Field test comparing frost insulation materials in road construction

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Abstract

Three products are presently used on a regular basis in Norway as thermal insulation in roads; lightweight clay aggregate (LWCA), foam glass aggregate and extruded polystyrene boards (XPS). As a check on the present design guidelines for frost insulation and in order to compare the different insulation products, a field test is established in connection with the construction of a new main road (E6) south of Trondheim in Norway. The test site has 4 different sections. In addition to 3 sections where each of the 3 different insulation products are used, one additional section contains ordinary pavement materials produced from crushed rock.

Road construction and challenges in the Norwegian climate

Damages on roads caused by frost actions are a severe problem for roads in the Nordic climate. The damages are caused by frost heave during the winter and reduced bearing capacity in the spring thaw period. Different solutions to prevent the frost from penetrating down into frost susceptible subsoil have been used during the last decades. The easiest and most common solution may be to replace the in situ soil with sufficient amount of non frost susceptible soil. This solution may sometimes not be the technically or economically optimal solution. Different products that have thermal insulating effects have been used with varying degree of success.

Insulation products used in roads – history and today

Crushed rock is the most common material used in road construction in Norway. The availability is still good, but because a satisfactory frost protection design using crushed rock may result in very thick pavements, it may be economically preferable to use insulation materials in order to reduce the total pavement thickness required.
The Norwegian Public Roads Administration has a long tradition in applying various kinds of thermal insulating materials for road construction applications. Bark was used in the 1970’s and was very economically at that time (the material was available almost

for free). Extruded polystyrene boards (XPS) were used for the first time in 1965. Lightweight clay aggregate is commonly used today and presently also foam glass aggregate, produced from recycled waste glass, is an option.

Lightweight clay aggregate (LWCA)

Lightweight clay aggregate (Figure 1 to the left) is used both as lightweight fill and as frost protection in road construction, and the material is also used on a regular basis for other civil engineering application. By sintering clay in a special furnace, hard spheres of various sizes are formed (generally 0 – 32 mm). A typical loose bulk density is approximately 280 kg/m^3. Average moisture content in pavement structures is found to be 25% by weight (7.7 % by volume). The corresponding thermal conductivity at 10 ºC is 0.18 W/mK but it varies significantly with temperature and water content.

Figure 1 – Leca LWA to the left, Hasopor foam glass aggregate to the right

Foam glass aggregate (also called cellular glass)

Foam glass aggregate (Figure 1 to the right) is produced by recycling waste glass. The foam glass has a maximum grain size of about 60 mm with angular edges and the material may be produced in various densities. A typical loose bulk density is in the range of approximately 180 - 250 kg/m^3. On recent road projects deformations and possible variations in moisture content, unit density and grain size distribution have been monitored. The moisture content is found to be around 20 % by weight (6 % by volume), corresponding to a thermal conductivity at 10 ºC of 0.155 W/mK. The thermal conductivity for foam glass also varies significantly with temperature and water content.

Extruded polystyrene boards (XPS)

Extruded polystyrene boards are available in qualities with a high compressive strength. The material density is about 50 kg/m^3, and the thermal conductivity is approximately 0.04 W/mK.

Material parameters influencing the frost depth

The material parameters influencing the frost penetration is mainly the thermal conductivity, the volumetric water content, the volumetric heat capacity and the density. All parameters can vary for different applications, construction methods and material qualities. For pavement design best estimate values are used. However, a very coarse material may also lead to significant convection effects that may exceed and overrule the conductivity. Parameters like the grain size distribution should therefore also be evaluated.

Climatic parameters influencing the frost depth

Main factors for frost penetration in the ground are air temperature, solar radiation, wind and precipitation. The time integral of air temperature during the frost season defined as the air- freezing index (FI) is used for design, and this parameter is the most important factor. The surface temperature will differ from the air temperature and is influenced by solar radiation, snow cover, radiation heat excange with clouds and gas layers in the atmosphere, precipitation, wind etc. Another factor used for design is the annual mean temperature.

The field test at Melhus

Main objective for the ongoing field test

It is possible to estimate the theoretical frost penetration for the different materials depending on the material parameters found in the laboratory. The frost insulating effect for the different insulation materials may be compared using a numerical model of a standard pavement structure. The design guidelines were up to 2005 mainly based on research performed on structures with insulation boards. Newer field tests and research performed on LWCA and foam glass aggregate indicates that the ratio between required layer thicknesses is less than prescribed in the guidelines. A numerical model used for calculating the required thickness using LWCA also showed that the thickness recommended for insulation boards seems too low. Field tests using insulation boards (XPS) or LWCA have been performed earlier, but it is difficult to compare the results due to different tests conditions.

