Novel Heating Technologies to Control the Surface Conditions of Pavements

Ron van Wijk[1, a], **Cesare Sangiorgi**[2, b], **Francesco Baroncini**[2, c]

[1] *GFSC Consultants and Engineers BV, Arnhem, Netherlands*
[2] *Civil. Chemical, Environmental and Materials Engineering, University of Bologna, Bologna, Italy*

[a] r.van.wijk@gfsc-group.com
[b] cesare.sangiorgi4@unibo.it
[c] francesco.baroncini@studio.unibo.it

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ABSTRACT

In winter roads become slippery due to the influence of snow and ice. Despite traditional snow ploughs and salt sprinkling, statistics show that this results in the loss of many lives each year and causes severe material damage. Furthermore it disrupts traffic, causing significant economic damage. Winter conditions also accelerate the deterioration of asphalt, especially open structured surface layers, resulting in extra maintenance costs for road authorities.

Dutch based GFSC Consultants and Engineers, Grontmij, Reef-Infra and AHT Netherlands, united in the Heated Roads consortium, therefore have developed an alternative for combating the adverse effects of ice and snow on roads. It uses an innovative electric infra-red heating system that consists of a very thin coated metal alloy strip that is placed under the top asphalt layer (or binder). Due to its special amorphous molecular structure, it heats up the asphalt monolith structure very rapidly and is also energy effective.

Several test sections were built in Germany, Italy (in cooperation with the University of Bologna) and The Netherlands in order to study the effect of the ribbons on the deicing of the surface as well as on the extension of the lifetime of the asphalt structure. Several parameters were varied such as the distance between and depth of the ribbons, the use of insulation material and the generated power by the ribbons. Also test were done related to the application procedure, like prefixing the ribbons onto asphalt grids in order to speed up the application process.

The research was supported by the Dutch Provinces of Gelderland and Overijssel and rewarded a subsidy by the European Union as this innovation is as a new way to secure the safety on roads, to guarantee traffic flow and to extend the lifetime of asphalt (and thus reducing maintenance costs).

Keywords: De-icing, Freeze-Thaw, Maintenance, Safety

1. INTRODUCTION

Roads in winter become slippery due to the influence of snow and ice[1]**.** On main roads with intensive traffic, combatting this seasonal phenomenon is often well organized, as throughout large areas sophisticated detection systems are in place to collect data about local winter conditions. Based on this data snow ploughs that sprinkle salt are set in motion for these specific areas (Figure 1). Salts and other de-ice materials however are environmental unfriendly and quite chemically aggressive. This has a detrimental effect on the durability of the road infrastructure such as the asphalt pavement and associated concrete structures (tunnels and bridges)[2,3,4,5]. Cold temperatures also mean an accelerated deterioration of the asphalt pavement (Figure 2), leading to higher maintenance costs[7]. It also leads to pollution of the road edge environment[8].

Despite combatting snow and ice by sprinkling salt, statistics show that surfaces still become slippery because either the measuring system ‘missed’ the specific combination of low temperatures and moist or that the measures taken were just too late due to restricted snow plough capacity. This sadly results in the loss of many lives each year and a huge amount of personal injuries. In the Netherlands, within only a period of just two weeks, more than 6.400 people were treated at the emergency department of hospitals[9]. Besides material damage on cars, road surfaces and road furniture, accidents also disrupt traffic, causing discomfort[10] and significant economic damage. During a single rush hour in the Netherlands slippery roads led to a standstill of traffic over 1.000 kilometer causing at least 9 million euro of economic damage for goods transports only[11].

Figure: 1 Sprinkling de-icing materials

Figure 2: Damaged asphalt surface due to winter conditions

For ramps, bridges, etc., usually there are special deicing systems installed. This is either an electric system based on cupper wires or a hydronic system based on plastic hoses with hot running water. Although both these systems are effective, they have rather high initial costs and use a lot of energy. In case of the hydronic system other disadvantages are that the process of heating the water often is based on fossil fuel (emitting CO_2), that the heat is not evenly spread over the total surface and that leakage of the system due to frost protection measures (glycol) can cause serious pollution.

The Heated Roads Consortium[12], consisting of the engineering consultancies GFSC Consultants and Engineers BV[13] and Grontmij Nederland BV[14], contractor Reef-Infra BV[15] and provider of de-icing systems AHT Netherlands BV[16], therefore developed an alternative for combatting the adverse effects of ice and snow on roads and other surfaces. For road authorities the application of this infra-red heating system means significant less long term maintenance costs, for road users increased safety and comfort and less social costs.

