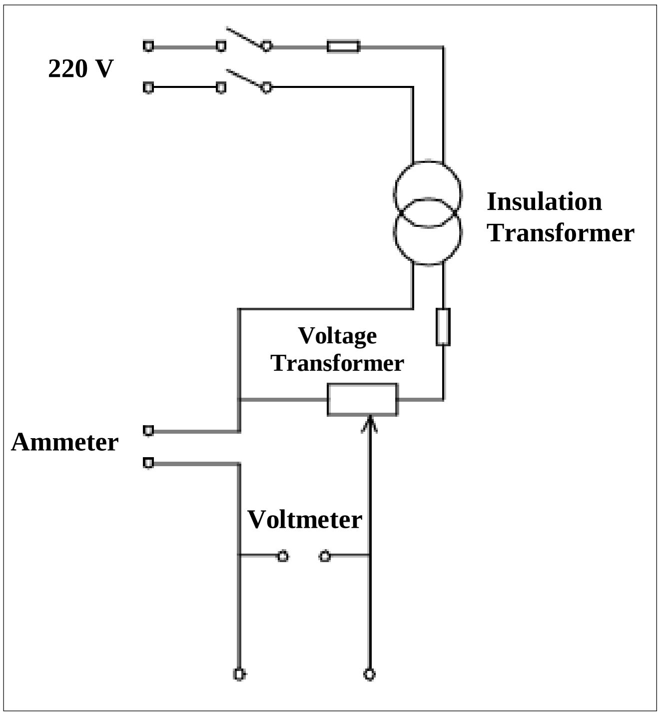

Figure 2 – Diagram Showing the Electrical Supply of Heating Elements

There are two main components: an insulation transformer and a voltage transformer.
The first one shall protect the user. It has a transforming ratio of 1:1, a power of 200 VA and is is working at a max. current of 0.8 A.
The voltage transformer allows to change the power supply from 2.5 V to 260 V and can work at a max. nominal current of 2.5 A, although it is sized to stand a current of 5 A.
Coming out from the voltage transformer, two cables supply current to the resistive filaments plunged in the asphalt concrete. Two fuses, one for the insulation transformer and one for the voltage transformer, protect the circuit from possible overloading.
A voltmeter, in parallel, and an ammeter, in series, allow a constant control of the electric measurements during the experiment.

4. Preparation of Test Samples
The experimental investigation simulated the heating of road pavement samples of congruous size (50 cm x 50 cm). The pavement samples were composed of a first layer of 120 mm thick, dense asphalt concrete. On this layer we placed the resistive filaments first, then the polymer modified bituminous emulsion and finally the 50 mm thick porouse asphalt concrete.
On this layer the resistive filaments were placed first, followed by the modified bituminous emulsion and finally by the 50 mm thick porous asphalt concrete. The resistive filaments were previously shaped in a sinusoid of 24 mm width and 8 mm wavelength and then laid out on the whole sample length.

Because of the unusual geometry of the samples compared with standard laboratory investigations on asphalt concrete, for the preparation of the samples a hydraulic compaction system was used, designed and built at the University of Parma.
This system perfectly imitates the action of the compaction rollers used on roads, with load axis adjustable up to 10 tons and programmable speed (Figure 3).
The porous asphalt concrete was prepared with bitumen modified by SBS polymers, porphyritic aggregates with a typical, gap-grading curve (16 mm max. diameter), with 19% of residual voids.
The X value, corresponding to the optimum distance between the single heating elements in the draining surface, is a variable in the problem and it is a function of the filament shape, of the heating element temperature and of the uniformity of temperature desired on the surface of the draining pavement.
Based on previous experiments on heated pavements (Montepara and Giuliani, 2001) a distance of 150 mm was selected.