The main objective for the present test is therefore to compare the different materials in the same field setting, both to investigate their relative differences and to compare the results with the numerical calculations and recommendations. The result is important both to ensure that the recommended structures have the expected frost protection, and to get a fair competition between the different materials and solutions.

Melhus test site

Melhus is a place in the middle part of Norway south of Trondheim. Trondheim has a coastal climate, and the climate at Melhus is therefore relatively warm compared to the eastern and northern part of Norway. At Melhus the annual mean temperature is 4.5 ºC. The field test sections are part of a new access road build in connection with the new main road E6. The air- freezing index at Melhus for different recurrence frequency are shown in Figure 2 together with some other places in Norway (vm = annual mean temperature).

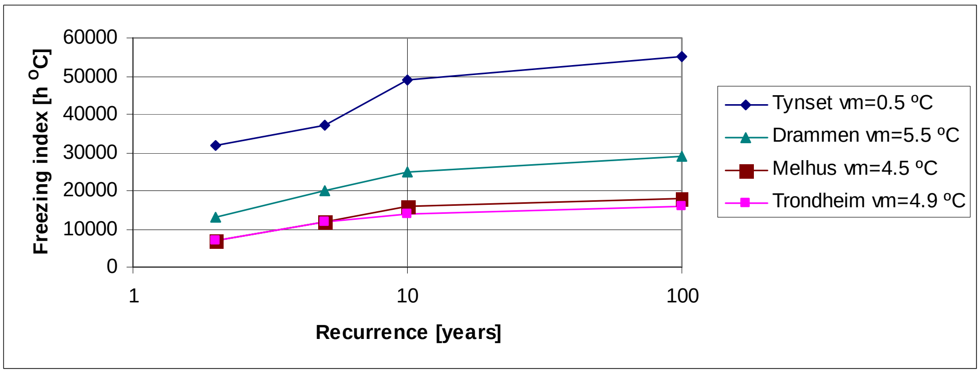

Figure 2 – Air- freezing index

Pavement design

Designing the required pavement thickness is normally based on that the bearing capacity shall be sufficient also in the spring thaw period. The field test is performed on a low volume road/access road and initially the required pavement thickness at the test site was set to 61 cm. The required thickness was later increased to 80 cm because the subgrade had a lower quality than first assumed.

The test field was divided into 4 different test sections. One section without insulation (for reference) and 3 sections with XPS insulation boards, light weight clay aggregate (LWCA) and foam glass aggregate as insulation respectively. Sand was used to lift the formation level to 61 cm below the pavement surface. In the insulated sections, the lower part of the sub-base layer is replaced with insulating materials. In the section with XPS 3 cm thick boards are used and in the sections with LWCA and foam glass a layer thickness of 15 cm (after compaction) is used. The pavement structure for the 4 test sections are shown in Figure 3. From the surface and down the pavement structure consists of two 40 mm thick asphalt layers, a 30 mm thick leveling layer of sand and 350 mm of crushed rock with grading 20-100 mm. The lower part is different for the 4 sections; either 150 mm crushed rock, or 150 mm LWCA, or 150 mm foam glass aggregate, or 120 mm crushed rock over 30 mm XPS boards.