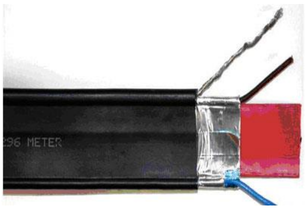
The development is based on the use of an innovative electric infra-red heating system that heats up asphalt monolith structures rapidly and evenly in an energy effective way. This means, that the asphalt no longer reaches temperatures below 0 ˚C which reduces the deterioration of asphalt due to winter conditions (mainly cracking). This especially is a problem with open structured surface layers, as they normally are badly affected by winter conditions. In the Netherlands, freezing of the asphalt surface on two roads (A7 and N33) alone caused 5 million euro of damage in one winter[17]. According to the Dutch Ministry of Infrastructure and Environment, responsible for the maintenance of the main infrastructure facilities, this technology is likely to be most successful when applied at the ‘weakest’ points of the infrastructure such as ramps of highways, tunnels and bridges[18]. In order to test the infra-red heating technology under realistic conditions, in 2014 laboratory tests were done and three test sections were built to study the effect of the ribbons on the deicing of the surface. The test sections were conducted in cooperation with a number of road authorities that showed interest in this new technology. In a first test section, in cooperation with the road authority Landesbetrieb Mobilität Autobahnamt Montabauer, the technology was applied in a service road to the German Autobahn in

Montabauer, whereby the focus was mainly on developing an application method. In a second test section, a service road at the Bologna airport in Italy, the focus was on temperature measurements within the asphalt structure. This fully instrumented test section was coordinated by the Road section of the Department of Civil, Chemical, Environmental and Materials Engineering of the University of Bologna[19] with support of AHT Italy[20]. In addition to these test sections laboratory tests were conducted, also focusing on the heating-up process of asphalt.

Based on the information gathered with the above tests a third test section was conducted on a provincial road in the Netherlands near the city of Laren (Gelderland). Here, the technology was built in two ramps of an underpass.

2. INFRA-RED HEATING RIBBON TECHNOLOGY

With traditional means of deicing an asphalt surface with electric or hydronic means, the warming-up process is solely based on conduction. Therefore the time that is needed for the generated heat to be transported through the asphalt mixture is mainly defined by the thermal conductivity of the asphalt mixture. Using the infra-red heating technology, the heating process is based on a combination of conduction and long wave radiation (3 – 1000 µm) within the light spectrum. The efficiency of transforming electric energy into infra-red radiation is about 100 % and there is no electric field generated. The infra-red radiation is generated by a steel tape with a width of 25 mm and only 25µm thick which is connected to an electric circuit of 230 V. Moreover, it is also possible to use another AC voltage or even a DC power source. The tape is insulated with a coating of tie-layer adhesive resin and jacketed with a PO compound and overall covered with a high density polyethylene coating (Figure 3).



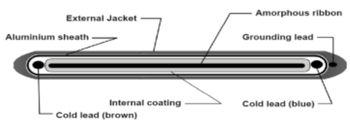


Figure 3: Infra-red ribbon

Unique about the heat source is, that the tape is made of an amorphous metal alloy, a metallic material with a disordered atomic-scale structure. In contrast to most metals, which are crystalline and therefore have a highly ordered arrangement of atoms, amorphous alloys are non-crystalline (Figure 4).

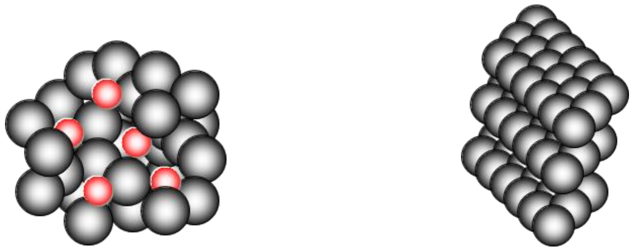


Figure 4: Amorphous structure **Crystalline structure**

Materials in which such a disordered structure is produced directly from the liquid state during cooling are called 'glasses' and so amorphous metals are commonly referred to as metallic glasses. The alloy contains atoms of significantly different size, leading to low free volume (and therefore up to orders of magnitude higher viscosity than other metals and alloys in molten state). The viscosity prevents the atoms moving enough to form an ordered lattice. The absence of grain boundaries, the weak spots of crystalline materials, leads to a better resistance to wear and corrosion. Amorphous metals, while technically glasses, are also much tougher and less brittle than oxide glasses and ceramics.

The fact, that the metal tape is very thin also means that the generated heat easily can send forth to the surrounding area, while in case of a traditional round wire the heat is partly 'stuck' within the heating element itself and leading to a high temperature gradient. In case of the infra-red heating ribbon there is a better heat flux (Figure 5), so no accumulation of heat and therefore no temperature stresses[21].