Figure 3 – Preparation of Test Samples

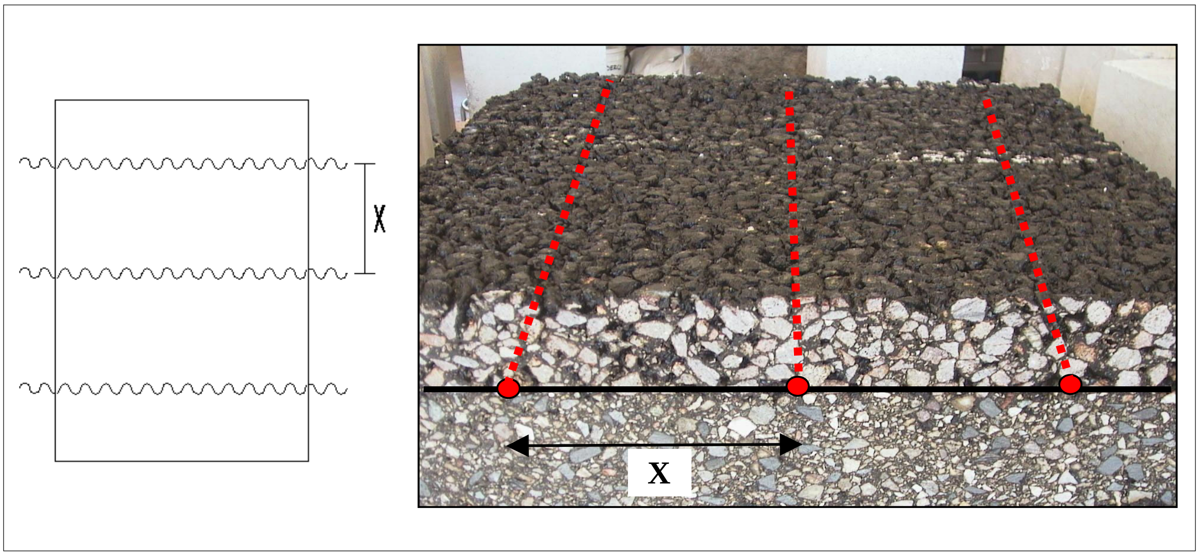

Figure 4 – Setting Up of Test Samples

5. Test Results

The laboratory tests checked the power dissipated by the resistive filaments due to the Joule effect while considering at the same time the current flowing through them, the variation in temperature of the filaments and that of the road surface.

The best results were obtained when the power dissipated by the filaments, with the above-mentioned length and geometry, became steady at 8 W approximately. In this configuration the filament temperature is about 43°C, the voltage is 12.08 V and the current is 2.01 A.

Although the filaments are energised, there is no risk of short circuit due to the possible presence of water, since the whole system is protected by an insulation transformer that prevents any risk of electrocution.

The temperatures achieved by the heated samples were analysed by a thermal vision infrared camera. This sophisticated instrument, whose specifications are listed in Table 1, makes it possible to detect in a continuous and very precise way surfaces at different temperatures by highlighting them in different colours.

Furthermore, infrared vision becomes a powerful instrument of analysis when the single pictures are processed to produce a detailed thermal study.

Figure 5 shows a series of 6 thermal pictures of a sample taken in 6 different instants, from 0 to120 minutes. One can clearly see the sample heated by the three parallel resistive filaments, placed horizontally at a distance of 150 mm from one another.

The different colours, ranging from blue to deep pink and orange and visible in parallel horizontal stripes, identify the temperatures on the draining road surface.

The temperature tends to increase by increasing the time during the which current is flowing through the resistive filaments. After 120 minutes the temperature on the pavement surface will be approximately 10°C higher than the environment's initial temperature.

The temperatures of the most important points of the road pavement sample (items 1-6, Figure 6) have been obtained by a thermal analysis carried out in different times. They are listed in table 2.

The heating filament (point 2), duly energised, remains at a constant temperature of 43°C, which means 22°C more than the ambient temperature.

Therefore the road surface heating produced by the resistive filaments is an effective anti-icing tool. At the same time, the thermal gradient induced in the asphalt concrete is certainly consistent with the rheology and the mechanical performance that the bituminous binder must guarantee (Montepara and Giuliani, 2000).

The temperature on the draining surface rises by a gradient of 4÷5°C/h approximately. This is an important fact to be considered in order to start the heating system well in advance compared to the evolution of the weather conditions.

With reference to Figure 6, the temperatures' evolution in time along the geometrical development of the sample can be analysed in parallel (X-X) and orthogonal (Y-Y) direction to the heating elements respectively.

The temperature distribution in correspondence with the heating element, X-X direction (Figure 7), is uniform along all the sample development.

In orthogonal direction, Y-Y (Figure 8), temperature values locally higher by 2°C can be measured only in direct correspondence with the resistive filament.

