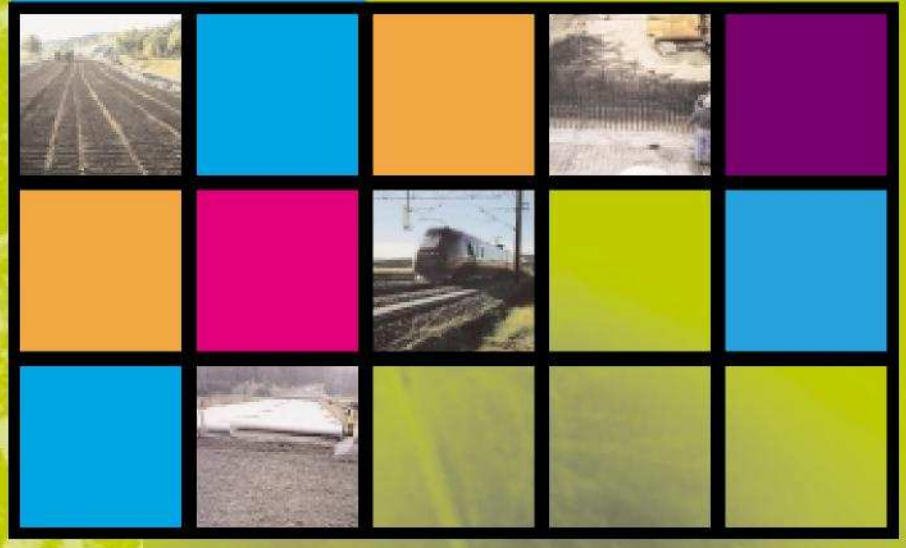

LWAgeolight

Nordisk Industrifond
senter for innovasjon og næringsutvikling

SINTEF REPORT

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LWAgeolight
LWA for Roads and Railways
Internordic Research and Development Project
Final technical report
REVISION

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ABSTRACT

LWAgeolight is an internordic project aiming at developing technical solutions for the use of light weight clay aggregate (LWA) for insulation and light weight fill in roads and railways. The project is performed with financial support from Nordic Industrial Fund.

The project has been organised with national activities in Finland, Sweden and Norway on the topics LWA in combination with geosynthetic reinforcment, hydraulically stabilised LWA and mechanically stabilised LWA. Internordic working groups have been established on the topics surface icing, required properties and test methods, publication and implementation of results in CEN.

The project includes laboratory testing, numerical analyses, model tests and field tests. It has provided data on characteristics of LWA, structural behaviour and relevant factors for the construction with LWA.

A separat Nordtest project on required properties has been performed in close co-operation with the LWAgeolight project. The conclusions are incorporated and are also forwarded as basis for a new work item in CEN.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1	Geotechnical Engineering	Geoteknikk
GROUP 2	Highway Engineering	Vegteknikk
SELECTED BY AUTHOR	LWA-Expanded Clay Aggregate	Lettklinker
	Properties	Egenskaper
	Testing	Forsøk

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Preface

The LWAgeolight project has been running over a period of 4 years. It has involved public authorities, researchers, university staff, producers, consultants and contractors and has included a large number of activities in Finland, Sweden and Norway. The results have been presented and proven to be useful, not only in the Nordic countries, but also in several other European countries like Portugal, Germany, Poland and Estonia. The project has been very useful to exchange experience and increase co-operation between the Nordic countries, which has been one of the aims of the project.

The project group would like to take this opportunity to express our appreciation to Nordic Industrial Fund (NI) for their support to the project. This is not only related to the financial support, but also to the support provided by the possibility to use the project WEB-site at NI as a working tool for the project and to disseminate the project results to the group.

The LWAgeolight project has not only given a lot of useful technical know-how, but has also established a new Nordic network and enhanced existing ones. Knowledge transfer and co-operation are essential, and will be even more important for the Nordic industries in the future. The LWAgeolight project has proven to be a successful tool in this respect.

Bill Herrmansson
Project leader
Optiroc Group PA Exclay

Arnstein Watn
Technical responsible
SINTEF Civil and Environmental Engineering

SUMMARY

LWAgeolight is an internordic project aiming at developing technical solutions for the use of LWA for insulation and lightweight fill in roads and railways. The project is performed by participants from Finland, Sweden and Norway and with financial support from Nordic Industrial Fund (NI) and industry partners.

The project has focused on the following topics: LWA in combination with geosynthetic reinforcement, LLP-Light Load spreading plate, mechanically stabilised LWA, surface icing, required material properties and test methods for LWA, publication of results and implementation of results at European level through CEN.

LWAgeolight includes laboratory tests, numerical analyses, model tests and field tests. Thermal, physical and mechanical properties of different types of LWA are determined as basis for design and product control purposes.

The project has proved that LWA with mechanical stabilisation (compaction) can be used as light weight fill and insulation material in roads and railways. The compaction typically will result in a volume reduction of 10-12 % with a corresponding increase in unit weight compared to loose state. Compacted LWA has high stiffness and resistance to permanent deformations provided the stress level is not causing crushing of the grains.

LWAgeolight has verified that LWA in combination with geosynthetic reinforcement increases the stability of the structure and improve the structural performance. The geosynthetic reinforcement will increase the resistance to plastic deformations (e.g. rutting). Reinforcement on top of the LWA should be of a grid type where the aperture size is correlated with the grain size of the granular material.

The LLP method has proven to provide beneficial effects to level out deformations and settlements e.g. in connection with bridge abutments. Different types of light aggregate concrete (LAC) can be used for the LLP which can result in a density varying from 520-1310 kg/m^3. The results from the project verify that dependent on the type of LAC and the layout of the plate the LLP can have a capacity for bending moment varying from about 50-150 kNm/m and a shear force capacity varying from 30 to more than 80 kN/m.

The Isolitest part of the LWAgeolight project has provided a proposal for a Nordtest method with requirements and related test methods for verification of characteristic properties of LWA. The Nordtest method is currently being circulated on national level for comments and is forwarded as basis for a new work item in CEN.

The use of insulation in roads may give increased risk of surface icing. The LWAgeolight project has evaluated the risk for surface icing and has proposed a method for determining the required level of documentation of the surface icing risk by use of LWA as frost insulation in roads.

The results of the LWAgeolight project are presented in articles in technical magazines, in conferences and on special LWA seminars both in the Nordic countries and in several European countries.

1 INTRODUCTION

Optiroc Group PA Exclay has been running an internordic research and development project entitled “LWAgeolight”. Nordic Industrial Fund and the industry fund the project. The aim of the project is to improve and further develop technical solutions concerning lightweight clay aggregate (LWA) for insulation and for lightweight fill in roads and railways.

LWA has been used for civil engineering applications in the Nordic countries for many years. The LWAgeolight project is a continuation of a previous Norwegian research project called MiljøIso, ”Miljøriktige isolasjonsprodukter for BA-bransjen” /1/. This project was carried out by Norsk Leca as (later Optiroc as, present Maxit Group as) with support from the Norwegian Research Council (NFR). One of the main activities in this project was to investigate how LWA material would perform used as frost protection in roads, railways and other cold structures. The MiljøIso project included laboratory investigations, field investigations, model experiments in the laboratory and theoretical analyses. The MiljøIso project confirmed the suitability of LWA as insulation and lightweight fill in roads and railways. However it was concluded that more research and development were needed on the determination of characteristic properties fulfilling present requirements and to further develop technically sound and cost effective structural solutions.

Based on the results from the MiljøIso project it was decided to continue with an internordic project, LWAgeolight, focusing on the topics identified in MiljøIso. The project was started with an internordic project seminar in November 1998 and the main part of the project was completed with a final seminar in January 2002. Some activities related to Tuupakka Test field and surface icing continued also in 2002 and these activities were completed in the autumn 2002.

The main goal of the LWAgeolight project was to develop sustainable solutions for LWA in roads and railways in a Nordic perspective. The following sub goals were identified:
-prepare requirements on properties and related test methods for LWA
-prepare conceptual structural solutions for LWA in roads and railways
-prepare design recommendations for LWA in roads and railways

The results of the project are also intended to be the basis for implementation into the standardisation work at a European level through CEN.

This report is the summary technical report from the project and presents the organisation of the project, the performed work and a summary of the results. Guidelines for design and construction with LWA for civil Engineering applications are planned prepared as a separate publication based on the results from the project.

2 PROJECT ORGANISATION

The project LWAgeolight is performed as a Nordisk Industrifond project and includes participants from Finland, Sweden and Norway. The project participants and their roles in the project are presented in Table 2.1.

Table 2.1 Project participants and responsibilities

Participant	Country	Role in project	Contact person
Nordic Industrial Fund			Oddurmar Sigurdssonn
Optiroc Group PA Exclay		Project leader main project	Kjell Ove Amundsgård Bill Hermansson
Svensk Leca AB	Sweden	Project leader Swedish national activities	Lennart Ideskär
Optiroc Oy	Finland	Project leader Finnish national activities	Jouko Partanen
Optiroc AS	Norway	Project leader Norwegian national activities	Jon Hauge
SINTEF Civil and Environmental Engineering	Norway	Project leader Isolitest Technical responsible main project	Arnstein Watn
SCC Viatek Oy	Finland	Technical responsible Finnish national activities	Juha Forsman
VTT Communities and Infrastructure	Finland	Participant Isolitest	Seppo Saarelainen
SP Swedish National Testing and Research Institute	Sweden	Activity leader laboratory testing in Isolitest	Lennart Hagnestål
Helsinki University of Technology	Finland	Project leader Surface Icing Participant Finnish activities Participant advisory group	Henry Gustavsson Jarkko Valtonen
Bohusgeo	Sweden	Technical responsible Swedish national activities	Per-Gunnar Larsson Mats Johansson
Noteby as	Norway	Participant in activity field test control methods	Odd M. Solheim
Kaitos OY	Finland	Participant Finnish national activities	Jukka Hämäläinen
VTI	Sweden	Participant surface icing	Åke Hermansson
Nordisk Vegteknisk Forbund		Co-ordination Publication	Mikko Leppänen
Finnish Road Enterprise	Finland	Participant Finnish activities and advisory group	Pannu Tolla
Finnish Road Administration	Finland	Participant Finnish activities and advisory group	Pentti Salo
Swedish Road Administration	Sweden	Participant advisory group	Hans Wirstam
Norwegian Directorate of Roads	Norway	Participant advisory group	Roald Aabøe Geir Refsdal

The project has been financed by Nordic Industrial Fund, Nordtest, Optiroc Group PA Exclay, District road office of Sør-Trøndelag, Optiroc OY, Optiroc AS, Svensk Leca AB, SP Swedish National Testing and Research Institute, Finnish Road Administration and Kaitos OY.

LWAgeolight has been organised with national activities in each country combined with internordic working groups on selected topics. The organisation of the project activities with main goals is given in Table 2.2.

Table 2.2 Organisation of project activities

	Project Topic	Aim
National activities	LWA in combination with geosynthetic reinforcement (Finland)	Investigate structural behaviour and develop structural solutions and design recommendations for LWA in combination with geosynthetic reinforcement.
	LLP Light Load spreading Plate (Sweden)	Investigate physical and mechanical properties of LLP. Develop structural solutions for LLP.
	Mechanically stabilised LWA (Norway)	Investigate structural behaviour of mechanically stabilised LWA. Develop structural solutions and design recommendations for mechanically stabilised LWA.
Internordic Working groups	Surface Icing	Develop methods for evaluation of risk of surface icing on roads with LWA insulation
	Nordtest method: Isolitest	Develop Nordtest method for required characteristics and relevant test methods for LWA in roads an railways
	Publication	Dissemination of results from the project
	Implementation in CEN	Implement results from the project into the standardisation work performed at a European level in CEN

The project organisation chart is presented in Figure 2.1.

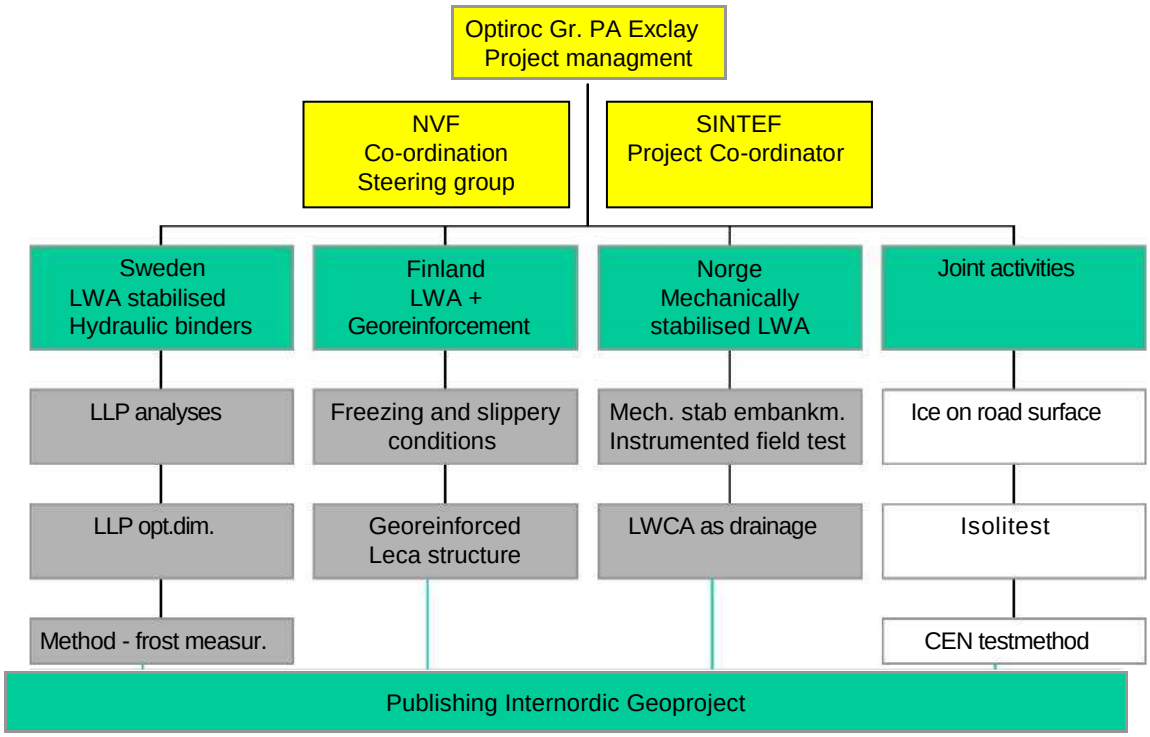


Figure 2.1 LWAgeolight. Organisation chart

3 LWA IN ROADS AND RAILWAYS

3.1 Material

LWA is produced of clay expanded and burned in rotary kilns at a temperature of 1150°C. The resulting product is a granular material where the material properties may vary slightly dependent on the basic clay material and the production process. Previous research work has provided a good documentation of the physical properties of the material. Key figures for some essential physical properties of LWA from Optiroc are presented in Table 3.1.