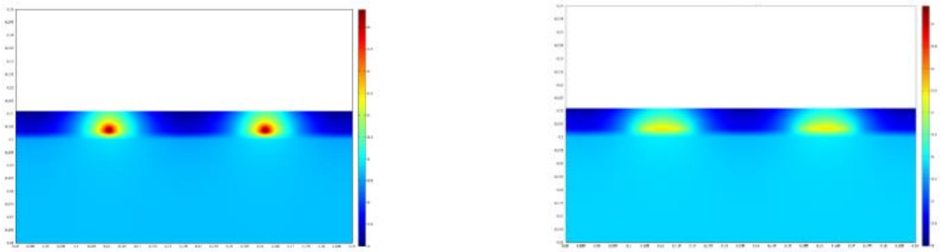


Figure 5: Cross section with traditional heating wire   Cross section with infra-red heating ribbon

The prefabricated ribbons, available in adjustable lengths, are based on a closed electric circuit with an electric connection on only one side. The power that is produced by the ribbon can be varied from ca. 10 to 60 Watt/m^2. In a normal situation the ribbons are positioned in parallel tracks at a distance of ca. 20 cm. As the ribbons are flexible and fully waterproof, application of the ribbon has lots of possible outdoor applications. As it is an electric system, it is very easy to define different sections that are heated individually and independently based on locally built in sensors that react to a critical combination of moist and temperature. Using a specially developed control box, it is ensured that only a limited number of ribbons that are in place generate heat at the same time, leading to less energy use per time unit and thus a smaller electric connection to the grid.

The ribbons are available in three types, depending on the characteristics of the outer jacket. There is a standard ribbon that is suitable for most applications, a UV-resistant ribbon for roof de-icing (where the ribbon is constantly exposed to sun light) and a high temperature resistance ribbon (up to 130 ^{0}C) that is used for application in asphalt.

3. LABORATORY TESTING

Before executing the different test sections, laboratory tests were conducted. These partly focused on the ribbons, e.g. determining the relation between temperature and electrical resistance[22], and on a scale model in order to collect data about the speed in which the heating system is capable of heating up a monolith asphaltic structure. In order to do so, asphalt slabs were prepared with a length of 80 cm, a width of 80 cm and a height of 12 cm, by filling and compacting an asphalt mixture in a steel mould (Figure 6). As the asphalt slabs were tested within the mould, a small wooden lining was built in for insulation purposes, in order to prevent the steel case to have an influence on temperature measurements.

Figure 6: Preparing asphalt slabs for laboratory measurements

In one asphalt slab the heating ribbons were built in at a depth of 4 cm under the asphalt surface, in the other slab at a depth of 8 cm. In both cases the mutual distance was 20 cm. Under half the ribbons a small layer of insulation was placed to prevent losing the produced heat to the lower part of the asphalt (Figure 7). On top of the ribbons a 0/16 mm asphalt concrete surface layer with moraine aggregate was applied.

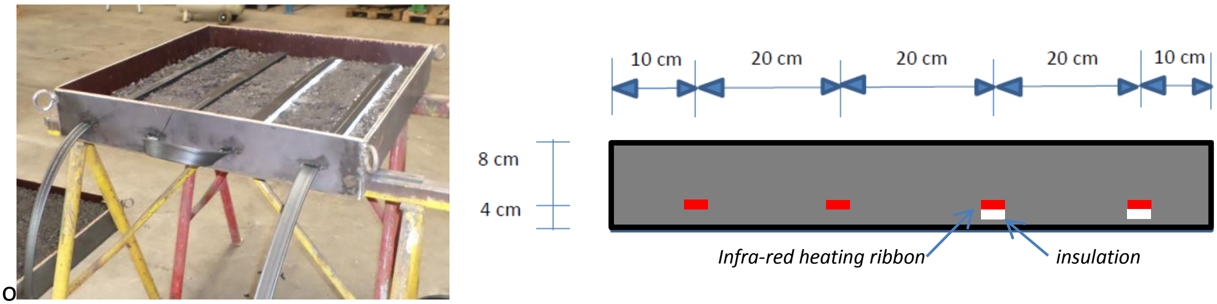


Figure 7: Infra-red heating ribbons built in asphalt trial, 8 cm under surface, partly with insulation (under two right ribbons)

Temperature measurements were done by using a calibrated infra -red camera that was situated on an aluminium frame above the two instrumented asphalt slabs at a height of 1.20 m (Figure 8). By varying the applied voltage, given the length of the infra-red heating ribbons that were built in the asphalt slabs (Ohm's law), the heating power of the ribbons was set on 30, 40, 50 and 60 Watt/m[1].