Table 1: Thermal Vision Infrared Camera Data

Observable Temperature Range	–20 °C to +300 ° C
Temperature Resolution	0.1 °C
Precision of Measurement	± 1.0 % of scale limit
Detection wavelenght	3.0 to 5.3 μm
Detector Type	HgCTe – 270.000 pixel
Field of view	21.5 ° h x 21.5 ° v
Shooting distance	0.3 m/infinitely
Frame rate	1/22 sec

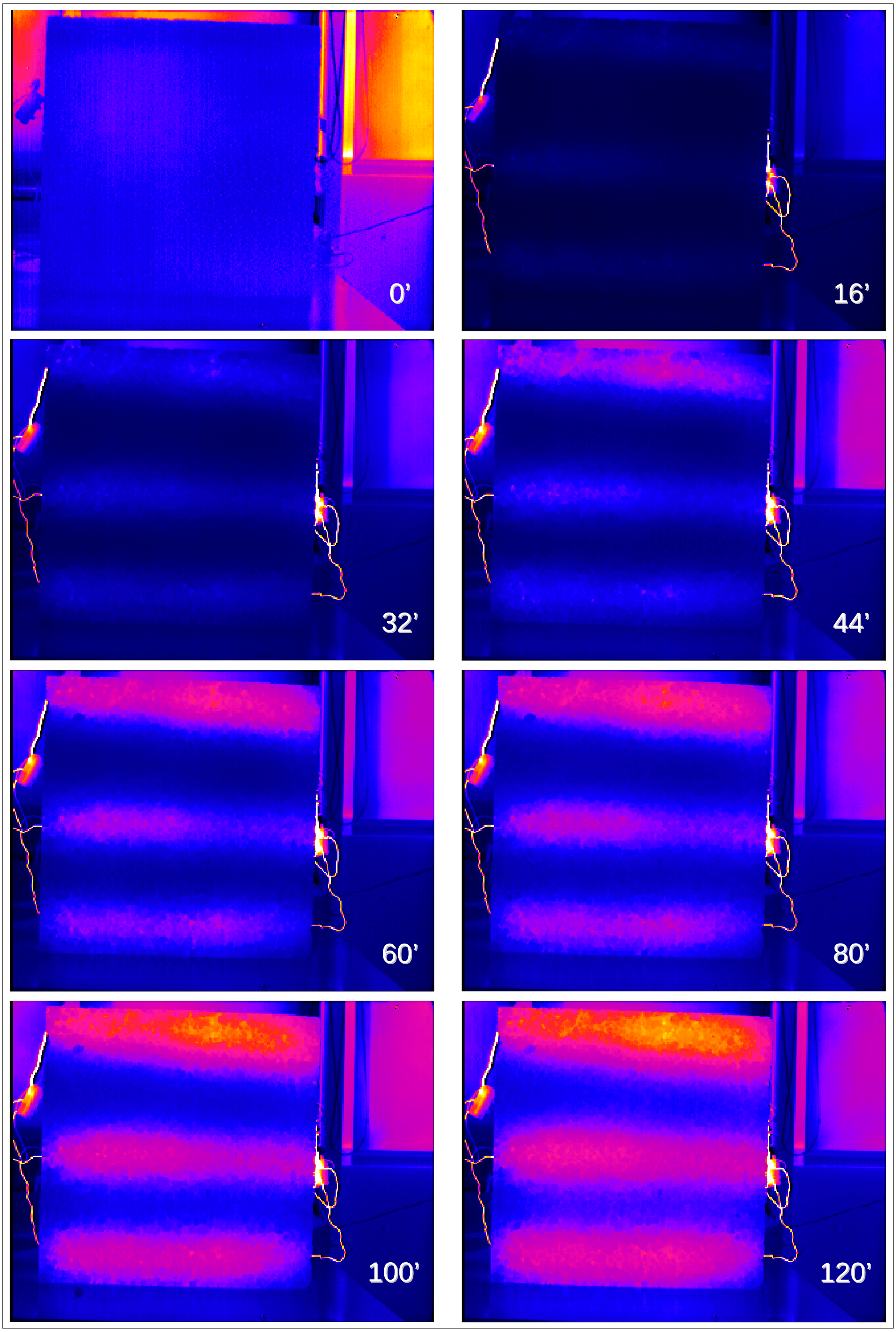

Figure 5 – Temperature Distribution in a Road Pavement Sample