Table 3.1 Physical properties of LWA from Optiroc /2/,/3/

Property	Type of material				
	4-32 mm	4-20 mm	10-20 mm	8-20 mm	0-32 mm
Dry loose density (kg/m^3)	300-340	280-320	230-290	250-300	300-350
Particle density (kg/m^3)	560-620	525-590	480-560	450-540	560-635
Water content, w (weight %) (delivered on site)	<15	<15	<15	<15	<15

The water content is given as weight of water related to dry weight of the material. As the unit weight of LWA is very low compared to more conventional granular material, the figure for relative water for LWA compared should not be compared directly with other materials.

Typical curves for grain distribution for LWA produced by Optiroc are given in Figure 3.1, Figure 3.2 and Figure 3.3.

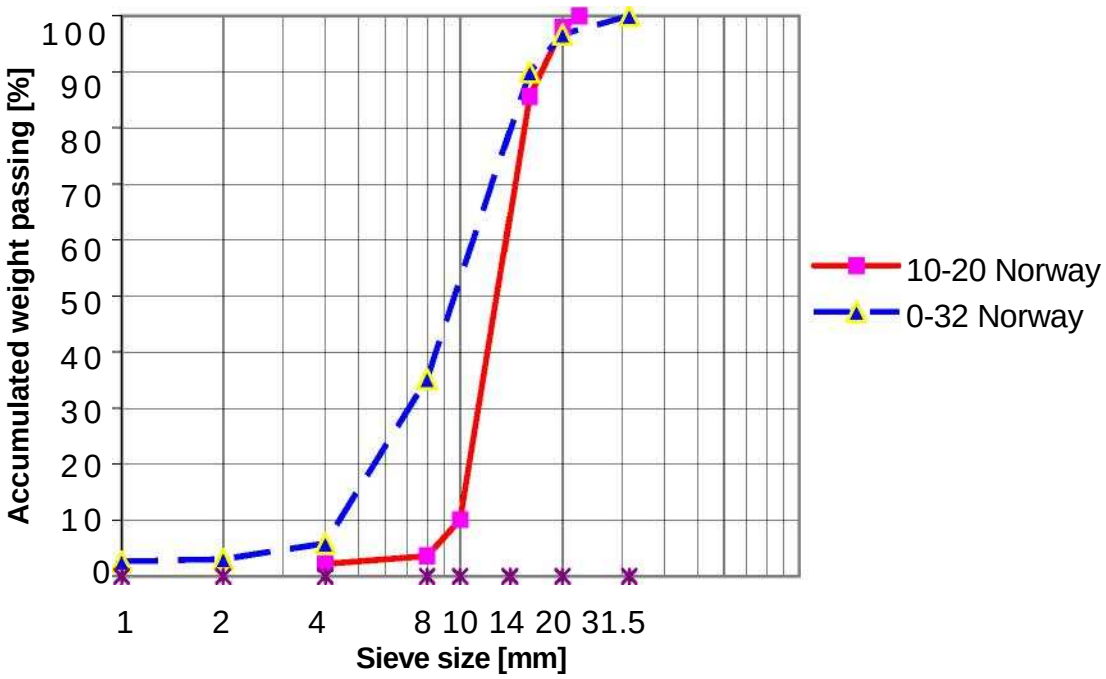


Figure 3.1 Typical grain distribution curves for LWA produced by Optiroc in Norway

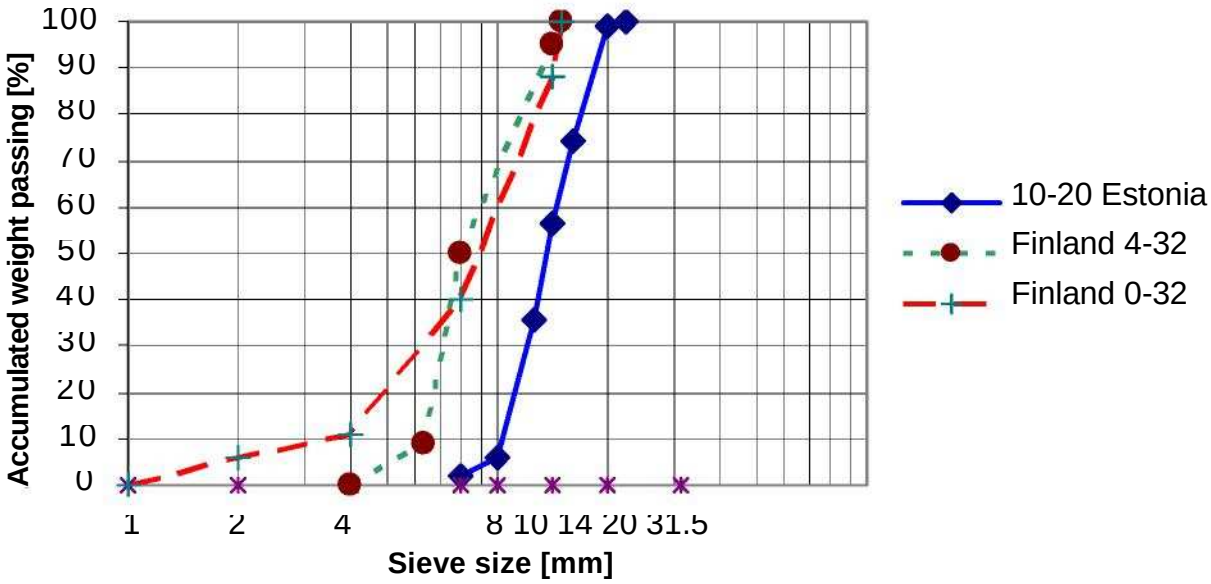


Figure 3.2 Typical grain distribution curves for LWA produced by Optiroc in Finland and Estonia

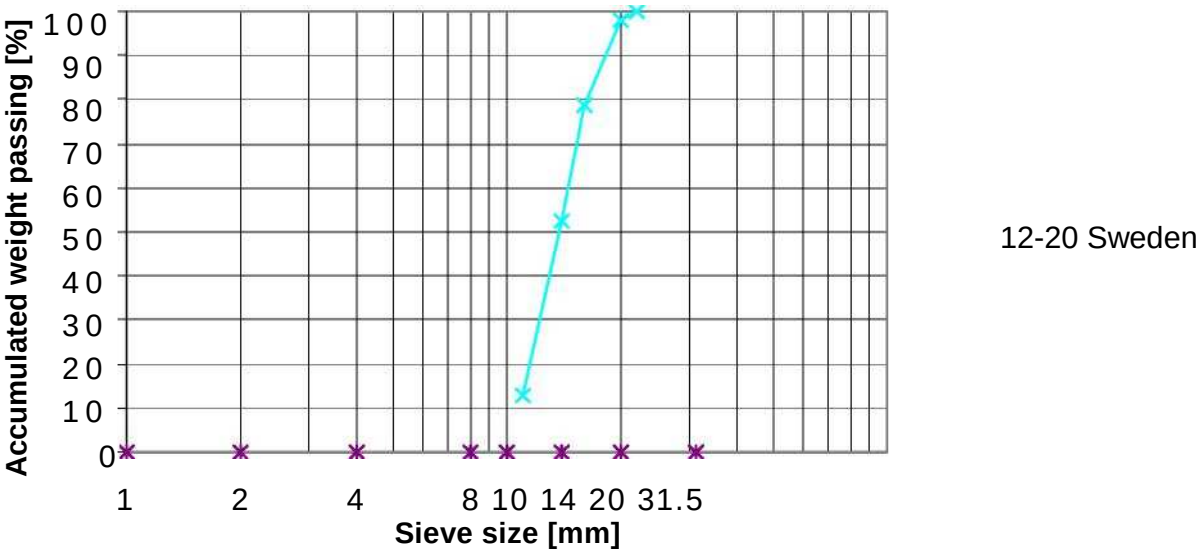


Figure 3.3 Typical grain distribution curve for LWA 12-20 produced by Optiroc in Sweden

3.2 Applications

The Nordic countries have difficult geotechnical conditions with soft and frost susceptible soil combined with severe climatic conditions with frost and rapid temperature variations. LWA as a light weight fill material with good insulation properties may beneficially be used in roads and railways to increase stability, reduce settlements, reduce frost heave and increase bearing capacity during the thawing period.

3.2.1 Loose LWA with mechanical compaction

LWA has already been used for different applications in the Nordic countries for more than 40 years. Also in other countries a lot of research has been done and a number of projects involving LWA have been performed. Considerable experience with the use of mechanically stabilised LWA for civil engineering applications accordingly already exists. LWA is commonly used as insulation material, as lightweight fill and as light weight back-fill to reduce soil pressure on structures. An example of LWA used as lightweight fill in a railroad embankment to reduce settlement and as insulation material to prevent frost penetration is presented in Figure 3.4.

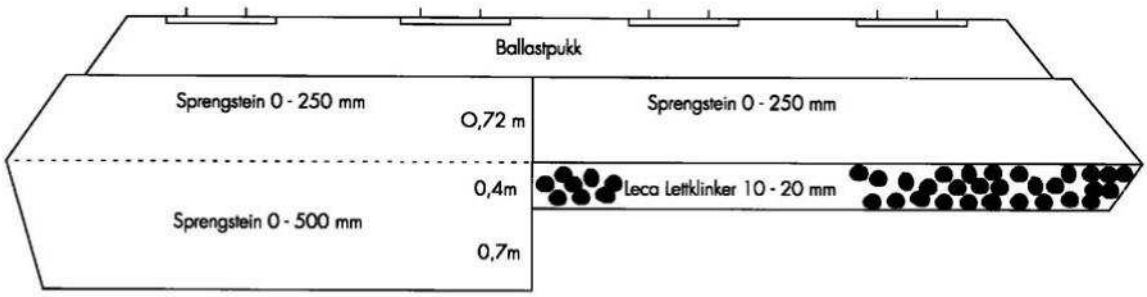


Figure 3.4 LWA as frost insulation in railroad embankment, Vestfoldbanen, Norway

3.2.2 LWA in combination with geosynthetic reinforcement

LWA in combination with geosynthetic reinforcement is an interesting option to be able to reduce the mechanical impact and deformations of the LWA from traffic loads and hence increase the bearing capacity and the service lifetime of the LWA-structure. LWA in combination with geosynthetic reinforcement has been tested previously and a test structure in Finland is presented in Figure 3.5. Geosynthetic reinforcement has previously been used in combination with LWA in some projects. A systematisation of the results with evaluation of effects was however lacking at the time of the starting of LWAgeolight.

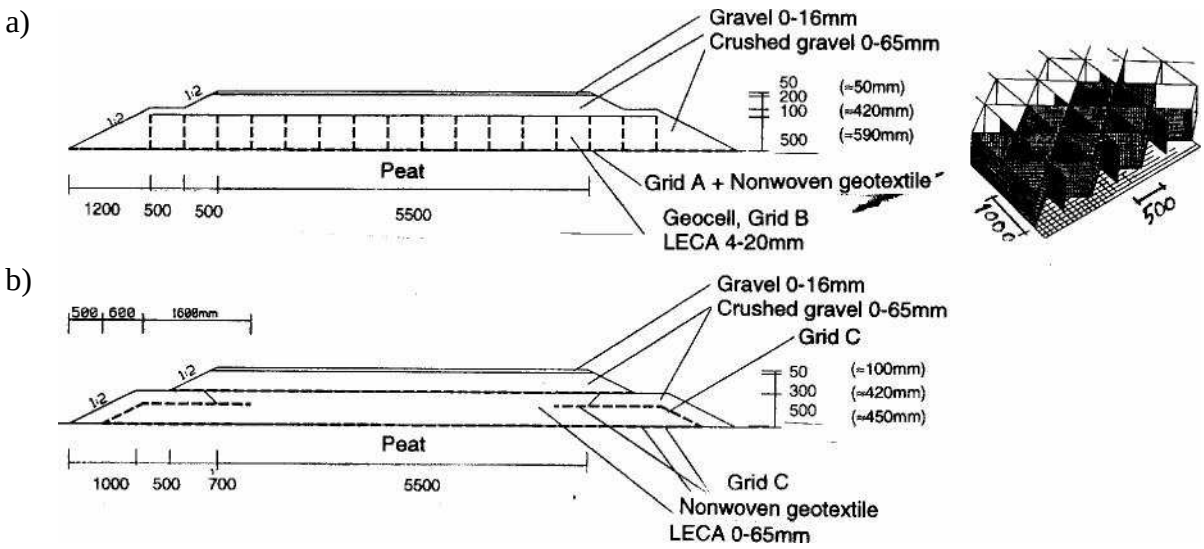
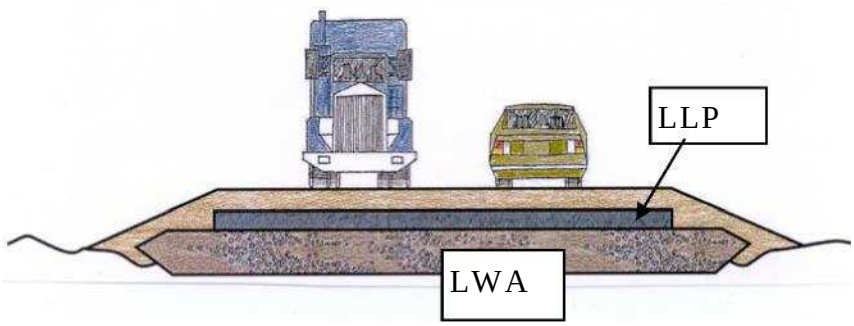


Figure 3.5 Geogrid and geocell reinforced test structures of Leteensuo peat area: (a) geocell + LWA, (b) 2 x geogrid + LWA. The fulfilled layer thickness is presented in the brackets/4/

3.2.3 Light Loadspreading Plate (LLP)

LLP can be beneficially used to distribute traffic load and level out settlements e.g. in bridge abutments and embankments for roads and railways. The concept has been developed in Sweden and some projects have already been carried out.