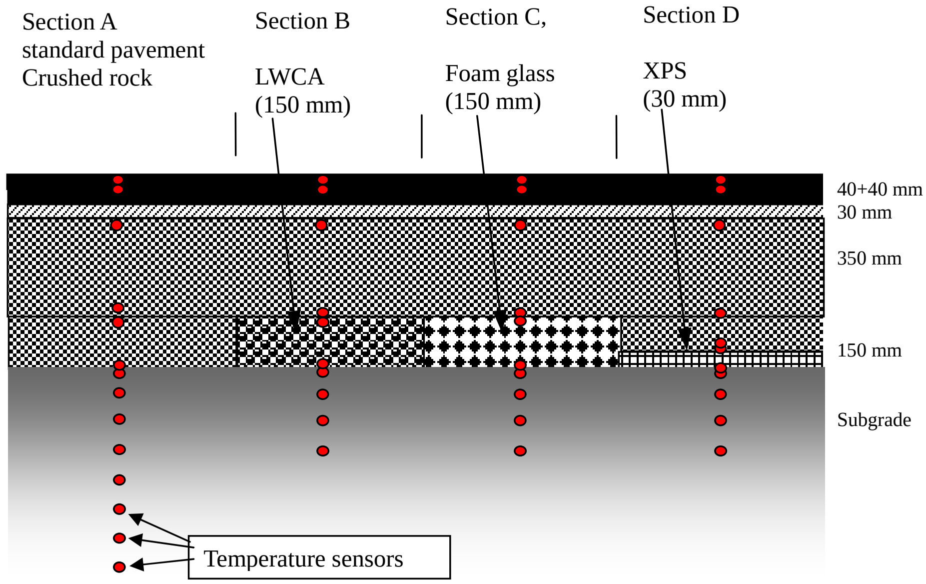

Figure 3 – Test section overview

The reference section is estimated to withstand a freezing index between 1000 and 2000 hºC. The insulated sections are estimated to withstand an air-freezing index of about 7000 hºC when allowing the frost to penetrate 5 cm into the subgrade. This corresponds to an average winter (with recurrence 2 years). Based on calculations for Trondheim the frost will penetrate the LWCA layer at a freezing index close to 5600 hºC. The road surface is assumed not to be covered with snow. Due to radiation heat excange with gas layers in the atmosphere etc. the freezing index at the end of the winter based on the surface temperature is normally larger than the air-freezing index. The difference at Melhus is about 5200 hºC for the section without insulation and about 7000 hºC for the insulated sections. It is not possible to give this as a factor/ratio based on air-temperature since this effect does not vary much with the air temperature. It is however expected that the surface will be covered with snow several times during the winter. Both the air temperature and the surface temperatures are recorded.

Instrumentation

The test sections are instrumented with 43 temperature sensors and connected to a logging device for recording the temperature automatically every 10 min. The recorded data are automatically transferred to a computer and the hourly mean value is saved for each sensor. Table 1 shows the installation depth for all sensors in the four test sections, and the sensor positions are also shown in Figure 3.

Table 1 – installed temperature sensors

Std. pavement	LWCA	Foam glass	XPS
Surface / 2 cm	Surface / 2 cm	Surface / 2 cm	Surface / 2 cm
4 cm	4 cm	4 cm	4 cm
12 cm	12 cm	12 cm	12 cm
42 cm	45 cm	45 cm	45 cm
47 cm	47 cm	47 cm	58 cm
60 cm	60 cm	60 cm	58+ cm
62 cm	62 cm	62 cm	61+ cm
70 cm	70 cm	70 cm	62 cm
80 cm	80 cm	80 cm	70 cm
90 cm	90 cm	90 cm	80 cm
100 cm			90 cm
110 cm			
120 cm			
130 cm			

Figures 4 to 7 show the installation of the insulation materials. In Figure 4 the insulation boards are covered gently. In Figure 5 the LWCA surface is leveled and we also see the foam glass to the left. Both the LWCA and the foam glass are compacted after the materials are covered with crushed rock (subbase layer) (Figure 6). Two layers of asphalt constitute the pavement surface (Figure 7).

Figure 4 – Installing XPS insulation boards

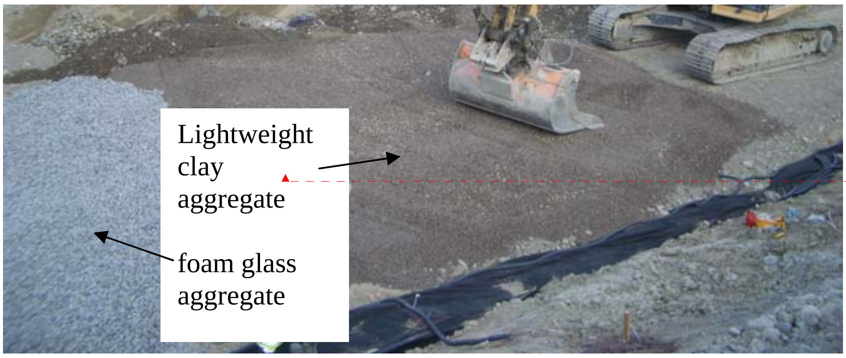

Figure 5 – Installing LWCA and foam glass

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Figure 6 – Separating geotextile, covering with crushed rock

Figure 7 –temperature sensors between asphalt layers

Follow up

The data readings are planned to continue for at least 3 years. At the moment only results from the first winter (2005/2006) are available. During a cold period in March the frost penetrated through the insulation in all test section.