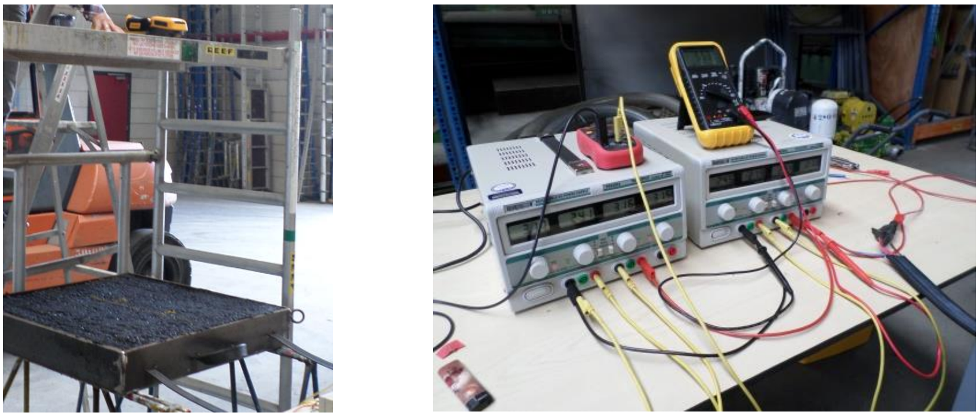


Figure 8: Heating the asphalt slabs at several power levels

Temperature measurements were done within a time frame of five minutes. In the graphic (Figure 9) the results are shown of the temperature measurements on both slabs. The upper row of pictures is applicable on the slab were the ribbons where built in at a depth of 4 cm, the lower row on the slab where the ribbons were built in at a depth of 8 cm.

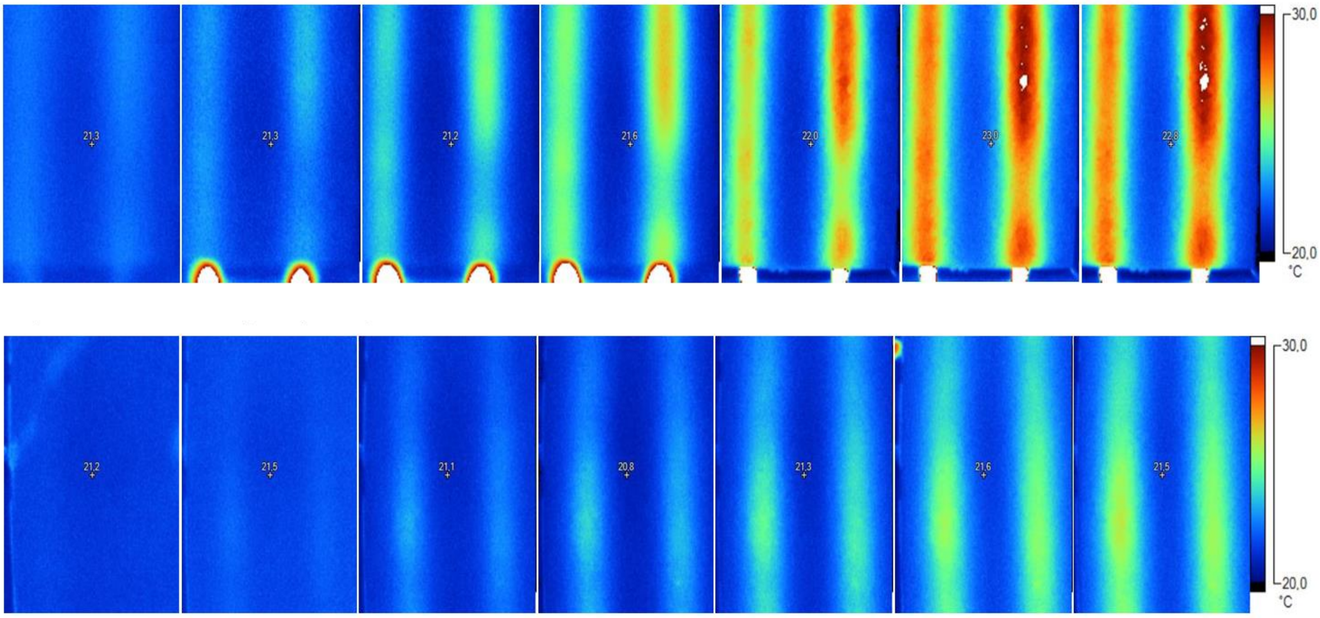


Figure 9: Heating up of the asphalt surface with 50 W/m^2, the two ribbons on the right of the slab (with insulation) at a depth of 4 (upper row) and 8 cm (lower row) respectively

Within a time frame of ca. 30 minutes the surface temperature of the asphalt slab was raised by 10 ^{0}C. As expected there was a delay of 10 - 12 minutes in heating the surface in case of the deeper situated ribbons. The presence of the insulation, situated underneath part of the built in ribbons, was hardly of influence on the heating up process of the surface.

4. TEST SECTION MONTABAUER (GERMANY)

This test section (ca. 4 x 40 m) is situated on a service road that connects a truck parking place with the E35 Autobahn to Frankfurt. In cooperation with the road authority Landesbetrieb Mobilität Autobahnamt Montabauer, Volkmann & Rossbach[23] in Montabauer and Manns Ingenieure in Wirges[24] the infra-red ribbons applied in the wheel tracks of the entrance route in a truck parking area (Figure 10).