<u>LLP-Structural solution, principle:</u>



Construction of LLP-solution in Aneby, Sweden:

Figure 3.6 LLP-Light loadspreading plate

3.3 Need for Research and Development

However, the experiences with LWA have not been very well systemised and a consistent overview of LWA properties, test methods, technical solutions and design recommendations have been lacking. A harmonisation of the required properties, test methods, better documentation of structural solutions and design methods was necessary both to obtain better overall technical solutions and to harmonise the recommendations. As an example the National Road administration of Sweden, Finland and Norway have set three different criteria for the minimum thickness of aggregate layer above the LWA material in a road structure. There was a strong need for exchange of experiences and transfer of knowledge between users, producers, research organisations, consultants and contractors.

The LWA as material is as such well known and a lot of experience exist in the Nordic countries for a number of different applications. Outside these countries this technology is however not so well known even the potential for use should be very good. There was accordingly a need to co-ordinate the efforts to enhance the implementation of the LWA-technology outside the Nordic countries.

This was the background for starting the LWAgeolight internordic project. This project is aiming at collecting the existing experience with the use of LWA as a basis for technical and economical optimisation. It is also aiming at developing new solutions and applications for LWA for roads and railways.

4 PERFORMED WORK

4.1 Preproject

The project was started with a preproject including a collection of experience with LWA in the Nordic countries. The outcome was presented at a seminar in Oslo in November 1998. The preproject showed that LWA had been used both bound and unbound for civil engineering applications in the Nordic countries. The material had been used unbound in all the countries as lightweight fill and frost insulation material mainly in roads and railways. There was also some experience with the use of LWA in combination with geosynthetic reinforcement. In Sweden considerable work had been done on developing a light loadspreading plate with hydraulically bound LWA.

The conclusions from the preproject was that there was a need for a harmonisation of requirements on properties and laboratory test methods of LWA and development of structural solutions and design methods for LWA in roads and railways. Based on the preproject the main project was then related to five main topics:

* LWA in combination with geosynthetic reinforcement
* LWA-LLP-Light loadspreading plate
* LWA - mechanically stabilised (loose LWA with mechanical compaction)
* LWA - required properties and test methods (harmonisation of required properties and test methods)
* Surface icing risk evaluation

4.2 Finland

Finland has been main responsible for the topic LWA in combination with geosynthetic reinforcement. The activities are mainly related to the test field at Tuupakka Interchange. The test field is located close to Helsinki and is build at a bus ramp. A plan of the test ramp is presented in Figure 4.1 and a picture from the construction is presented in Figure 4.2.

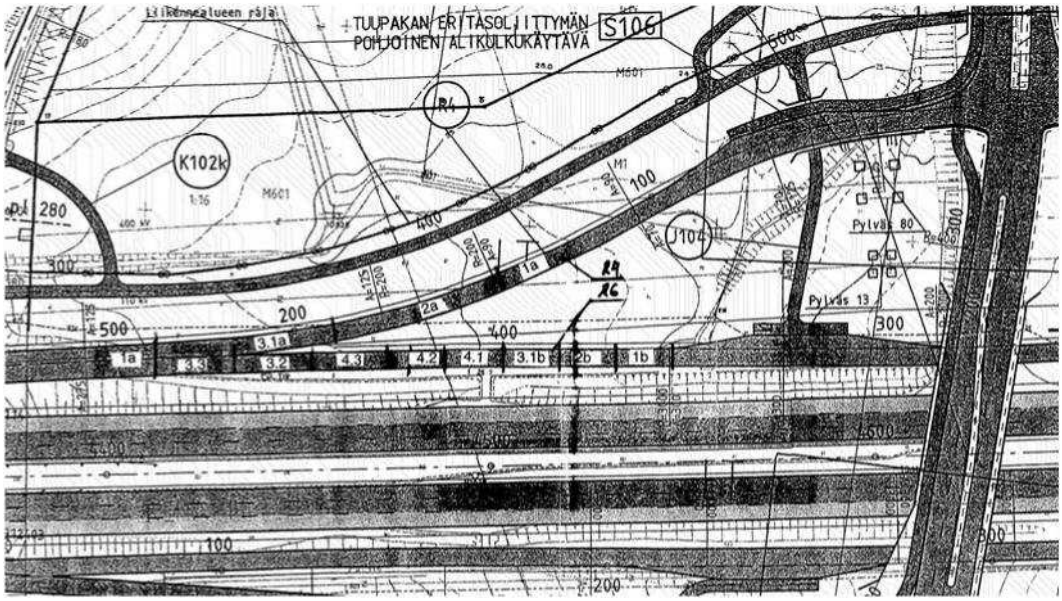


Figure 4.1 Location of the test structures at the test site of Tuupakka. Structures 1a, 2a and 3.1a at the ramp R4 and structures 1b, 2b, 3.1a, 4.1, 4.2, 4.3, 3.2, 3.3 and 1a at the ramp R6 /5/

Figure 4.2 Construction work at Tuupakka Test field

4.2.1 Tuupakka, structural layout

The test field consists of nine sections whereof seven sections are insulated with LWA 10-20 mm produced in Estonia. Reinforcing geogrids are used in four of the sections with LWA. The layout of the test structure is presented in the test construction report /5/. An overview of the test structures is presented in Table 4.1.

Table 4.1Test structures of Tuupakka /5/

Number of the test structure	Thickness of the layer above the LWA-layer (as designed) [m]	Special / Reinforcements	Length of structure [m]	Ramp: Station numbers
1a 1a 1a 1b	no LWA	- - - crushed rock instead of blasted rock	- - - 15 m*	R4: ...145 R4: 235... *** R6: 490 *** R6: 355...370
2a 2b	0.7 m	-	45 m 15 m*	R4: 145...190 R6: 370...385
3.1a 3.1b	0.5 m	-	45 m 15 m*	R4: 190...235 R6: 385...400
3.2	0.5 m	Fornit 20/20 -geogrid	20 m	R6: 450...470
3.3	0.5 m	Fornit 40/40 -geogrid	20 m	R6: 470...490
4.1	0.35 m	-, **	15 m*	R6: 400...415
4.2	0.35 m	TRC 20 –geogrid, **	15 m	R6: 415...430
4.3	0.35 m	TRC 40 –geogrid, **	20 m	R6: 430...450
		The length of LWA structures =	250 m	

* Structure is instrumented with thermo couples
** Crushed concrete instead of crushed rock in the base layer
*** Test structures R4 station number 235 = R6 station number 490

Four types of geogrids were used as geosynthetic reinforcement: Fornit 20/20, Fornit 40/40, TRC 20 and TRC 40. A summary of the properties of the geogrids is given in Table 4.2.

Table 4.2 Geosynthetic reinforcement used in the test structures

Technical properties	FORNIT 20/20	FORNIT 40/40	TRC-grid 20***	TRC-grid 40***
Raw material	Polypropylene	Polypropylene	Aramid	Aramid
Tensile strength longitudinal transversal *	 20 kN/m 20 kN/m	 40 kN/m 40 kN/m	 20 20	 40 40
Strain at failure	≤ 10 %	≤ 10 %	3.5 %	3.5 %
Tensile strength at 1 % strain *	-	-	7 kN/m	14 kN/m
Tensile strength at 2 % strain *	9 kN/m	16 kN/m	13 kN/m	26 kN/m
Tensile strength at 5 % strain *	18 kN/m	32 kN/m	-	-
Modulus at 2 % strain	450 kN/m	800 kN/m	650 kN/m	1300 kN/m
Mesh size	40×40 mm^2	40×40 mm^2	14×14 mm^2	14×14 mm^2
Weight **	200 g/m^2	330 g/m^2	130 g/m^2	170 g/m^2
Roll dimensions	5.2×200 m^2	5.2×200 m^2	3.1×200 m^2	3.1×200 m^2

* ISO 10319 ** DIN EN 965
*** aramid grid + polyester nonwoven

4.2.2 Performed measurements and results

The investigations and measurements at the Tuupakka test field include:
-temperature measurements of the structures and air temperature
-frost penetration depth
-control of layer thickness of granular material above LWA
-bearing capacity with plate load tests and falling weight deflectometer (FWD)
-rutting measurements
-friction measurements
-observation of weather conditions

Temperature measurements were performed to investigate the insulation properties of the LWA and the frost penetration into the structure. The temperature measurements are also used to evaluate the possibility for surface icing which is a specific topic in the project. The temperature measurements have been performed at regular intervals during the whole test period. The maximum frost depth from the temperature measurements was only possible for the reference structure were a maximum frost penetration of 1.33 m was found. The results of the temperature measurements are presented in /6/.

Frost penetration has also been measured by using a Ganthal's rod (methyl-blue indicator). The frost penetration was measured 2002-03-21 and the frost depth at the reference structure at that time was 1.3m.

Layer thickness of the granular materials was measured using ground penetrating radar. There was a difference between the designed layout and the real construction and it was therefore necessary to perform control measurements. The measured layer thickness is presented in /7/ and shows that the layer thickness over the LWA is generally significantly thicker than designed.

Bearing capacity was controlled both on top of the bearing layer by the use of plate load test and on top of the AC layer by the use of FWD. The measurements were performed on both lanes 1 m

from the centre line of the road. A summary of the results from the plate load tests are given in Table 4.3.

Table 4.3 Results from plate load tests

Station number	Thickness of the LWA layer as designed [mm]	Thickness of the layer on top of LWA as measured* [mm]	Crushed rock/ crushed concrete (CR/CC)	Special	Bearing capacity [MPa] (average)
335…370	-	-	CR	Crushed rock –structure	196
370…385	700	620…750	CR		*149*
385…400	700	360…440	CR		*127*
400…415	700	240…280	CC		*100*
415…430	700	390…490	CC	TRC 20	*124*
430…450	1450	360…460	CC	TRC 40	*104*
450…470	1300	430…540	CR	Fornit 20/20	170
470…490	1300	*≈500…600*	CR	Fornit 40/40	173
490…510	-	-	CR	Blasted rock –structure	244

* without AC-layer ≈100 mm

Generally the bearing capacity measured on top of the base course layer (plate load test) was considerably lower for the LWA structures (E_2 =100-150 MPa) than for the reference structures (E_2 = 200-240 MPa). The sections were designed aiming for a bearing capacity of minimum 160 MPa, accordingly the requirement for bearing capacity was not achieved for the LWA-sections. For the sections including geosynthetic reinforcement the results varied from E_2 = 104-124 MPa (TRC -grid) to E_2 = 170-173 MPa (Fornit-grid).

The results from the measurements of bearing capacity on top of the AC-layer (FWD-measurements) were significantly lower for the LWA-structures compared to the conventional structures. The results have large variations and differ with time but typically the reference structures obtain a bearing capacity (E_2) 70-100% higher than the LWA structure. For the sections with geogrid the measured bearing capacity vary from 20% lower (TRC-grid) to 20% higher (Fornit) than the unreinforced structures.

The FWD-measurements are used to back calculate the values of E-modulus of the different layers. Results of back calculations of the E_2 modulus are presented in Table 4.4. The results indicate very clearly the difference between the E-modulus of the sub-base of crushed rock compared to the LWA layers. It should though be noticed that the calculated E-modulus for the LWA layer varies from 35 to 120 MPa.

Table 4.4 Back calculated E-modulus of the test structures at ramps R4 (a) and R6 (b)

a) Station number	Thickness of the LWA layer as designed [mm]	Thickness of the layer on top of LWA as measured [mm]	AC-layer [MPa]	Crushed rock (base laeyr) [MPa]	Crushed rock (sub base) [MPa]	LWA 10…20 mm [MPa]
110…145	-	-	3000…3500	350	300…320	-
145…190	1100	640…840	3000…3300	240…280	200…240	100…120
190…235	1300	580…710	2200…3000	180…280	100…240	50…100
235…270	-	-	2500…3000	200…380	280…360	-

b) Station number	Thickness of the LWA layer as designed [mm]	Thickness of the layer on top of LWA as measured [mm]	AC-layer E-modulus [MPa]	Crushed rock / C. concrete (base layer) E-mod. [MPa]	Crushed rock / C. concrete (sub base) E-mod. [MPa]	LWA 10…20 mm E-modulus [MPa]
335…370	-	-	3000…3500	280…320	240…270	-
370…385	700	720…850	3000…3500	220…300	120…200	70…80
385…400	700	460…540	3000	220…300	80…200	50…70
400…415	700	340…380 (CC)	2000…2500	140…360	70…140	40…45
415…430	700	490…590 (CC)	2400…3000	180…220	90…95 (T20)	35…42
430…450	1450	460…560 (CC)	2000…2300	100…230	60…80 (T40)	35…40
450…470	1300	530…640	2200…3500	180…260	110…220 (F20)	50…100
470…490	1300	*600…700 ?*	3300…3500	260…350	200…240 (F40)	100…110
490…510	-	-	2700…3000	180…200	200…250*	-

T20 = TRC-grid 20/20 T40 = TRC-grid 40/40 F20 = Fornit 20/20 F40 = Fornit 40/40
CC = Crushed concrete

Generally the E-modulus of the LWA seems to increase with increased cover layer above the LWA, Figure 4.3, i.e. with increased stress level of the LWA.