Accumulated data and preliminary results

Figure 8 shows the daily mean temperature at the subgrade level (61 cm below the surface) for all test sections together with the air temperature. The figure also shows the accumulated air-freezing index. The temperature is slightly lower in the section with LWCA (Leca) than in the sections with foam glass (Hasopor) and XPS boards. Around March 13th, 2006 the temperature is at the freezing point below the foam glass layer and the XPS layer corresponding to about 5100 h°C (air). The frost penetrated the LWCA layer some 10 days earlier (for the second time this winter) corresponding to about 3700 h°C (air). The measurements are indicating that the frost insulating capacity for the structure may be somewhat lower than estimated.

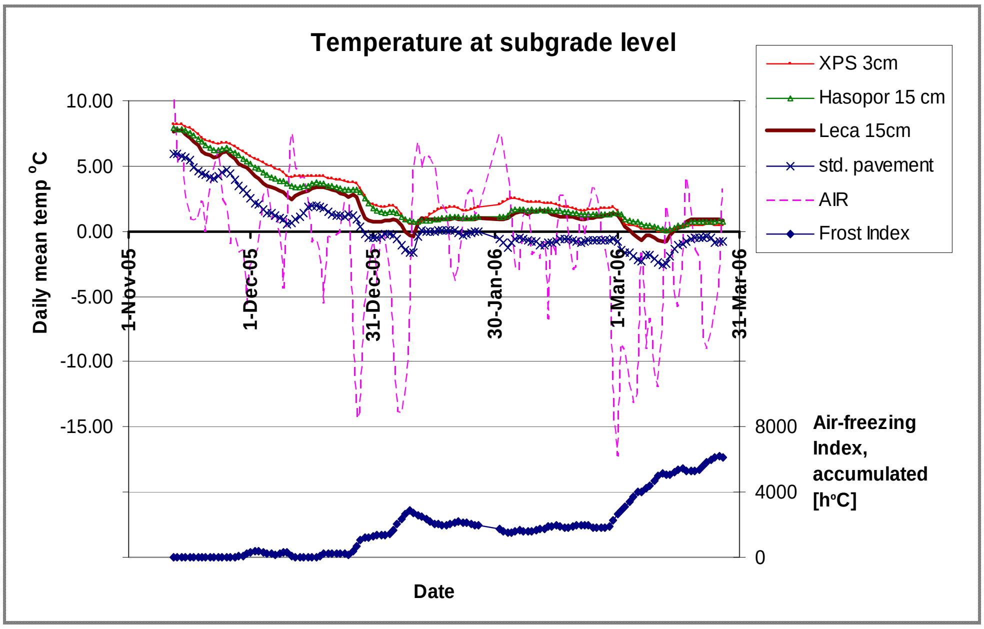

Figure 8 – Temperature at subgrade level 61 cm below surface

Table 2 shows the accumulated freezing indexes at March 27th based on surface temperatures measured. The freezing index for the XPS surface is lower than for the standard pavement surface and do not correspond with theoretical assumptions. However, the sensors may not have the accuracy to distinguish such small differences.

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Table 2 – Accumulated freezing indexes based on surface temperatures and air temperature at March 13th, 2006.

Section	Air temp.	Std. pavem.	Foam glass	LWCA	XPS
Freezing index (at surface) [h°C]	(5086)	9494	10003	10176	8473

Figure 9 shows the temperature profiles for the different sections at March 13th. From this we see that the frost had penetrated almost 10 cm into the subgrade at the Leca LWA section and about 35 cm into the subgrade at the section without insulation.