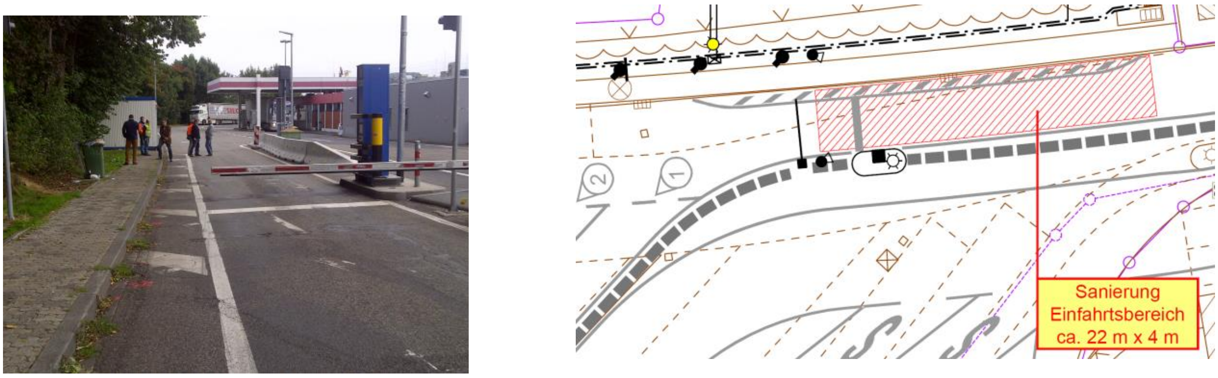


Figure 10:Test section Montabauer

The main goal of this test section was to verify different types of applications of the infra-red ribbons and the fixation to the asphalt surface. The ribbons were fixed with metal strips that were mounted to the asphalt surface with metal nails using a pneumatic hammer. Extra configurations were made in order to test if the ribbons are capable of being folded, due to this some of the folds were heated with a hot air blower and some not (Figure 11). For the (thicker) end connections of the ribbons, small holes were created in order to create a flat surface for the asphalt paver.

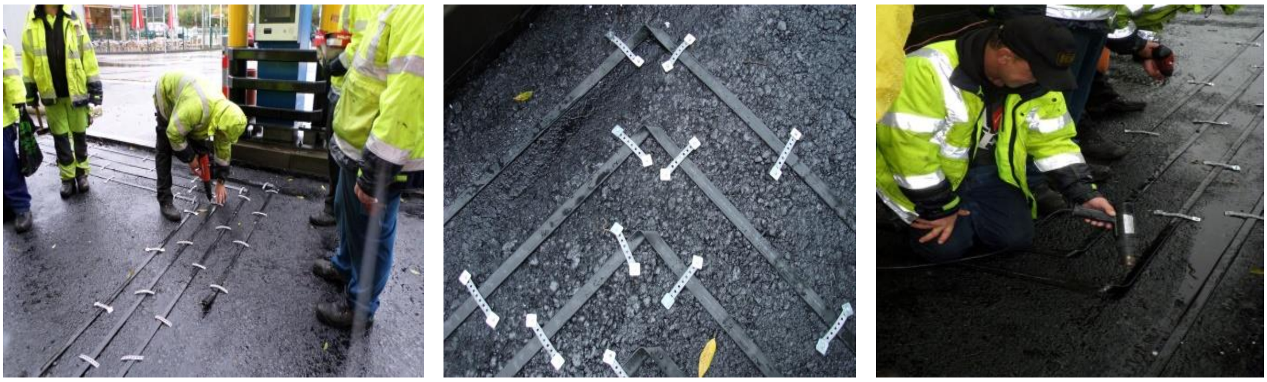


Figure 11: Applying the infra-red ribbons to the asphalt surface with metal strips

Finally the ribbons were covered with 4 cm asphalt, using an asphalt paver on rubber wheels (Figure 12), that was compacted with a roller. During the actual paving process, due to the influence of the asphalt mixture bow wave in front of the paver or the movements of the asphalt truck delivering the mixture to the paver, the longitudinally movements of the ribbons could be limited to a few millimeter, transversally there was no movement detected. The test section showed that using metal bands is an adequate way of fixation, especially when a special configuration of the ribbons is required. After completion of the asphalt works, temperature measurements with a hand held infra-red meter were conducted on the asphalt surface in order to test the functionality of the infra-red (ribbons).

Figure 12: Applying the top asphalt layer

5. TEST SECTION BOLOGNA (ITALY)

This test section was set in a stretch of the air-side service road of the "G. Marconi" International Airport in Bologna. Main aims of this installation were to:

- compare the results achievable with different ribbon depths;
- assess the performance of 20 cm span between the ribbons;
- estimate the required time to reach the thermal equilibrium of the system;
- assess the temperature profile in the asphalt and in other surface points of the infrastructure.

Moreover, testing the surface conditions of the road after construction and after several months allows to evaluate any effects due to the presence of the ribbon inside the pavement.

Figure 13 shows the scheme of the section installation: four different zones are visible, characterized by the depth (6 or 10 cm) of installation if any. Asphalt milling was required before laying two separate 20 m long ribbons with a serpentine layout at 20 cm span between the ribbon axis. Ribbons were fixed to the surface with metal strips and steel nails (Figure 14).