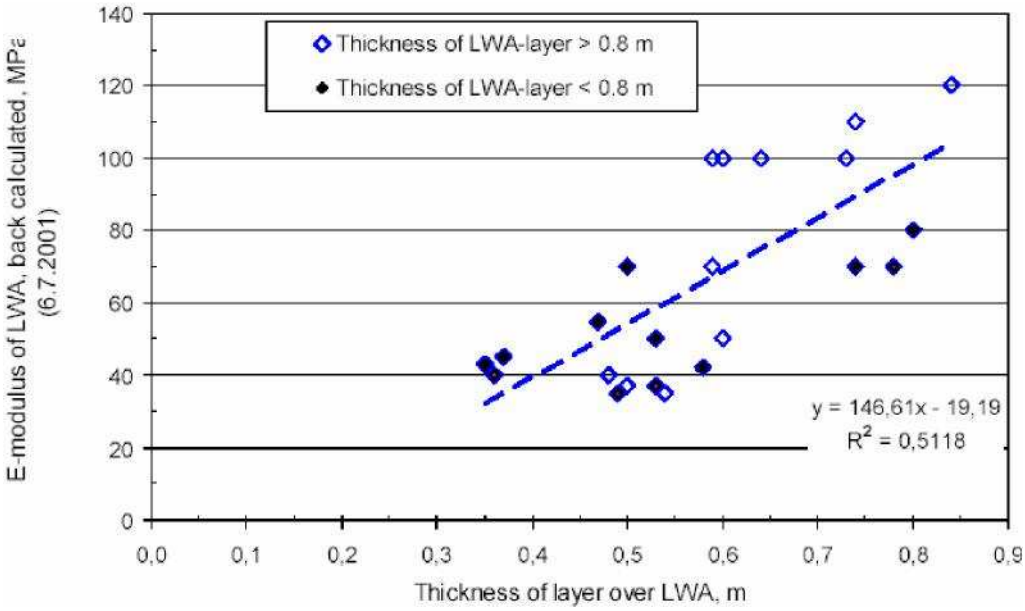
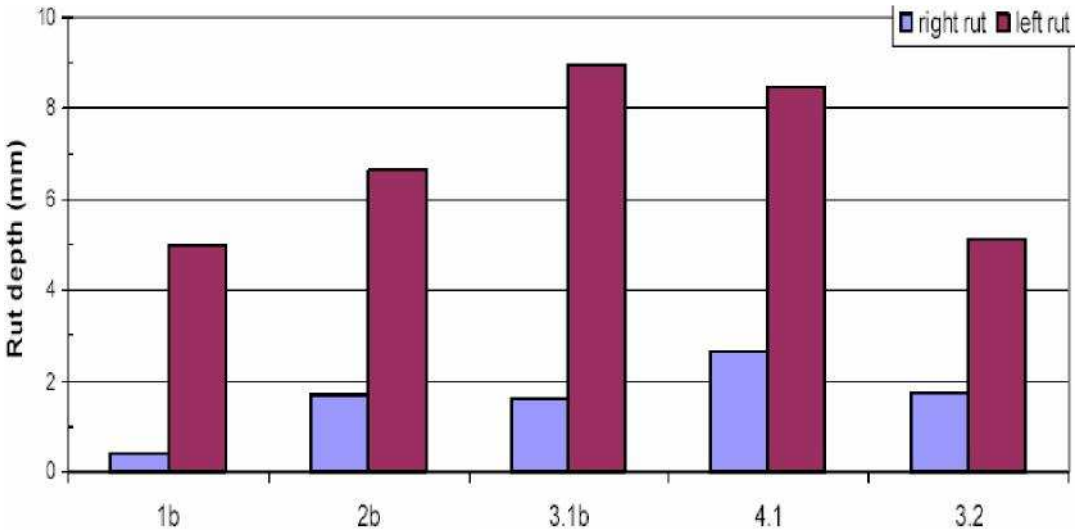


Figure 4.3 E-modulus of LWA versus thickness of cover layer

The results from the bearing capacity measurements are presented in /7/.

Rutting was measured with laser-profilograph in three profiles in October 2000, May 2001 and October 2001. Rutting measurements from 4 sections are presented in Figure 4.4. Section 3.1b and section 3.2 both have 50 cm overlay over the LWA, section 3.1b has no reinforcement while section 3.2 is reinforced with Fornit 20/20. The time period for the rutting measurements is quite short but the measurements indicate that the amount of surface rutting is reduced 15-45% by the use of geosynthetic reinforcement of type Fornit 20/20.



LWA + 50 cm, no reinforcement

LWA + 50cm, reinforcement Fornit 20/20

Figure 4.4 Rut depths of the test sections in Tuupakka at 2001-10-01

The results from the rutting measurements are presented in /7/.

Friction of the surface is measured in autumn and winter 2000-2001 and 2001-2002 using portable friction tester (PFT and C-Trip friction meter installed in a passenger car. The measurements indicate a generally lower friction on the LWA structures compared with the conventional structures. The differences in the measured friction (measured at occasions where surface icing is likely to occur) is 13 % lower for 700 mm overlay over LWA to 23% lower for 350 mm overlay thickness compared to the conventional structures. The friction measurements are presented in /8/.

Weather conditions have been observed in terms of air temperature, dew point, relative humidity, air pressure, wind speed and direction and cloud height. The weather conditions are all collected at Vaisala measuring station located 1.8 km from Tuupakka test site. A summary of the results are presented in /8/.

4.2.3 Conclusions from Tuupakka

The test structure at Tuupakka has provided useful information on the construction and structural behaviour of LWA used as insulation in roads.

Insulation:
The results verify the insulation effect of LWA as the frost penetration is reduced compared to the sections with no insulation. The frost never penetrated through the LWA layer but due to some measurement problems the maximum frost penetration depth in the insulated layers has however not been determined.

Construction:
The layer thickness of the LWA layer and the granular cover material above the LWA varies from the design indicating that the accuracy of the levelling during construction is not sufficient.

Bearing capacity:
The bearing capacity of the structure as determined by the E-modulus increases with increasing aggregate layer thickness above the LWA. The measurements both on the surface and on the base layer indicate that the compaction of the LWA is varying and is partly not sufficient. The results indicate that there is a need for better compaction equipment and procedures and for methods of controlling the quality of the compaction. The results do not give a reliable basis for estimation of an E-modulus of LWA for design purposes.

Effects of geosynthetic reinforcement:
The effects on bearing capacity from geosynthetic reinforcement have not been clearly documented in the project. The results indicate that an increased bearing capacity can be achieved by the use of reinforcement but the effect is dependent on type of reinforcement and interaction with the surrounding material.

The results verify that the rutting of the surface is reduced by the use of geosynthetic reinforcement. In general reinforcement seems mainly to improve the resistance to plastic deformations (rutting) while the elastic properties (as measured by FWD) are only marginally influenced.

4.3 Sweden

Sweden has been main responsible for the topic LWA-Light loadspreading plate (LLP). The LLP is a steel reinforced plate made of light weight aggregate concrete with an open structure (LAC). It has been developed by AB Svensk Leca and is used to reduce the impact of traffic loads on underlying material and to level out differential settlements in road and railway embankments primarily.

The LLP has previously been tested at CTH, SP, SINTEF and AB Svensk Leca. In the Geolight project the LLP has been tested both on unreinforced samples and on reinforced beams.

The material tests were carried out during 1999 at SP. The tests and evaluations have been done on commission of Swedish Leca in co-operation with Swedish Leca, SP and Bohusgeo. The test programme is presented in *Table 4.5*.

Table 4.5 Test programme LLP

Type of sample	Type of test
Unreinforced samples	Compressive strength
	Tensile strength
	Modulus of elasticity
	Bulk density
	Compressibility cyclic loading
	Frost resistance
	Heat conductivity
Reinforced beams Cross sections height 0.3, 0.4, 0.5 m. (steel reinforcement in top and bottom)	Moment capacity
	Shear strength capacity
	Unit weight

A picture from the testing of the full-scale beam is presented in Figure 4.5.

Figure 4.5 Full scale testing of LLP

Bohusgeo has performed theoretical analyses of capacities of the

LLP. **4.4 LLP – results testing and evaluations**

The project includes testing both of the Light weight aggregate-concrete (LAC) itself and on full scale LLP-beams.
The main results from the testing of the LAC (three different types) are given in Table 4.6.

Table 4.6 LAC-characteristic properties

Characteristic	Type of LAC		
	LAC-type 1	LAC-type 2	LAC-type 3
Compressive strength (MPa)	2	2	18
Tensile strength (MPa)	-	-	1.4
Modulus of elasticity (MPa)	1400	1700	11000
Density (dry) (kg/m^3)	520	530	1310
Heat conductivity (W/mK)	-	-	0.5

The tests have also showed that the lightweight aggregate concrete of strength LAC 2 (comparable to LAC-type 1 and LAC-type 2) and LAC 15 (comparable to LAC-type 3) both were frost proof.
The main results from the testing of the LLP-beams are given in Table 4.7.

Table 4.7 Results from testing of LLP-beams

Characteristic	Type of LLP			
	LAC-type 1 H=500 mm	LAC-type 2 H=500 mm	LAC-type 3 H=300 mm	LAC-type 3 H=500 mm
Moment capacity, per m width (kNm)	50	50	75	150
Shear force cap. per m width (kN/m)	30-40	30-40	>40 *)	>80 *)

*) Shear force when failure due to bending occurs

The evaluation has shown that calculations of the reinforced beams moment capacity and shear strength capacity, based on measured compressive strength and tensile strength, gives relatively good correspondence with the bending tests. The calculations have been done according to conventional calculation methods aimed for concrete.

The LLP has been tested in real field structures and has proven to give very good results in terms of load distribution and in levelling out settlements. Pictures from construction of LLP in Mølndal is presented in Figure 4.6.

Figure 4.6 LLP construction, Mølndal

Detailed information on the results on the testing and evaluation of LLP is given in /9/.

4.5 Norway

Norway has been main responsible for the topic LWA – mechanically stabilised. The LWA material from Norsk Leca has been thoroughly investigated in the project MiljøIso. The main activities in the Geolight project have been related to the test field at Sandmoen. There has also been an initial activity related to the use of LWA for drainage applications.

4.5.1 Test Site Sandmoen

The aim of the Sandmoen test site was to investigate the structural behaviour of LWA as a part of the bearing layer of a road. The work at Sandmoen has been done in close co-operation with a Dr.Eng thesis at NTNU related to edge deformations of roads /10/.

The test site is located at a weight control station and includes four different sections whereof two sections with LWA as a part of the bearing layer. One of the sections with LWA is a wedge section where the overlay over the LWA is gradually reduced. The layout of the test field and the instrumentation are presented in /11/. The test structure layout is presented in Figure 4.7.

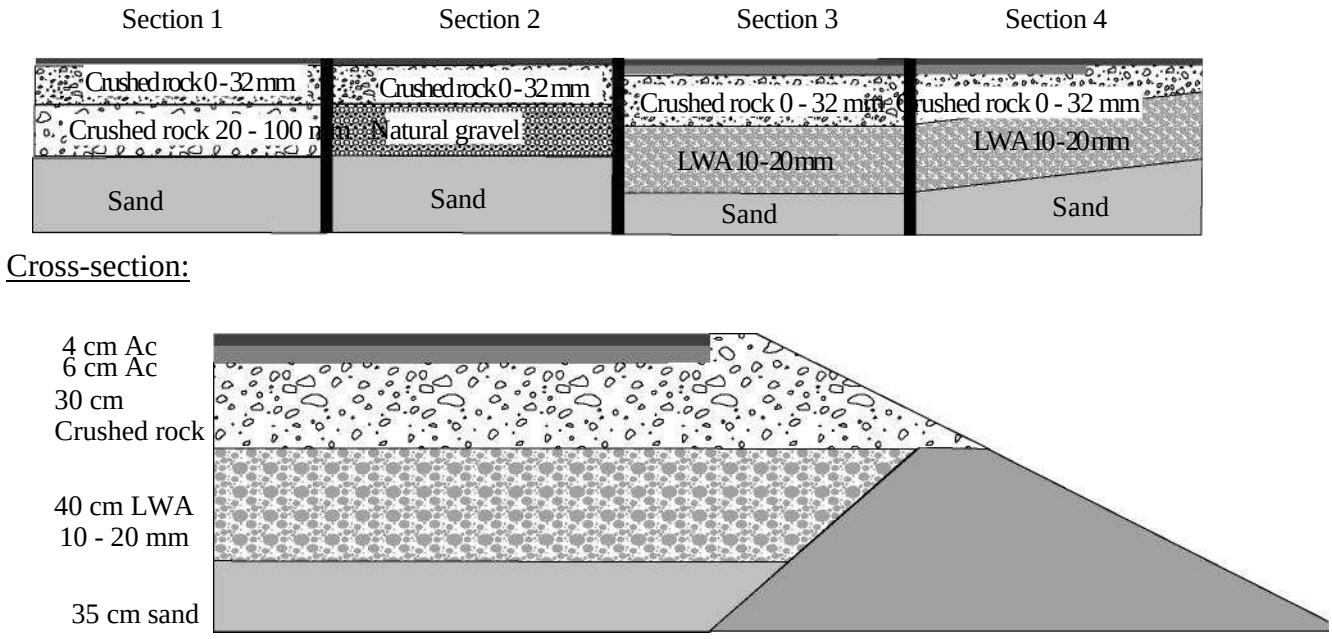


Figure 4.7 Test field at Sandmoen, structural layout

4.5.2 Performed measurements

The investigations at Sandmoen include stress and strain measurements, temperature measurements, surface profiling and surface friction measurements. Measurements have been done both during controlled loading by a heavy vehicle and as continuous measurements under normal traffic loads. It has also been performed plate load tests and falling weight measurements. The test field became excavated after 2 years of service and the material have been examined both visually and in the laboratory.

Figure 4.8 Sandmoen test field. Construction work and controlled loading test

4.5.3 Test results

The Sandmoen test field has provided very useful results both related to construction techniques, structural behaviour and insulation effects of LWA. A summary of the test results from Sandmoen are presented in this report.

Stress measurements:
The stress distribution in the LWA – layer under a vehicle with 123 kN axle load and 690 kPa tire pressure is shown in Figure 4.9. The vertical stress is reduced to about 100 kPa at the top of the LWA for the inner track and to about 160 kPa close to the edge. At the bottom of the LWA layer the stresses are further reduced to 50 and 70 kPa.