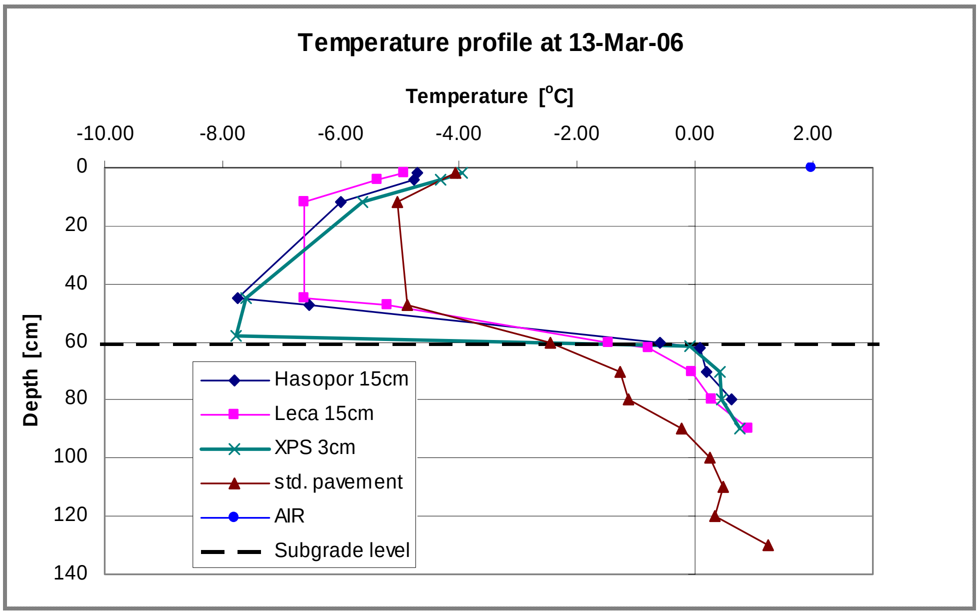

Figure 9 – Temperature profiles at March 13th , 2006.

Conclusions

The installation of the test field seems to be successful. The insulating capacity for the LWCA section is slightly lower than for the foam glass section. The thermal conductivity from laboratory tests is also some higher for LWCA than for foam glass and could explain some of the difference. Since the design values are based on freezing indexes for a whole winter it is to early to conclude about the insulating capacity. However, the first results indicate that the frost insulating effect for the LWCA section may be some lower than estimated, while the two other insulated section are close to the estimated effect. The frost depth at the section without insulation corresponds well with an estimated frost depth based on the measured accumulated air-freezing index. It is to early to conclude about the additional freezing index at the surface since the quantified values are given for the whole winter, but at the moment the difference to air-freezing index is not far from the expected values.

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References

Bakløkk L. et. al., 2001. *Hasopor skumglass (in Norwegian).* SINTEF report STF22-F01322.

European Technical Approval. ETA request no. 12.01/08

Furuberg, T. et. al., 2000. *Environmentally friendly insulation products for the construction and building business. Summary report SP1: Leca frost protection in roads, railways and ditches.* SINTEF report STF22 F00601, Trondheim 2000.

Hoff I. et. al., 2000: *Exclay Internordic Geoproject, Field test at Sandmoen, Norway - Construction and instrumentation*. SINTEF rapport STF22 F00612, Trondheim 2000.

Hoff I. et. al., 2000: *Exclay Internordic Geoproject, Field test at Sandmoen, Norway - Preliminary test results*. SINTEF rapport STF22 F00603, Trondheim 2000.

Horvli I., Øiseth E. and Henry K., 2005: *A review and reliability assessment of frost penetration models,* BCRA 2005, Trondheim

Håndbok 018 (2005) . *Vegbygging, (Road construction)* (Standard Specifications), Norwegian Public Roads Administration, Oslo (in Norwegian)

Publikasjon nr. 17 (1976), *Sikring mot teleskader, (Frost action in soils)* : Norwegian Public Roads Administration, November 1976, Oslo, Norway (in Norwegian)

Watn A. et. al., 2000: *Light-weight fill aggregates for insulation in roads - strength and stiffness properties,* 13th NGM-2000, Helsinki

Øiseth E., 2003. *Leca letttklinker som frostisolering i veg – dimensjoneringsdiagram (LWA as frost insulation in roads – design chart).* SINTEF report STF22

Øiseth E., 2005. *Hasopor Foamglass, Freeze-thaw resistance, giant oedometer tests.* SINTEF report STF22 F04154

Øiseth E.,2005. Hasopor Foamglass, Long term creep tests in giant oedometer. Sintef report STF50 F05067.

Øiseth E., 2005: *Lightweight fill aggregates as frost protection in roads – The design chart developed for the Norwegian guidelines, Handbook 018 Road Construction,* BCRA 2005, Trondheim.