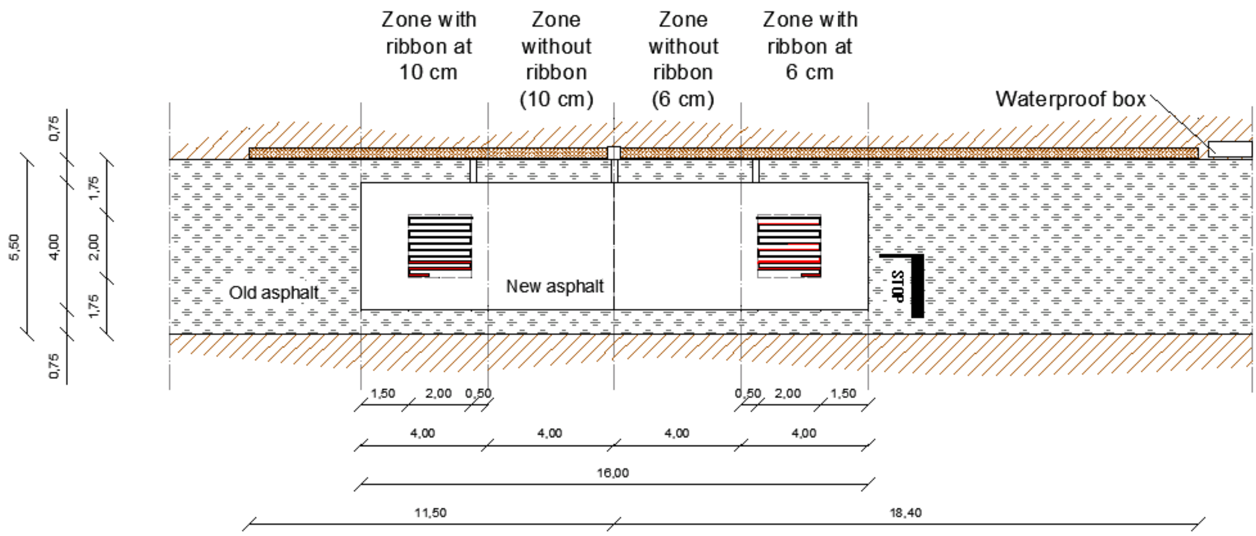


Figure 13: Bologna airport trial site scheme (in m)

Figure 14: Ribbon serpentine installation

A redundant set of thermocouples were installed at different depths and positions of the test section with the aim of measuring temperatures through the surface layer, on the edge of the heated zones and on the surface of the four pavement sections. Thermocouples will feed the online system that controls the ribbons and stores data on demand during any relevant climatic event (Figure 15).

Figure 15: Laying thermocouples on the milled surface and completed trial site

The trial section was completed in March 2015 and no cold climate occurred since then. Nevertheless, ribbons were activated and their effectiveness was tested measuring surface temperatures. The first measurement was made on the deeper installation section before the activation of the thermocouples, thus temperatures were measured only on the top of pavement and only using an infra-red camera. With an air temperature of 20 °C and a non-heated surface temperature of 22°C, the system reached equilibrium after 1.5 hours and the heated pavement surface was up to 4 °C warmer than the non-heated one (Figure 16). Future testing will enable the thermocouples measurements during cold climate when ribbons are on.

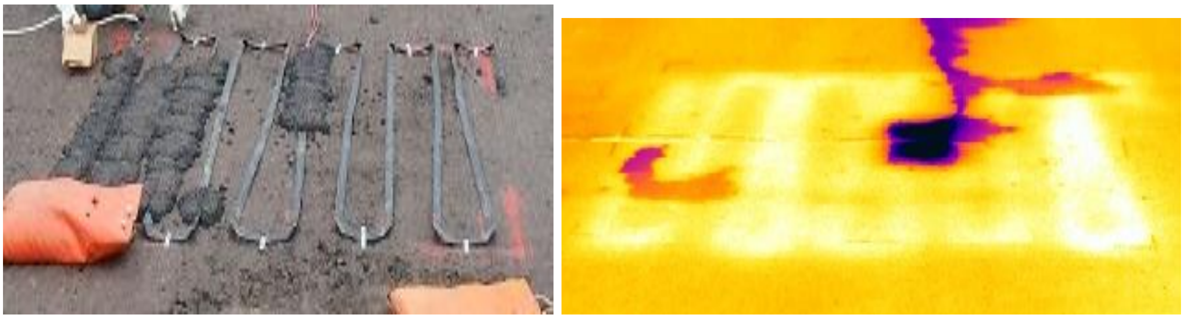
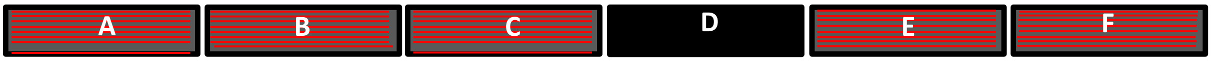