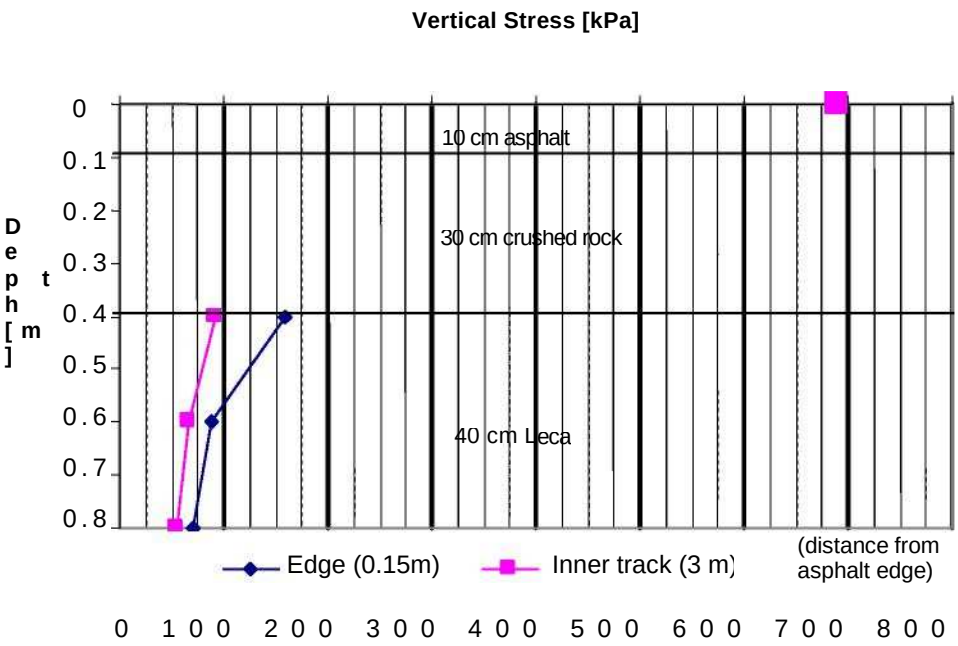


Figure 4.9 Measured vertical stress in the LWA layer (axle load: 123 kN, 690 kPa)

Deformations:
The vertical deformations are measured in the LWA and in the crushed rock. The strains are plotted in the middle of each layer in Figure 4.10. The measured strains are substantially larger in the layer of crushed rock (approx. 2.4 ‰) than in the LWA layer (approx. 0.8 ‰). This corresponds well with the lower stress-level in the LWA layer. One of the sensors in the crushed rock layer (inner track) has deformed more than the measuring range, meaning that no reliable measurements are available for this point.

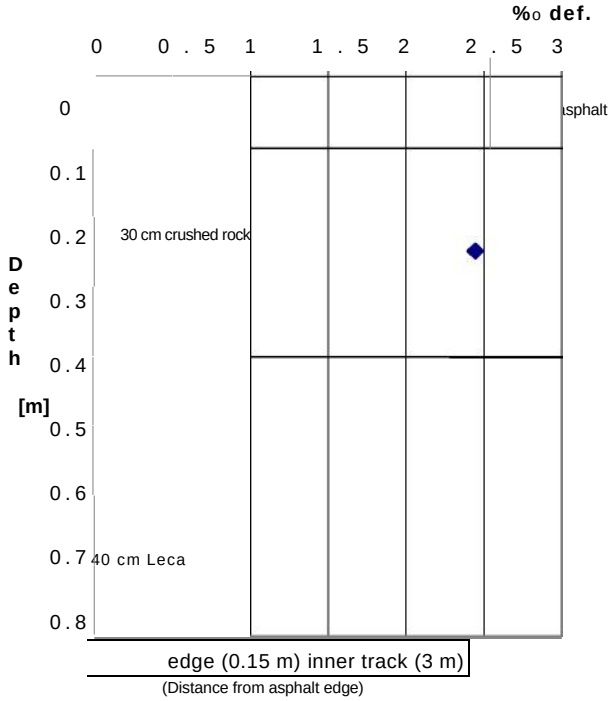


Figure 4.10 Resilient vertical strain in the crushed rock and LWA materials (axle load: 123 kN, 690 kPa)

Bearing capacity:
The bearing capacity (given in tons) based on FWD-measurements along section 3 and 4 is shown in Figure 4.11.

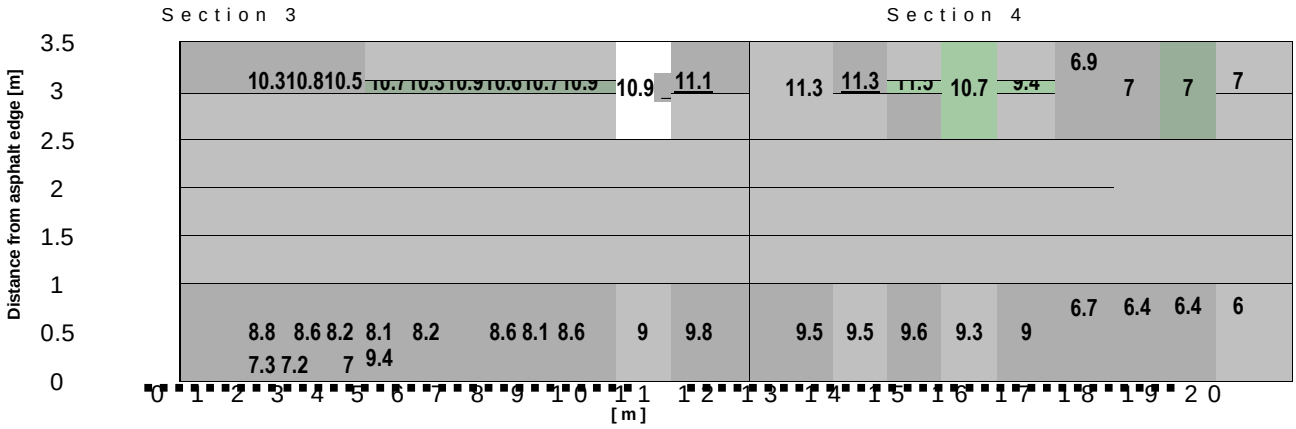


Figure 4.11 Bearing capacity (tons) measured with FWD (1 ton eq 10 kN)

As can be seen from Figure 4.11 the measured bearing capacity was comparable to a traditional road structure both for section 3 and for section 4 except for the area with only one layer of asphalt at the weak end of the wedge – out section (section 4). As expected the bearing capacity was lower when the FWD – measurements were taken close to the pavement edge. This is due to the fact that the horizontal stresses close to the edge are lower and accordingly the bearing capacity is reduced close to the edge. The same effects were also observed at the adjacent section with conventional granular material /10/.

Plate load tests:
Plate loading tests were performed on all layers during the excavation of the test field. During construction plate loading tests is difficult to perform directly on the LWA material for two reasons:
-the surface of the material is too unstable to give meaningful results
-placing of a truck to take the reaction forces requires special precautions to obtain trafficability

In comparison the plate loading tests during excavation could be performed easily. The surface of the LWA was very stable during the excavation and with some load spreading plates under the wheels the truck could be moved on the LWA material and perform the test, Figure 4.12.

Figure 4.12 Plate loading test directly on LWA layer

Figure 4.13 shows E_1, E_2 and $_{E2/E1}$ values for plate loading tests on different levels. Average values from the testing during the original construction of the test field (summer 1999) and during the excavation (summer 2001) are summarised in Table 4.8 and Figure 4.13. The E_2 values for the LWA obtained by the loading tests during the excavation is surprisingly high considered the lack of stabilising material on top of the material. As previously stated it was not possible to perform the loading tests directly on the LWA at the time of the original construction. After the testing was finished the plate load equipment was recalibrated. This revealed that too low stress was applied (32 %); the results below have been adjusted according to the last calibration.

It should also be noted that both the E_1 and E_2 values at the top of the crushed rock bearing layer have increased significantly from the values obtained at the construction stage (summer 1999) to the values obtained during excavation (summer 2001). This indicates that the stiffness of LWA layer is significantly increased after the installation and compaction of the cover layer.

Table 4.8 Results from plate loading tests

Time	Level of plate loading	E1	E2	E2/E1
During construction (summer 1999)	On top of crushed rock	44	124	2.86
During excavation (summer 2001)	On asphalt	71	159	2.25
	On top of crushed rock	88	163	1.86
	On LWA	29	95	3.6

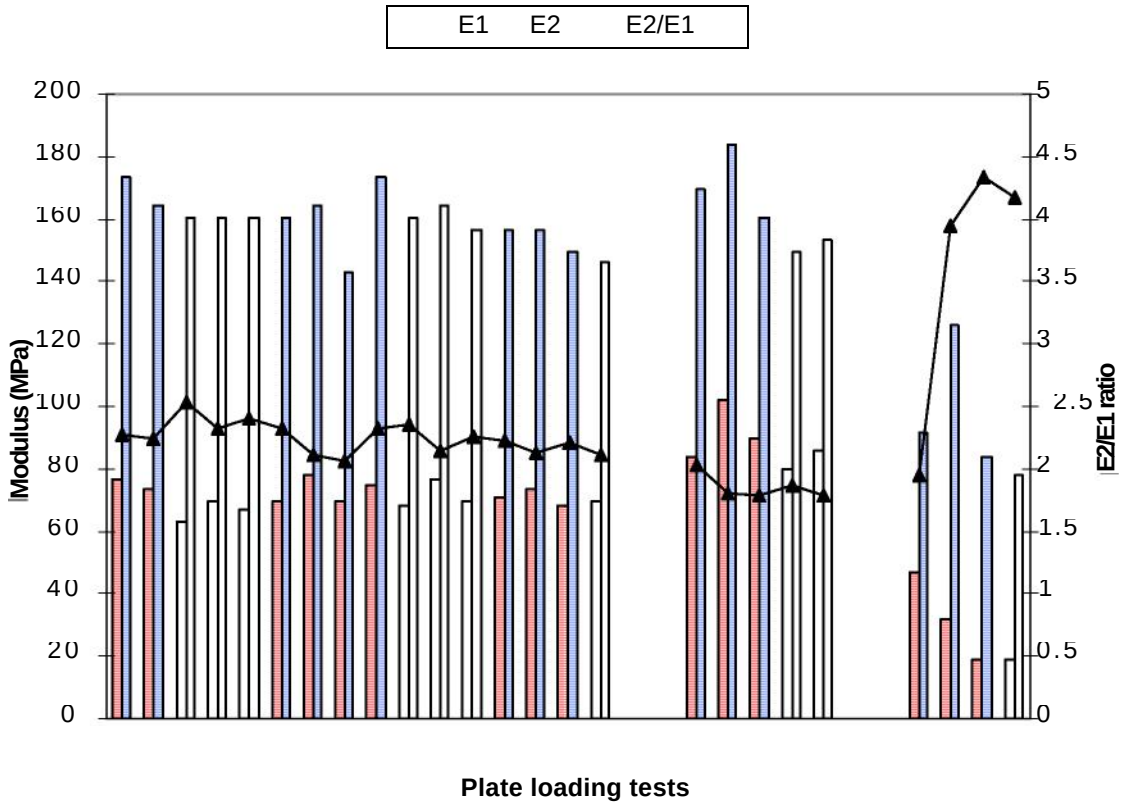


Figure 4.13 Results from plate loading tests during excavation

Structural behaviour:
The structural behaviour of the test sections has been very good. The measured rutting of the surface is presented in Figure 4.14. The amount of rutting at the "normal section" (section 3, 400 mm overlay) is in the same amount as for the first part of the wedge section (section 4). Most of the rutting was observed initially after the field was constructed. The development of rutting stabilised after a few months except for the weakest part of the wedge – out section (section 4) where a total of 80 mm of rutting accumulated after two years of service.

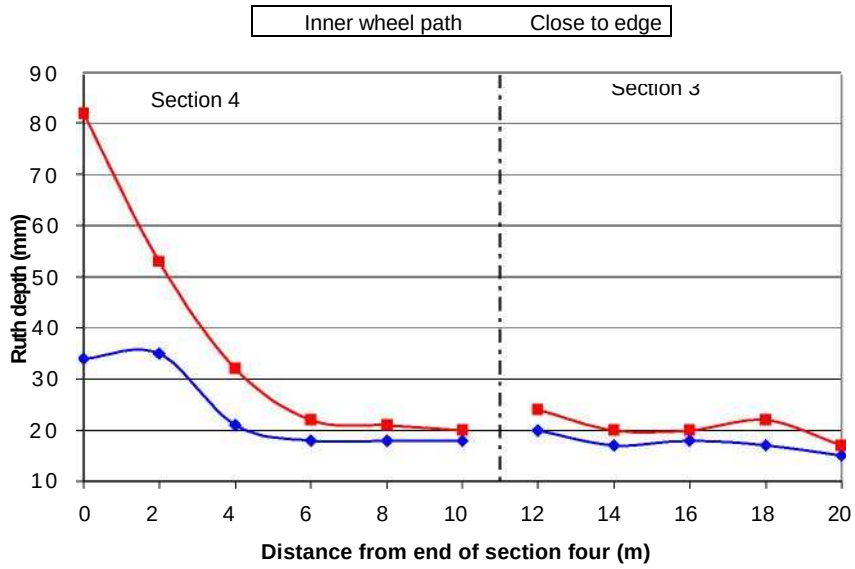


Figure 4.14 Final rutting measured manually with a 3 m straight beam

Temperature measurements:
The analyses of the temperature measurements are not completed yet. However, Figure 4.15 shows some measurements for some selected temperature sensors for the winter 1999/2000. Notice that the temperature in the bottom of the LWA layer never drops below freezing point during the winter. This means that the problems with frost heave and spring thawing are eliminated.

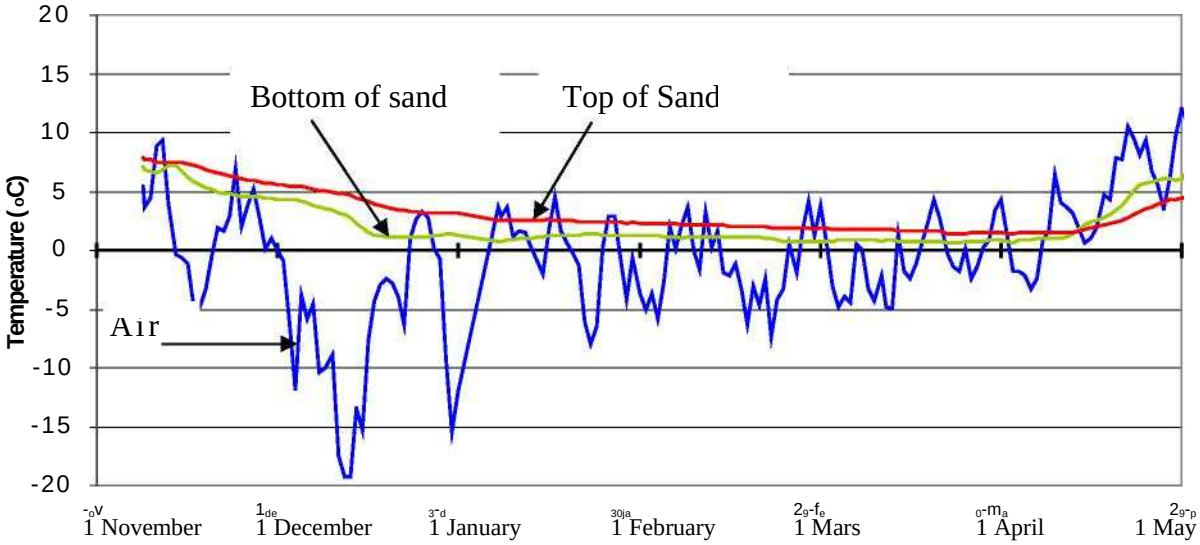


Figure 4.15 Registered temperatures (daily mean) at different levels in the LWA –section for the winter 99/00

4.5.4 Sandmoen-conclusions

The test field at Sandmoen has verified that from a mechanical point of view LWA can be used as a insulation layer with significantly thinner overlay than previously recommended. Section 3 (400 mm overlay) was able to withstand the traffic without developing severe damages. It is also believed that heavier compaction on top of the base layer would have reduced the initial rutting. The weakest part of the wedge – out section (overlay thickness 200 mm) seems to be too weak. The development of rutting is more rapid than what could be accepted on a regular road.