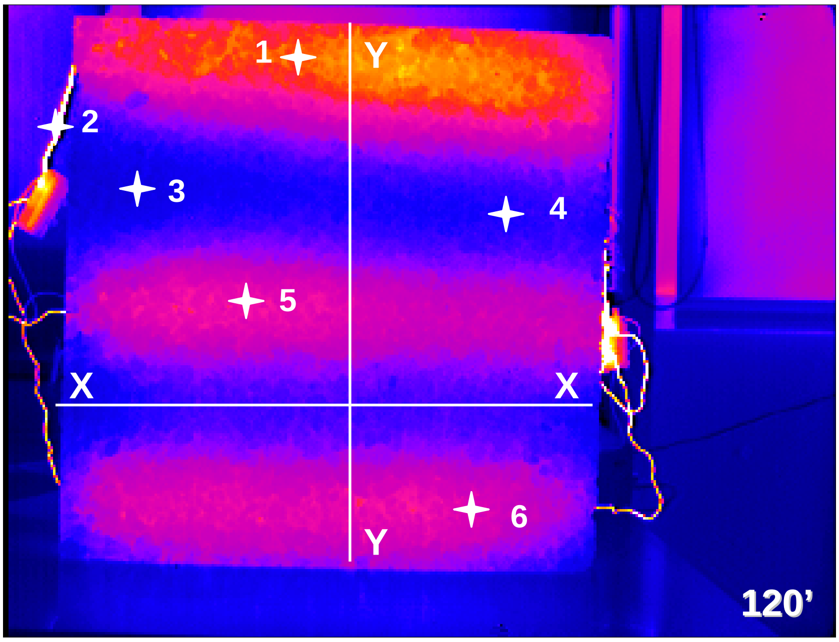

Figure 6: Thermal Vision of the Sample after 120 min Heating

Table 2: Temperatures in Time for Some Significant Points of the Sample

Point	Time 0'	Time 32'	Time 60'	Time 120'
1	20.72 °C	23.67 °C	25.86 °C	30.16 °C
2	21.64 °C	43.37 °C	43.34 °C	43.38 °C
3	21.04 °C	22.17 °C	24.12 °C	26.74 °C
4	20.81 °C	22.64 °C	24.43 °C	28.62 °C
5	20.95 °C	23.41 °C	25.11 °C	29.18 °C
6	21.08 °C	23.32 °C	24.93 °C	29.08 °C