Figure 16: Infra-red photo of the 10 cm depth heated area

6. TEST SECTION LAREN (NETHERLANDS)

Based on all the experiences gathered with the laboratory testing and the small test sections in Montabauer and Bologna, a (main) test section was conducted in the city of Laren (Gelderland) with support of the road maintenance department of the Province of Gelderland. It is an underpass of the N332 provincial road (Figure 17), consisting of a concrete tunnel and adjacent concrete elements (ramps) with a 4 cm layer of asphalt on top of it. The infra-red heating technology was applied between the concrete surface and the asphalt top layer at the ramps of the tunnel which were divided in 5 different sections with a length of about 12 m and a width of about 4 m each (Table 1). Within these test sections parameters such as the power of the ribbons (40 – 60 Watt/m[1]) and the mutual distance of the ribbons (20 – 25 cm) were varied. Under a neighboring road surface of block paving with a foundation of sand, also infra-red ribbons were applied, some of them with insulation strips underneath the ribbons.

Figure 17: Tunnel underpass test section



Sub section	A	B	C	D	E	F
Type of paving	Concrete blocks	Asphalt	Asphalt	Asphalt	Asphalt	Asphalt
Mutual distance between ribbons (cm)	18	15	22,5	Roofed tunnel (no heating system installed)	22,5	15
Power (W/m^1)	54	36	54		54	43
Power (W/m^2)	310	260	255		250	285

Table 1: Sub test sections

Within these test sections, a different way of fixation of the ribbons was chosen. Instead of the metal clips that were applied in the Montabauer test section the ribbons were mounted onto a plastic (flexible) asphalt reinforcement grid first (Figure 18). For the fixation on the asphalt grid plastic tie wraps were used. Then the 'heating mats' were rolled up and transported to the test section. This way of fixation had the advantage, that the ribbons have (and keep) their exact fixations and time can be saved on site during the application process.

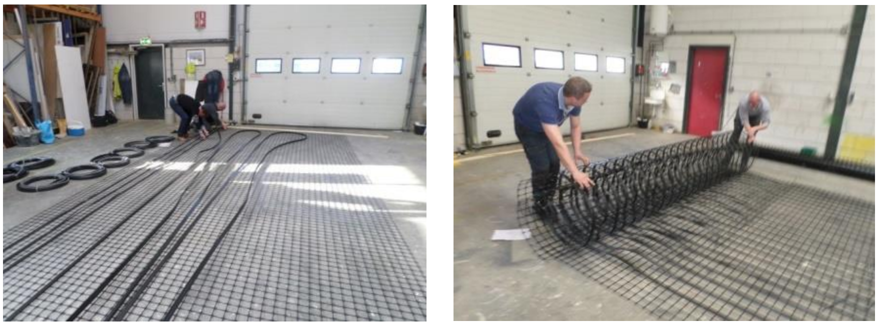


Figure 18: Fixing the infra-red ribbons to an asphalt reinforcement mat and making it ready for transport

The test section started with a milling process in which the existing asphalt layer was removed. After cleaning the surface, the heating mats were rolled out (Figure 19) and fixed to the surface with nails. Also was experienced with 'gluing' the mats to the surface' with a very thin fast curing cement layer (Figure 20). A additional advantage of this process is, that the ribbons are fully protected during the paving process. The cement slurry was produced on site with a mobile production unit and brought to the mats with simple manual means. After hardening of the cement slurry a bituminous tack coat was spread after which the asphalt layer was applied with traditional means and the ribbons were connected to two electric switch boards on both sides of the tunnel.

Figure 19: Unrolling the prefixed heating mats on site

Figure 20: Applying cement slurry and asphalt top layer

In order to test how the infra-red ribbons react under block paving, in test section A the ribbons were situated between a layer of sand and the paving blocks (Figure 21). Again, the ribbons were fixated on a mat before. Under half of the ribbons small insulation strips were placed to avoid loss of heat to the underground. Both forms of application, using a cement layer under asphalt and applying the heating mats on sand under block paving, were sastifactory. The performance of the different sub test sections will be monitord over the next coming winters.

Figure 21: Infra-red heating ribbons under block paving

7. RESULTS

Based on laboratory tests and preliminary field results, the different test sections showed, that the infra-red heating ribbons are an effective and efficient way to de-ice road surfaces, whether this is for block paving or asphalt surfaces.

During the installation process it appeared, that the infra-red heating ribbons were sufficiently flexible and could be bent easily. In case of low air temperatures (below ca. 5 ^{0}C) though, using a hot air blower is recommended. Fixation with metal strips is suitable for smaller areas or specific configurations. For larger, as well as smaller, areas mounting the strips beforehand on a plastic (flexible) asphalt reinforcement grid is also suitable as these prefabricated heating mats shorten the application process. Fixing these mats to the surface with nails or with cement slurry both gave good results. Although the ribbons can resist asphalt temperatures up to 130 ^{0}C and can withstand the physical impacts of paving machinery, a cement slurry gives extra protection.