The test field has provided information of how high stress levels the LWA material can be exposed to without starting to develop severe damages. Since the experience with this type of materials used in pavements is yet limited it is recommended to perform a stress strain analysis in the design process for pavements including LWA. From a mechanical point of view 40 cm of material above the LWA – material seems to be sufficient for a low – volume road. For design of a high volume road, it should be considered to increase the thickness somewhat to reduce the risk for abrasive wearing of the grains.

The measurements during the excavation have verified that the bearing capacity of the LWA layer after compaction and covering with a granular bearing layer is generally very good provided the LWA is properly compacted. The measurements have also verified previous results on 10-12 % increased density by compaction of LWA.

The dry density of compacted LWA material measured at Sandmoen is about 400 kg/m^3. This seems to be relatively high compared to previous results found in the laboratory and from field. Similarly the measured water content at Sandmoen, in average about 35 weight %, seems to be relatively high compared to previous results from the field.

Investigation of the LWA-material after excavation did not reveal severe crushing of grains, even at the weakest part of the wedge – out section. This indicates that crushing is not likely to be the dominating mechanism even at relatively high stress levels.

The temperature measurements verify that the insulation effect of the LWA material significantly reduces the frost penetration.

More detailed information from the Sandmoen test field is presented in /12/.

4.5.5 LWA for drainage applications

An initial activity has been carried out to investigate the use of LWA for drainage applications. LWA has previously been found to have good drainage capacity and in combination with the insulation effect the use of LWA in drainage ditches seemed very promising. LWA has been used as drainage material and for frost protection in some cases. In the project some numerical analyses were performed as a basis for evaluation of necessary amount of LWA for insulation of drainage ditches. It has also been planned to run a field test on a drainage ditch with LWA as drain medium but this has not been realised so far due to lack of financing.

4.6 Internordic working Groups

Three topics in the LWAgeolight project have been performed as joint internordic activities. These topics are:
-preparation of requirements on properties and tests methods for LWA-Isolitest-project
-evaluation of risk for surface icing
-publication

4.6.1 ISOLITEST –project

The main goal of the Isolitest was to develop a Nordtest method giving required properties and corresponding test methods for LWA used in road and railway construction. This project was partly financed by Nordtest.

The Isolitest project included a precision trial between seven different Nordic laboratories and an evaluation of different test methods based on previous experience. The test programme is presented in Table 4.9.

Table 4.9 Performed work in ISOLITEST

Property	**Relevant test method(s)**	**Supplementary work**
Dry loose bulk density	EN 1097-3	Supplementary testing as basis for evaluation of variation in the test method
Grain size distribution	EN 933-1	Supplementary testing as basis for evaluation of variation in the test method
Particle density	prEN 1097-6, annex C SP 758 *) SP A1 865 *)	Evaluation of results from earlier tests to determine variation in results
Water content	EN 1097-5	Determined as part of the testing of dry loose bulk density
Water absorption	1097-6	Preparation of revised procedure with increased duration of test
Compressibility	prEN 13055-2 Large scale oedometer	Supplementary testing in large scale oedometer. Comparison of results with EN 13055-2.
Compressive strength	prEN 13055-2 Large scale oedometer SP Method A1 861 *)	Supplementary testing in large scale oedometer. Comparison of results with EN 13055-2.
Cyclic compression	SP Method 2563 *)	Revision of procedure to specify relevant load levels
Elastic stiffness and resistance to permanent deformations	Cyclic triaxial testing	Exchange of results from previous testing. Comparison of results with EN13055-2 (stiffness and resistance to permanent deformations) Prepare procedures based on current practice
Effective stress properties: friction angle, attraction/ cohesion, dilatancy	Static triaxial testing	Prepare procedures based on current practice
Sampling	EN 932-1 EN 932-2	Sampling performed as part of the supplementary testing

*) SP method: Test method developed by SP Swedish National Testing and Research Institute

As a part of the Isolitest project SP has developed a method for determination of compressibility and compressive strength after compaction by vibration, SP-method 2670, Nordtestproject 1391-98. The method is also a draft Nordtest method and a draft European Norm prEN 13055-2, Annex A. SP has also developed a test method, originally created by the Swedish Railway authority "Banverket", for determination of the resistance to cyclic compressive loading, SP-Method 2563. The method is also a draft Nordtest method.

Isolitest results:
The result from the ISOLITEST project is presented in a presentation of the project results /17/ and as a proposal for a Nordtests method: "Light weight clay aggregate for roads and railways. Required properties and test methods." /13/.

This report is used as a basis for a proposal for a work item on this topic for the work in CEN TC 88. The proposed Nordtest method has provided a list of required characteristics for LWA for roads and railways. The purpose of the testing is influencing the equipment and procedures to be used.

In this Nordtest method the purpose of the testing is divided into the following groups:
- verification of environmental acceptance
- design purposes
- quality documentation
- production control

Environmental acceptance:
Characteristics and relevant test methods listed under column "environmental acceptance" are required to ensure that the material fulfils requirements related to possible leakage of environmental hazardous substances.

Design:
Characteristics and relevant test methods listed under column "design related" are required to provide the designer with sufficient documentation of the material properties. The requirements and test methods required for design in this Nordtest method are related to the following applications:

- light weight fill beneath roads, railways and other traffic areas (F)
- light, insulating and draining fill material against structures (FS) -
insulating material in roads and railways (I)
- frost protection of pipe ditches (FP)

Quality documentation:
Characteristics and relevant test methods listed under column "quality documentation" are required as a material documentation, i.e. that the material has a given set of characteristics and that the material quality can be verified according to these characteristics.

Production control:
Characteristics and relevant test methods listed under column "production control" are required as a basis for the producers own continuous quality production control.

The required characteristics and relevant test methods related to the application and intended use of the LWA are presented in Table 4.10. More detailed information on the required characteristics and the test methods can be found in /13/.

Table 4.10 Required characteristics and relevant test methods

Properties	Test methods			
	Environmental acceptance	**Design related *)**	**Quality documentation**	**Production control**
Dry loose bulk density		EN 1097-3 F, FS, I, FP	EN 1097-3	EN 1097-3
Grain size distribution			EN-933-1 EN-933-2	EN-933-1 EN-933-2
Particle density			prEN 1097-6	SP 758
Water content		EN 1097-5 I, FP		EN 1097-5
Water absorption			prEN 1097-6, annex C	prEN 1097-6, annex C
Stiffness, static loading		Large scale oedometer	prEN 13055-2 annex A.	
Compressive strength			prEN 13055-2 annex A.	prEN 13055-2 annex A. SP A 861
Characteristic limit stress level		Large scale oedometer		
Cyclic compression		Nordtest method SP Method 2563 F, I		
Elastic stiffness and resistance to permanent deformations		Cyclic triaxial tests: F, I	prEN 13055-2	
Resistance to mechanical degradation (crushing)		Not relevant	Not relevant	Not relevant
Effective stress properties, frictional angle, dilatancy		Triaxial tests F, FS		
Sampling			EN 932-1 EN 932-2	
Water suction height		Not relevant	Not relevant	Not relevant
Resistance to disintegration			prEN 13055-1, annex B	
Chemical analysis			EN 1744-1	
Thermal capacity		SP method	SP method 2296	
Thermal conductivity		prEN 12664	prEN 12664	
Freezing and thawing resistance			prEN 13055-2, annex B	
Leaching	NT ENVIR 002 NT ENVIR 003 prEN 12 457			

F: Light weight fill in roads, railways and other traffic structures
FS: Light, insulating and draining material against structures I: Insulating material in roads and railways
FP: Frost protection of pipe ditches

4.6.2 Surface icing

Basics:

Insulation close to the road surface may prevent heat transfer from the underlying embankment and cause icing on the road. Based on earlier research works in 1970's it was decided by the Finnish road authorities that at least a 700 mm covering layer of mineral soil over an insulation should be used. In Sweden the road authorities ended up with a required thickness of 500 mm for the covering. In Norway no specific minimum thickness was required but it is stated that if insulation is used the possibility for surface icing should be considered carefully. If the thickness of the covering could be reduced without increasing the risk of icing, the use of various insulating materials could be increased.

Performed work:

The work to examine surface icing was started in 1999. During 1999 and 2000 research was done mainly nationally. In spring 2001 an internordic working group was established to co-ordinate the activities on this topic. The aim of the working group is to evaluate the risk for surface icing in roads with LWA used as insulation and light weight fill material.

Two test sites have been constructed with LWA-insulation at different depths and is used for friction and temperature measurements as a part of the activities. One test site was constructed at Sandmoen, Norway and the other at Tuupakka, Finland. Temperatures of the air and pavement surface for both insulated and not insulated (reference) structures have been measured to find out the differences in the behaviour of the road surfaces. Friction with different equipment has been measured and also modelling of the surface temperatures has been performed.

Temperatures:

In the winter, the relative humidity of the air in Scandinavia is often near 100%, and the dew point is only a couple of degrees centigrade lower than the air temperature. When the surface temperature under these circumstances drops below the dew point and below the freezing point, vapour in the air condensates and hoar frost is formed on the road surface. To examine this effect the number of hours has been calculated, when the surface temperature is below 0 ºC and also, when the surface temperature is below 0 ºC and below the dew point temperature. The Relative Icing Risk of different structures, obtained by dividing the values of these "risky hours" of other structures with the values of the Reference structure at Tuupakka in winter 2000-2001 and autumn 2001 is shown in Figure 4.16. Also in the similar way obtained results from a conventional road at Helsinki-Vantaa Airport (Ref. Hki-V) is added to the figure. The total time, which the surface temperature was below 0 º C and below the dew point, was 431 hours for the reference structure and 756 hours for the LWA+350 –structure.

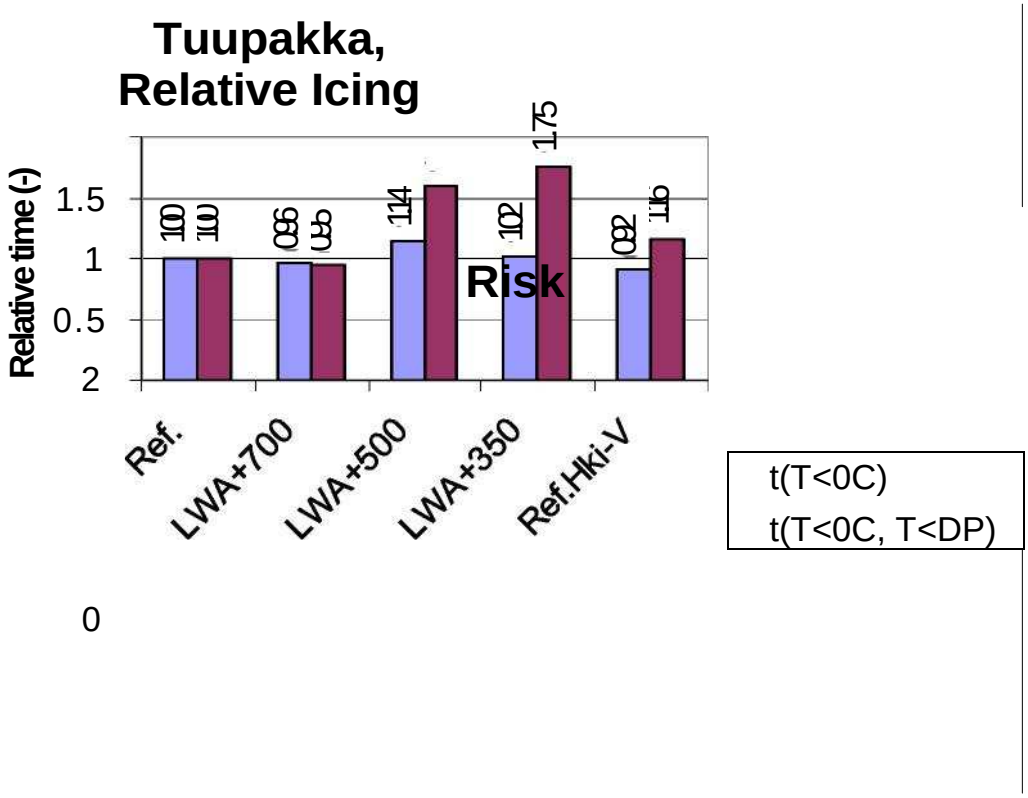


Figure 4.16 Relative Icing Risk of test structures based on temperature measurements in winter 2000-2001 and autumn 2001

In Sandmoen the differences of risky hours between the reference structure and LWA+400-structure were very much smaller than in Tuupakka: the time for icing risk based on dew point and measured surface temperatures was only 19% longer with the LWA-structure. The results from the measurements at Sandmoen are presented in /14/.

The modelling of the pavement surfaces has been done using a model developed at VTI /15/. The results of the modelling for the reference structure and LWA+350 mm seem to support the observations made in Tuupakka. In Sandmoen the difference between air and surface temperatures are higher and the modelling does not agree as well to the observations.

The surface temperature differences between different structures are often very small. This phenomenon demands very high accuracy of the temperature measurements and very precise installation depth of the sensors.

Friction of the surface:
The research programme also included friction measurements on the test structures, in order to verify the results in practice. These measurements were made at Tuupakka using a portable friction tester PFT owned by The Swedish National Road and Transport Research Institute and a C-Trip friction meter installed in a passenger car /6/.