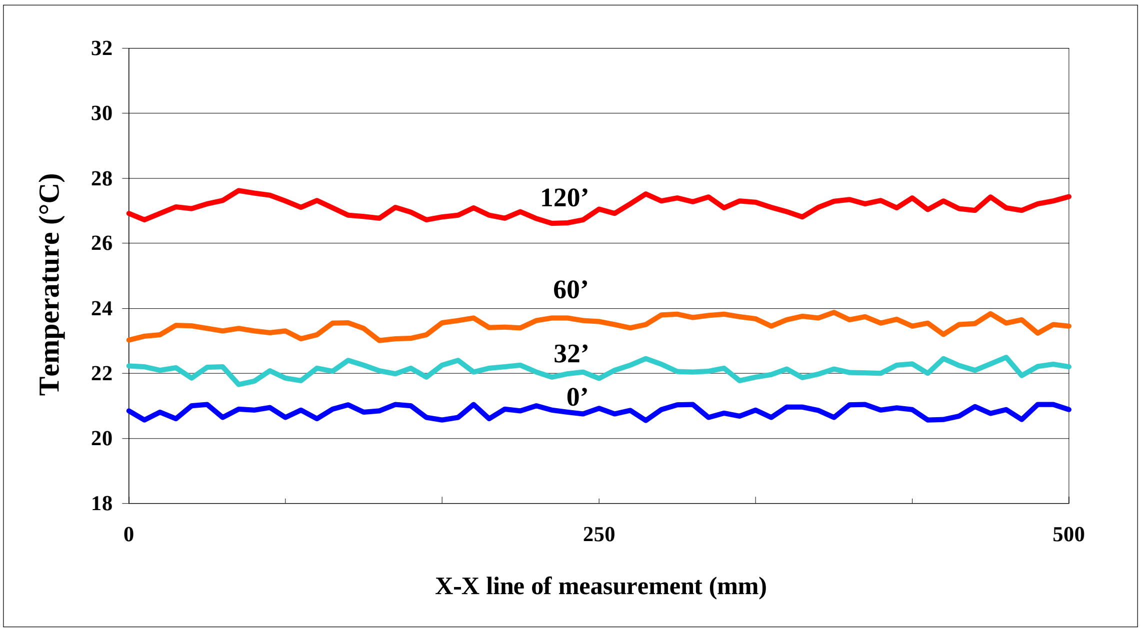

Figure 7 – Temperature Evolution in Time along X-X Line of Measurement

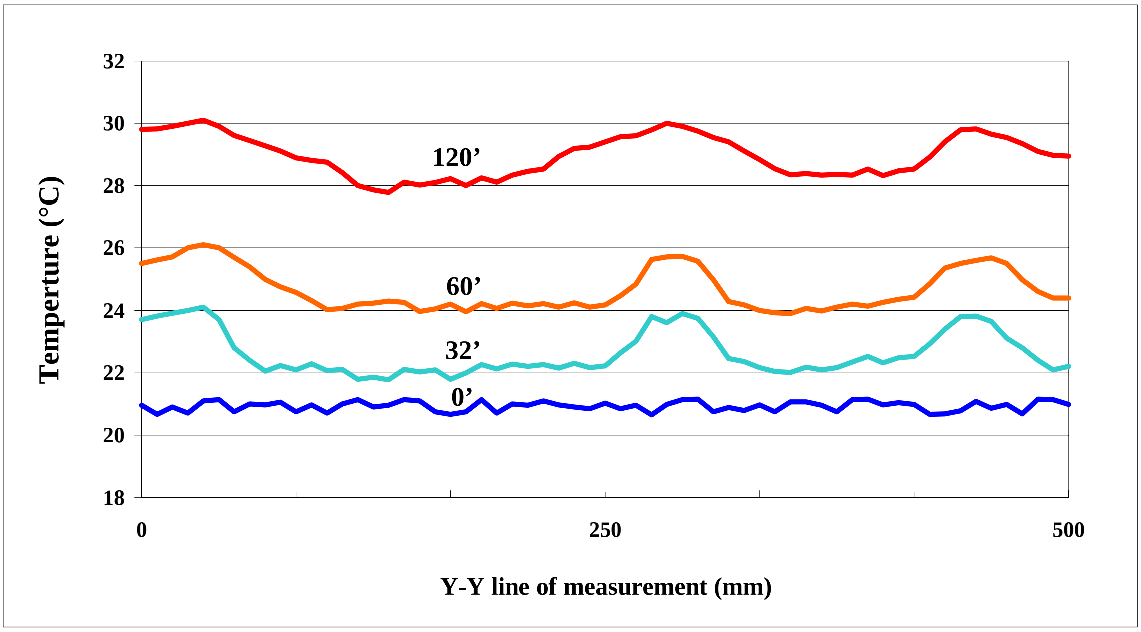

Figure 8 – Temperature Evolution in Time along Y-Y Line of Measurement

6. Conclusions

Winter maintenance of asphalt pavements can be made highly effective by installing heating elements directly underneath the road surface course, above all when the latter is made up of porous asphalt concrete. In fact, for such pavements an anti-icing programme is much more important and effective than any de-icing technique.

The experimental investigation, whose main results have been summarised above, has shown on a lab scale that:

- The heating elements bring the road surface to a temperature which is higher than the external ambient temperature, with programmable thermal gradients.
- The heating elements, taking advantage of the Joule effect, can be supplied with a very low voltage on condition that the most resistive, cheap, lasting and mechanically strong material is selected.
- The sinusoid-shaped resistive elements create a bigger heating surface inside the asphalt concrete and can best stand the aggregates’ motion and the stress due to laying and rolling operations.
- A higher temperature of road pavements in winter allow to prevent the formation of a durable ice layer, particularly dangerous in draining pavements. It also improves the lifetime of porous bituminous mixtures by intervening of the factors that make the bitumen-aggregate bonds more fragile (Nakanishi et al., 2000).
- Placing a system of resistive elements inside a road pavement is certainly easy and can be technologically compared to the laying of metal reinforcements as already available in the technical literature on road construction.
- The temperatures measured at the interface resistive element – bitumen are certainly compatible with the binder’s full structural efficiency.

7. References

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