Depending on the application and type of pavement, by varying the length of the prefabricated ribbons, in combination with varying the space between two parallel ribbons, basically any desirable power per square meter for de-icing purposes is possible. Temperature measurements on asphalt slabs, were infra-red ribbons were built in at 4 cm under the surface, showed a raise of temperature of up to 10 ^{0}C within 30 minutes, using maximum power of 60 W/m^{1}. At a depth of 8 cm this took around 40 minutes. Under realistic conditions (test sectionBologna) it took 90 minutes to heat up the surface 4 ^{0}C, here the ribbons were situated 10 cm under the surface. Small insulation strips underneath the ribbons did not significantly contributed to faster heating of the surface, neither did it matter if the ribbons were installed horizontally or vertically.

More field data will be gathered in the years to come as both the main test section in Laren as well as the test section in Bologna will be monitored in order to gather information about the de-icing performance of the different subsections and the associated energy consumption.

8. ACKNOWLEDGEMENTS

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BIBLIOGRAPHY & REFERENCES

1. *Analysis of tire-road contact under winter conditions, Walus, Olszewski, Proceedings of the World Congress on Engineering, London (July 2011)*
2. *Best Management Practices for Airport Deicing Stormwater, Switzenbaum M.S., Veltman S., Schoenberg T., Durand C.M., Environmental Engineering Program Dept. of Civil and Environmental Engineering University of Massachusetts/Amherst (July 1999)*
3. *Aircraft and runway deicers at general Mitchell international airport, Milwaukee, Winscnsin, USA. 1. Biochemical oxygen demand and dissolved oxygen in receiving streams, Corsi S.R., Booth N.L., Hall D.H., U.S. Geological Survey, Winter Resources division, 8505 Research Way, Middelton (Wisconsin 2000)*
4. *Impact of airport pavement deicing products on aircraft and airfield infrastructure, a synthesis of airport practice, Xianming Shi, Western Transportation Institute, Montana State University, Bozeman (Montana 2008)*
5. *Deicer impacts on pavement materials: introduction and recent developments, Xianming Shi, Atkin M., Pan T, Fay L.,Liu Y. and Yang Z. The Open Civil Engineering Journal (2009)*
6. *Deicer impacts on pavement materials: introduction and recent developments, Xianming Shi, Atkin M., Pan T, Fay L., Liu Y. and Yang Z. The Open Civil Engineering Journal (2009)*
7. *Investigation of low temperature cracking in asphalt pavements, National Pooled Fund Executive Summary, Minnesota Department of Transportation (May 2007)*
8. *Environmental effects of deicing and anti-icing chemicals, Xianming Shi, P.E., Michigan Winter Operations Conference Midland USA (2011)*
9. *Investigation of low temperature cracking in asphalt pavements, National Pooled Fund Executive Summary, Minnesota Department of Transportation (May 2007)*
10. *Gezondheidsnet, www.gezondheidsnet.nl/medische/6400 -gewonden-door-gladheid(05-02-2013)*
11. *Verkeersinfarct door gladheid, www.112vandaag.nl/2015/02/verkeersinfarct-door-gladheid-op-a50-bij-oss(04-02-2015)*
12. *Sneeuw en gladheid zorgen voor veel schade, www.nu.nl/algemeen/1494951/sneeuw-en-gladheid-zorgen-voor-veel-schade (25-03-2008)*
13. *Heated Roads Consortium, www.heated-roads.com*
14. *GFSC Consultants and Engineers BV, www.gfsc-group.com*
15. *Grontmij Nederland BV, www.grontmij.nl*
16. *Reef-infra BV, www.reef-infra.nl*
17. *AHT Netherlands BV, www.aht-netherlands.com*
18. *Miljoenenschade aan asphalt door vorst, www.rtvnoord.nl/artikel.asp?p=80802(09-04-2009)*
19. *Storm Light Wegdekverwarming, Scan door Deltaris en Copernicus groep in opdracht van Rijkswaterstaat (November 2012)*
20. *University of Bologna, www.ingegneriarchitettura.unibo.it*
21. *AHT Italy, www.aht-italia.it*
22. *Vergelijking tussen AHT en traditionele elektrische verwarmingselementen, Landstra Bureau voor bouwfysica, rapportnr. 107190GLR01 (2007)*
23. *Warmtelint onderzoek, Grontmij, R. de Boer (April 2014)*
24. *Volkmann & Rossbach, www.volkmann-rossbach.de*
25. *Pilotprojekt 'Intelligenter Parkplatz', Manns-Ingenieure, www.manns-ingenieure.de/aktuell/lkw.htm*
26. *European Regional Development Fund, www.eur-lex.europa.eu*