The PTF equipment is a hand operated friction meter incorporating three wheels, one of which measures surface friction. The weight of the device is 38 kg and the operating speed is 0,5 m/s. The device provides an average friction based on eight measurements respective to every 104 mm. The C-Trip measurement unit is comprised of an electronic device installed in a car, which measures the friction

The friction measurement results obtained in winter 2000-2001 from Tuupakka did not show any differences between the structures /5/. This was mainly due to salting of the test road and failed timing of measurements. In autumn 2001 the timing of friction measurements was more successful for the purposes of this study: on four occasions (15.11., 17.11., 18.11. and 8.12.2001) visible differences between the four test structures were found, Figure 4.17. Using

the average results of these four measurements, Relative Friction Index (RFI) of the tested structures was calculated by giving value 100% for the reference structure: the average RFI for LWA+700 was 87%, for LWA+500 it was 80% and for LWA+350 it was 77%.

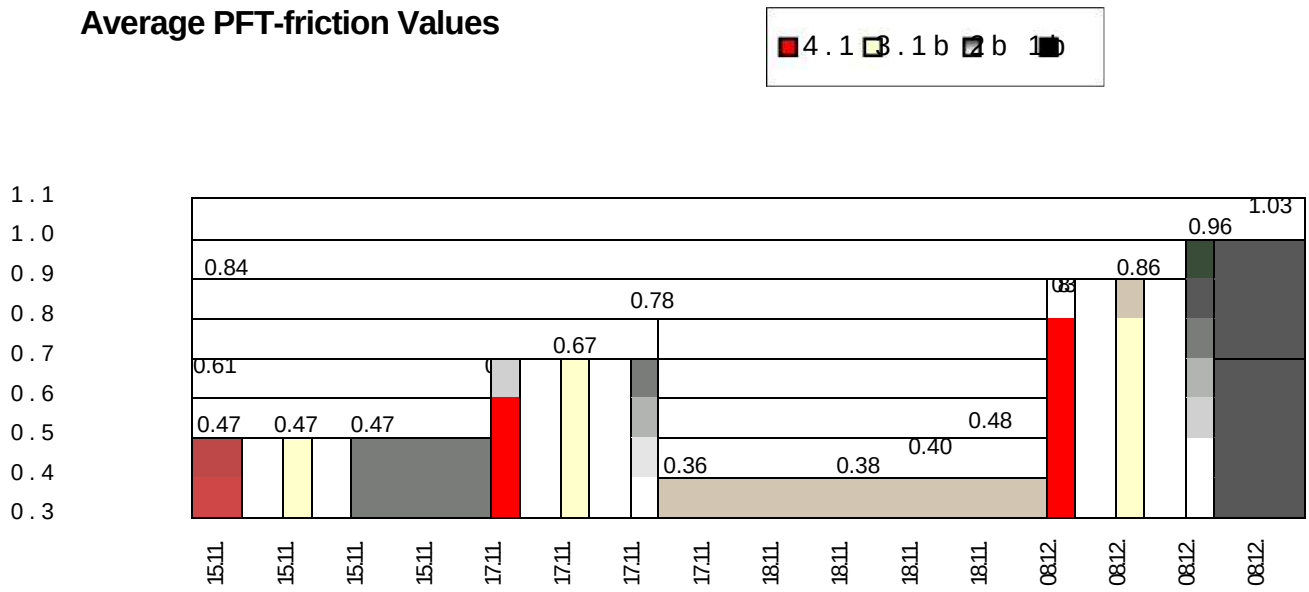


Figure 4.17 Average simplified PFT-friction values from Tuupakka 2001. (1b=reference, 2b=LWA+700, 3.1b=LWA+ 500 and 4.1=LWA+ 350)

The friction measurements in Sandmoen showed lower friction with the LWA+400 -structure both with BFP (British Friction Pendulum) and PFT (Portable Friction Tester). The average relative reduction of friction for LWA+400-structure with BFP was 42% (autumn 2000) and with PFT 15% (autumn 2001) in comparison to the reference structure /14/.

Evaluation of surface icing risk:
Icing risk evaluation of a pavement can be done by calculating the time that the pavement is assumed to be exposed to icing. The time that a pavement is exposed to icing can be defined as the sum of hours that the surface temperature is below 0°C. Another criterion is that the surface temperature is below 0°C and below the dew point temperature. This situation causes the humidity in the air to condensate on the road surface and building of hoar frost happens causing the friction of the road to decrease. This time ("risky hours") can be obtained from temperature and dew point measurements on an existing road and comparing it to the time at some reference structure nearby (the time can also be obtained by modeling the surface temperatures). By adding the information of lowered friction feature of different structures to the relative time that a structure is assumed to be icing risky, a Relative Slippery Index (RSI) has been created /8/.

The friction measurements in Sandmoen showed lower friction with LWA-structure both with BFP (British Friction Pendulum) and PFT (Portable Friction Tester) /14/. The average relative reduction of friction for LWA+400-structure with BFP was 42% (autumn 2000) and with PFT 15% (autumn 2001) in comparison to the reference structure. In Sandmoen the differences of risky hours between the reference structure and LWA+400-structure were very much smaller than in Tuupakka: the time for icing risk based on dew point and measured surface temperatures was only 19% longer with the LWA-structure.

In Tuupakka the average reduction of friction for LWA+700-structure was 13%, for LWA+500 it was 20% and for LWA+350 it was 23% measured with PFT in autumn 2001. When looking at these numbers one must remember that the friction measurements were done when biggest differences with friction were expected.

Using the measured surface temperature and dew point values, there does not seem to be very much difference between the reference structure and the structure with LWA+700mm in Tuupakka, Figure 4.16. The structures with LWA+500 and LWA+350mm have considerably higher slippery index (RSI=1,9..2,2) building up from longer risky time and lower friction than the reference structure, Figure 4.18. Using the **modeled** surface temperatures, even more distinguished differences between the structures were obtained.

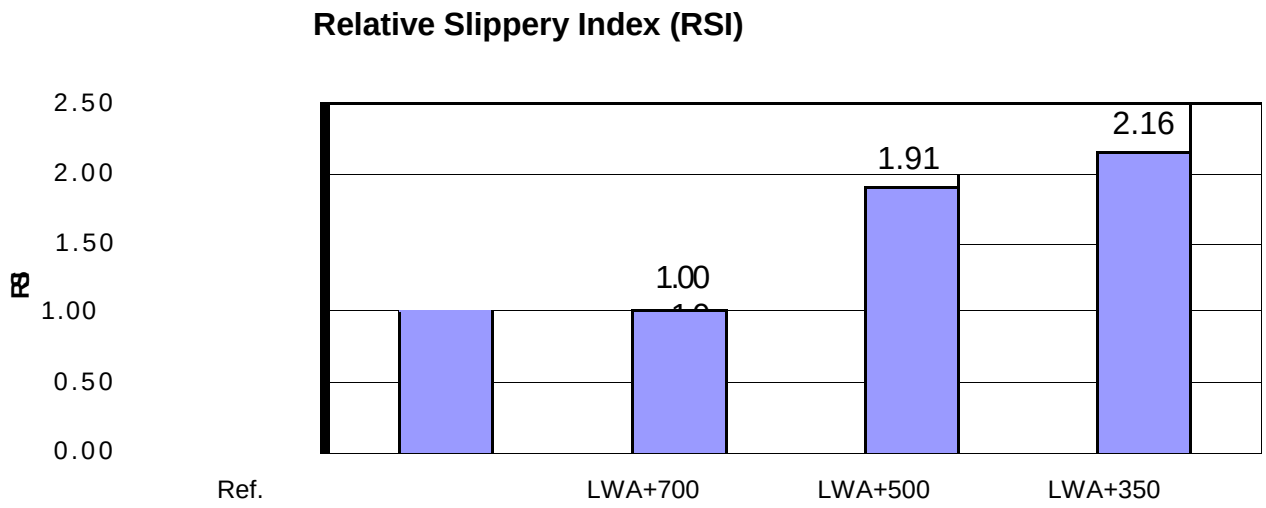


Figure 4.18 The Relative Slippery Index of test-structures in Tuupakka (based on measurements)/8/

If the adjudgement is based only on the time that surface temperature is below 0 °C, there will be no difference with the “risky hours” (modeled or measured) of any structure; the only difference on the Slippery Index is coming from the slightly lowered friction values of the LWA-structures.

The surface temperature differences between reference structure and all the LWA-structures are very small. This phenomenon demands very high accuracy of the temperature measurements and very precise installation depth of the sensors. In this study two parallel sensors in every structure were used at Tuupakka to satisfy this demand. When the sensors were recalibrated in June 2002, it was noticed that there was even 22 mm variation with the installation depths of the surface sensors, which induces difficulties to the comparison of the icing risk of different structures. On the other hand the results of modeling support the results based on measured temperatures.

Based on this study and earlier experiences, the use of LWA or other insulation materials near to the surface of a pavement can cause some reduction on the friction and also make the time that slippery conditions exist somewhat longer in comparison with a reference structure. This is true especially if same materials (AC and bearing layer) are used in the reference structure and the LWA-structures. The thermal behaviour of LWA-insulated pavement can be positively affected by using bearing layer materials that have high density and suitable amount of fines, which increases the water content. The friction properties of a pavement can also be somewhat affected by choosing coarse aggregate to the AC-layer and avoiding mastic asphalt. Non-insulated structures with thick asphalt layers and/or bitumen bound bearing layers have been found to be as sensitive to icing, especially with coarse grained, crushed rock–materials, as a structure with insulation at a depth of 350mm /16/.

4.6.3 Publication

A main part of the project is related to the dissemination of the results. The publication activities are mainly related to four types:
-presentations and meetings with users (public authorities, consultants, contractors)
-articles and presentations in seminars and conferences
-presentations of results in WEB
-brochures and guidelines from Optiroc.

Presentations and meetings with users are generally organised as national activities and have been done in all the Nordic countries.

Results from the project have been published on the WEB side of Nordisk Industrifond (http://prosjektweb.nordicinnovation.net/public/search.asp) and at the WEB-sides of Optiroc in each country.

Optiroc has also presented the results from the project in brochures and guidelines prepared in each country.

5 RESULTS

5.1 LWA-material properties

The results verify that mechanically stabilised LWA can be used as insulation and light weight fill in roads and railways. Thermal, physical and mechanical properties of LWA are essential for the design. These properties may to some extent vary due to the basic clay material and the production procedures.

5.1.1 Physical properties

Based on the results from the Geolight project the recommended design figures for physical properties are given in Table 5.1.

Table 5.1 Design values for physical properties of LWA as found in the project

Property	Grading			
	4-32	0-32	4-20	10-20
Water content at delivery				
Water content in drained fill, long term (normal conditions) (weight %)	<25%	<25%	<25%	<25%
Water content in drained fill, long term (unfavourable conditions, temporary flooding, variable ground water table) (weight %)	<40%	<40%	<40%	<40%
Unit weight (loose state) kN/m^3	3.5	3.5	3.5	3.0
Dry unit weight after compaction (normal compaction, 10-12%) kN/m^3	4.0	4.0	4	3.5
Design unit weight (normal drained conditions)	5	5	5	4.5
Design unit weight (unfavourable conditions, temporary flooding, variable ground water table)	6	6	6	5.5
Unit weight for uplift (immersed fill) kN/m^3	8.0	8.5	8.0	7.5

More detailed information of the physical properties of LWA can be found in /1/ and /21/.

5.1.2 Thermal properties

The LWA-material has very good insulation properties. Based on laboratory investigations and field measurements the thermal conductivity related to the water content is presented in Figure 5.1 /1/. The water content in a drained pavement structure is likely to be in the range of 20 – 40 % (5-10 volume %) /1/. Hence, the relevant thermal conductivity will be about 0.15 W/mK i.e. about $^1/_7$ of typical values for crushed rock.

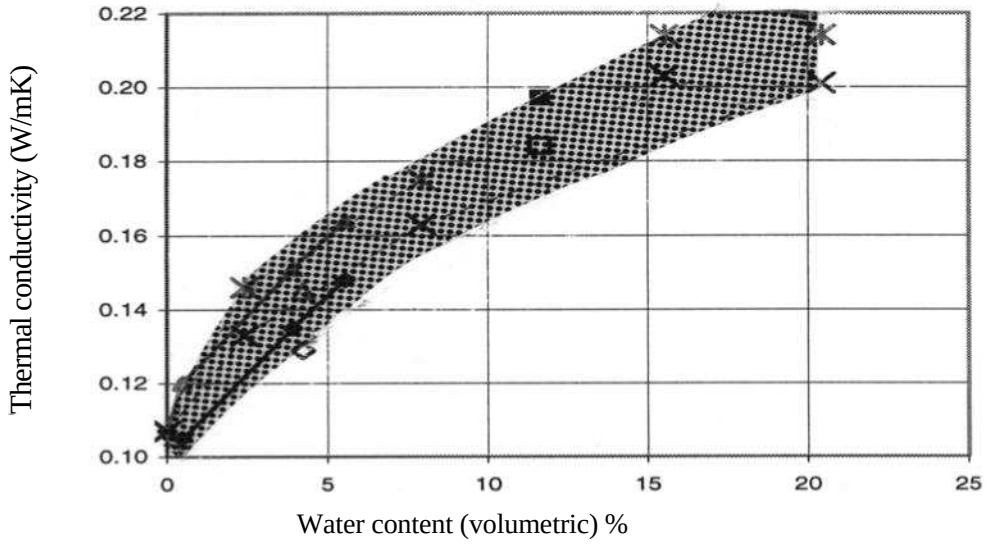


Figure 5.1 Thermal properties of LWA material related to water content /1/

More information on the thermal properties of LWA can be found in

/20/. **5.1.3 Hydraulic properties**

The permeability of LWA is generally high but is varying between the different gradings. Generally the highest permeability is found for the most single graded materials. Some investigations have been made on the water permeability /17/, /23/ but complete investigations for all types of materials have not been done. In Table 5.2 estimations of minimum permeability are given based on the performed test and on evaluation from the grading of the material.

Table 5.2 Hydraulic properties for different types of LWA

Property	Type of material				
	4-32	4-20	10-20	8-20	0-32
Water permeability (m/s)	$>10^{-3}$	$>10^{-3}$	$>10^{-1}$	$>10^{-2}$	$>5 \times 10^{-2}$

5.1.4 Mechanical properties

The mechanical behaviour of LWA to some extent differs from more conventional granular material, due to the porosity of the grains. Generally the stiffness and strength of compacted LWA is comparable to conventional granular materials provided the stress level is not causing crushing of the grains. The mechanical properties of LWA vary between the different product types and also depend on the installation and compaction of LWA. Generally LWA can be compacted mechanically 10-15% from the loose density without significant crushing of the grains. Characteristic load deformation curves can be prepared based on the results form the project related to type of material and state of compaction. An example of a load deformation curve for Leca ISO 10-20 in loose state, compacted 5% (representative for installation by blowing) and 1012% compaction (full compaction) is presented in Figure 5.2.

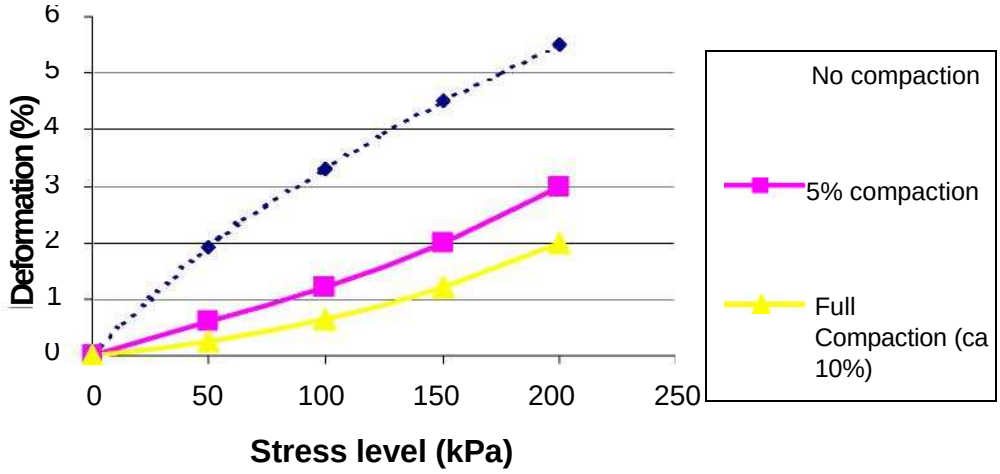


Figure 5.2 Characteristic load deformation curves, Leca ISO 10-20

Some key figures on mechanical properties after compaction related to the different types of LWA are given in Table 5.3.

Table 5.3 LWA-mechanical properties

Type of test	Characteristic	Types of LWA				
		4-32	4-20	8-20	10-20	0-32
Oedometer (compacted material)	Oedometer modulus (MPa)				15-20 (stress level 0-100 kPa)	25 (stress level 0-150 kPa)
Triaxial test (static)	Friction angle (°)	35-37	34-36	34-36	35-38	38-41

5.2 LWA mechanically stabilised

5.2.1 Structural solutions

Mechanically stabilized LWA can be used as light weight fill and as insulation material in roads and railways. The structural solutions should be based on the physical and mechanical properties of the LWA but special care should be taken to ensure that the stress level is not causing unacceptable deformations due to the crushing of the grains. As the grain strength of the LWA-material is lower than for traditional granular materials extra consideration is needed in the design to avoid stress levels that might cause crushing of the grains.

LWA will for normal compaction have a volume reduction of 10-12% and the unit weight will increase accordingly compared to the loose state.

The limiting stress level limit for the use of the LWA-material is yet to be finally determined. Some factors that might influence this decision are the grading and properties of the LWA-material, the traffic volume and the consequences of development of rutting. If no extra measures are taken to reduce the crushing of grains (e.g. geosynthetic reinforcement, extra compaction) it is provisionally recommended keeping the vertical stress below 100 kPa. Higher stresses can be applied but then higher degrees of deformation must be expected. For a road structure with asphalt pavement the stress level is generally acceptable with a thickness of minimum 300 mm overlay above the LWA. If less overlay thickness is required special analyses should be performed on the stress level and possible deformations of the LWA.

When LWA is used it is recommended to have a side cover with conventional granular material. This is to provide lateral support during installation and compaction of the material and to reduce deformation due to traffic loads close to the edge. When LWA is used as light weight fill in an embankment the side cover should be minimum 500 mm thick.

A proposal for a structural layout of LWA used as frost insulation in roads is given in Figure 5.3.

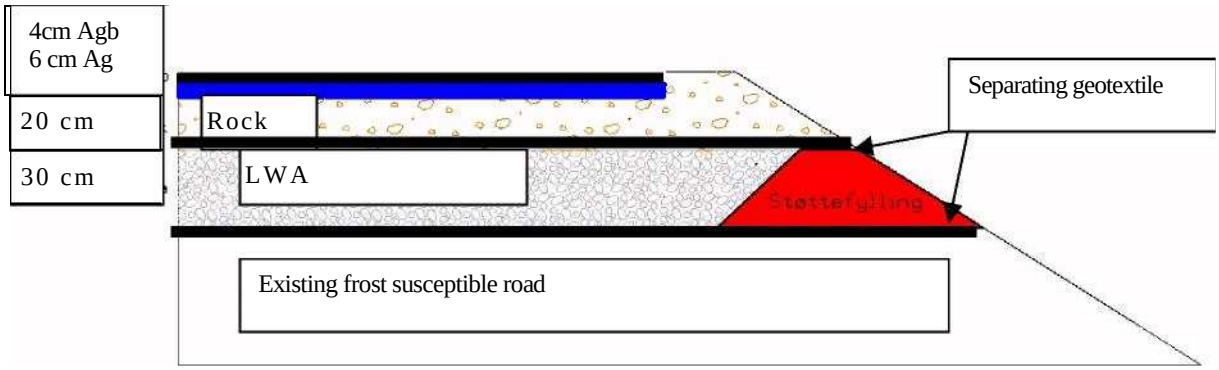


Figure 5.3 LWA as frost insulation in a road structure

5.3 Bearing capacity measurements

Bearing capacity is traditionally evaluated based on results from plate load tests or from falling weight deflectometer (FWD).

The performed tests in LWAgeolight indicate that the use of plate load tests directly on the LWA after installation and compaction has limited value. The LWA material has low density and no cohesion. Accordingly plate load tests directly on top of the material will give relatively low figures compared to more traditional materials. LWA has a relative high angle of friction accordingly the bearing capacity will increase significantly with increasing stress level, e.g. after the installation of a base layer on top of the LWA. The excavation of completed LWA structures indicates that the LWA surface after installation and compaction of the base layer on top of the LWA, is compact and with a high stiffness.

However the performed plate load tests in the LWAgeolight project indicate large variations in the results from plate load tests even when performed on top of the base layer. At Sandmoen plate load tests on top of 300 mm of the crushed rock base layer gives E-modulus, E_2, of 124 MPa just after installation and compaction of the base layer, increasing to about 160 MPa during the excavation after 2 years of traffic. At Tuupakka the plate load tests on top of the base layer vary from about 160 MPa (R4, 50-70 cm base layer) to 100 MPa (R6, 50 cm base layer) and 150 MPA (R6, 70 cm base layer) with considerable variations over the tests sections. There are differences both in the type of LWA material and in the type of base layer material between Sandmoen and Tuupakka but the differences are, even taking these differences into consideration, surprisingly high.

It is generally recommended to perform plate load tests on LWA structures after the installation of a base layer on top of the LWA. The results should however be evaluated very carefully until more experience with plate load tests on these types of structures has been gained.
FWD measurements are generally most relevant when used on top of the asphalt layer. Similar as for plate load tests the FWD measurements performed in the LWAgeolight project indicates significant differences in the results. The measurements at Sandmoen test field indicates bearing

capacity (indicated as bearing capacity in tons) of the LWA-insulated structure similar to a traditional structure with crushed rock. The FWD measurements at Tuupakka (given as E-values) indicate significant lower values for LWA-structures than those from a traditional structure.

It is likely that some of the observed differences between Sandmoen and Tuupaka of the FWD measurements are related to differences in LWA-material, granular material in the base layer and possibly differences in construction procedures. Generally it is recommended that FWD-measurements are performed on top of the asphalt layer but the results should be evaluated carefully and not used as a single indication of the bearing capacity of an LWA-structure.

5.4 LWA in combination with geosynthetic reinforcement

Geosynthetic reinforcement may be used in combination with LWA to improve the stability of the structure and to improve the structural performance. Geosynthetic reinforcement can be used on top of the LWA in road or railway structures to reduce vertical stress implied on the LWA. The geosynthetic reinforcement will provide lateral restrain of the material and hence reduce the deformations related to rutting and edge deformations caused by the traffic.

The results indicate that geosynthetic reinforcement primarily will increase the resistance to plastic deformations (i.e rutting) of the structure while the elastic properties are only marginally affected. The results also indicate that geosynthetic reinforcement on top of the LWA should be of a grid type where the aperture size is correlated with the grain size of the granular material to achieve the optimum effect.

5.5 Light Loadspreading Plate

The LLP method has proven to provide beneficial effects to level out deformations and settlements e.g. in connection with bridge abutments. Different types of light aggregate concrete (LAC) can be used for the LLP. The LAC tested in the project has modulus of elasticity varying from 1200-11000 MPa, and a density varying from 520-1310 kg/m^3. The results from the project verify that dependent on the type of LAC and the layout of the plate the LLP can have a capacity for bending moment varying from about 50-150 kNm/m and a shear force capacity varying from 30 to more than 80 kN/m.

5.6 LWA as drainage material

The initial work has showed that LWA may be beneficially used for drainage applications. LWA may be used as insulation material in drainage ditches in combination with drainage pipes. The high porosity results in high permeability of the LWA material and it may therefore in combination with a geotextile filter also be used as drainage medium. An example of LWA used for drainage application is presented in Figure 5.4.

Figure 5.4 LWA in drainage ditch

5.7 Required characteristics and relevant test methods

The Isolitest part of the project has provided a proposal for a Nordtest method with requirements and related test methods for verification of characteristic properties of LWA. The required characteristics are related to four application areas:
-light weight fill in roads, railways and other traffic structures
-light, insulating and draining material against structures
-insulating material in roads and railways
-frost protection of pipe ditches

The purpose of the testing and corresponding test methods are related to the following groups:
-verification of environmental acceptance
-design purposes
-quality documentation
-production control

The Nordtest method is currently being circulated on national level for comments and is planned used as basis for the preparation of a requirement standard in CEN.

5.8 Surface icing

The aim of the present study of the icing group was to clarify how the location of the LWA insulation in a road embankment affects icing and friction on a road surface. In winter 2000-2001 temperature measurements were performed on a test road at Tuupakka, having insulation at the depths of 350 mm, 500 mm and 700 mm and in Sandmoen (LWA+400mm). The results of the temperature measurements can be summarised as follows:

- comparing the different test structures, differences in the surface temperatures were relatively small - also including the reference structure with no insulation
- lowest average surface temperature in the winter 2000-2001 was measured in the LWA structure with a covering of 350 mm in Tuupakka and LWA+400 mm in Sandmoen, as it was expected
- on the test structures in Tuupakka with covering thickness of 500 mm and 700 mm even higher monthly mean surface temperatures than on the reference structure were measured, which was not expected

- the differences between air and surface temperatures are bigger in Sandmoen than Tuupakka for both reference and LWA-structures

On the basis of the measurements from winter 2000-2001, and the subsequent analyses the layer thickness above LWA insulation could be 500 mm without any substantial change in the thermal regime of the embankment. With a covering layer of 350-400 mm, it seems that surface temperatures are lower and risk of icing is somewhat increased. The differences are however relatively small and the differences between different structural solutions using conventional material may be greater than what is found at the test sites.

The friction measurements did not substantiate this study mainly because salting was used and timing for measuring icing and hoar frost was not very successful at Tuupakka. On the other hand, the friction measurements did not show any lowered friction of the insulated structures. With the analysis of the temperature and friction observations from the winter 2000-2001, hopefully even more convincing conclusions of the risk for icing of LWA-structures may be drawn.

It is recommended that an evaluation of possible surface icing by the use of LWA as insulation materials in roads is performed as a part of the design. The required documentation of surface icing should be related to the total overall icing risk for the structure. A recommendation for level of documentation is provided in Table. The overall icing risk of the structure is divided into 3 classes: low, medium, high and is found as a combination of likelihood of surface icing (climatic data, types of material used in cover layer) and possible consequences of surface icing (traffic amount, traffic speed) .

The required level of documentation is divided into 3 classes:
1: Complete site specific documentation of icing risk based on numerical analyses related to local climatic conditions
2: Icing risk evaluation based on evaluation of structural layout and local experiences
3: No special documentation required

Recommendations for level of documentation related to total icing risk and thickness of cover layer above the LWA insulation material is given in Table 5.4.

Table 5.4 Recommended level of documentation for icing risk

Total icing risk	Thickness of cover layer above LWA (mm)			
	<350	350-500	500-700	>700
Low	2	2	3	3
Medium	1	2	2	3
High	1	1	2	2

6 FURTHER WORK

The LWA Geolight project has provided valuable results related to material characteristics and test methods and to structural solutions for different applications. The project has however also proved that there is a need for further work on some topics. The main topics that have been identified for further work is related to:
-systematisation of product characteristics
-evaluation model for surface icing risk
-back calculation of data from measurements
-methods for field quality control

6.1 Systematisation of product characteristics

A great deal of work has been done to characterise the LWA material in the different countries. However the types of data provided and especially the test methods and procedures are partly different. There is a need for systematisation and updating of the data according to the Isolitest requirements. In general all LWA materials in the Nordic countries should have a documentation of the characteristics according to this proposed Nordtest method.

6.2 Surface icing risk

The results in the project indicate that there is an increased risk for road surface icing if the thickness of the overlay over the LWA becomes too small. The measurements and analyses so far do not provide sufficient background for an evaluation of absolute risk of icing. There is a clear tendency for increased risk of surface icing with modern types of structural solutions compared to older ones. The risk of icing for structures with LWA should be compared with risk of these types of new structural solutions.

There is a clear need for having more data and for supplementary analyses to have a sufficient background for developing a system for icing risk evaluation.

6.3 Back calculations

The LWAgeolight project has provided useful information from field measurements. There is however a need for back calculation of the results to obtain a basis for recommendations for design. These back calculations should be related to on insulation effect, elastic stiffness and bearing capacity.

6.4 Field quality control

LWA has proven to provide a good possibility for developing technical and economical structural solutions for civil engineering applications. The lack of relevant methods for field quality control is however a major obstacle to take the full advantage of the method. Existing field control methods for construction of roads and railways are commonly developed for traditional materials and are often not suitable for LWA, and for that case neither for other types of alternative materials intended for this applications.

As a part of the LWAgeolight project some initial work has been done on this, see /17/, /18/ and/19/. There is however a clear need both for revision of equipment and procedures with existing methods and possibly also for developing new test methods for field quality control.

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