Light Weight Aggregate (LWA) Used in Road Pavements

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ABSTRACT:

Damages due to frost penetration into frost susceptible sub soil are a severe problem in the Nordic countries. Traditionally road construction materials like gravel and crushed rock have very low insulation capacity and quite thick layers are needed to avoid frost penetration. Light weight expanded clay aggregate (LWA) is a promising alternative because of its good insulation properties.

To investigate the mechanical and thermal properties of the LWA – material laboratory and a full-scale instrumented field test were performed. The tests showed that the material behaves approximately as traditional granular materials as long as the stresses are low enough to prevent crushing of grains.

1 INTRODUCTION

1.1 *Technical background*

The Nordic countries have difficult geotechnical conditions with soft and frost susceptible soil combined with severe climatic conditions with frost and rapid temperature variations. Every year frost heave during the winter and spring thawing leads to unevenness and reduced bearing capacity of road pavements with considerable damages and costs. The Swedish Road Administration have estimated their cost to additional maintenance and reconstruction due to this problem to about 25 % of the total maintenance budget (Simonsen & Isacson, 1999). In addition to these costs are the increased transportation costs for road users due to reduced axle loads and delays.

Traditional materials used in pavements have low insulation values, which leads to frost penetration through the entire structure and into the subground. Frost depths of two meters or more are not uncommon in Norway. It is expensive and not always practical to use non-frost susceptible materials in the zone exposed to freezing. Different types of insulation materials in the road pavement have been tried occasionally to reduce the frost penetration. However, material properties, construction difficulties and economical considerations have so far limited the possibilities for a more extensive use.

Light Expanded Clay Aggregate (LWA) has been used for several other civil engineering applications as light- weight fill and frost insulation materials. The LWA material is a granular material and thus easy to install with common construction equipment. In Figure 1 a picture of the LWA material is shown.

1.2 *Description of the research project*

A research and development project called "MiljøIso" was started in 1997. The project aimed at developing environmentally friendly solutions for using the material as light weight fill and frost insulation in roads and other traffic areas.

If the material is to be used as a part of the pavement structure it will be subjected to considerable loads both during construction and the service lifetime. The material has to sustain these loads without being crushed or develop elastic or plastic deformation that would result in damage of the pavement. The physical, mechanical and thermal properties of the material are crucial for the design of the structural solution above the LWA layer and the behaviour of the structure, and therefore had to be verified before LWA material could be taken into common use. The LWA material has been thoroughly investigated in the laboratory. In addition to repeated load triaxial tests and test of compaction properties and particle strength, a full-scale model test was performed in the laboratory. The laboratory tests showed that the LWA material perform close to what has been observed for more traditional materials for pavement construction like crushed rock and gravel. The laboratory tests are reported in three different reports (Skoglund, 1998), (Hoff, 1998) and (Hoff and Øiseth, 1999) (all in Norwegian). A summary report from the laboratory tests (Furuberg 2000) has also been written in English.

Figure 1 LWA - material

2 MATERIAL PROPERTIES FROM LABORATORY TESTS

Materials for pavement structures need to satisfy certain criteria to be able to withstand the loads from heavy traffic under shifting climatic conditions. These criteria are normally specified in design guides and will vary for different countries and regions. For unbound granular materials the requirements are partly based on the performance as a temporarily road for construction traffic. Hence, quite strict requirements are set to strength against crushing and abrasive wear. The LWA material performs extremely poor in test like LA – value or Ball – mill tests. However, if special care is taken during construction these tests are not very relevant and other tests should be considered for the in – service situation after the asphalt layers are placed.

2.1 *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 2. The water content in a drained pavement structure is likely to be in the range of 5 – 15 % (volume). Hence, the relevant thermal conductivity will be about 0.15 W/mK i.e. about $^1/_7$ of typical values for crushed rock.

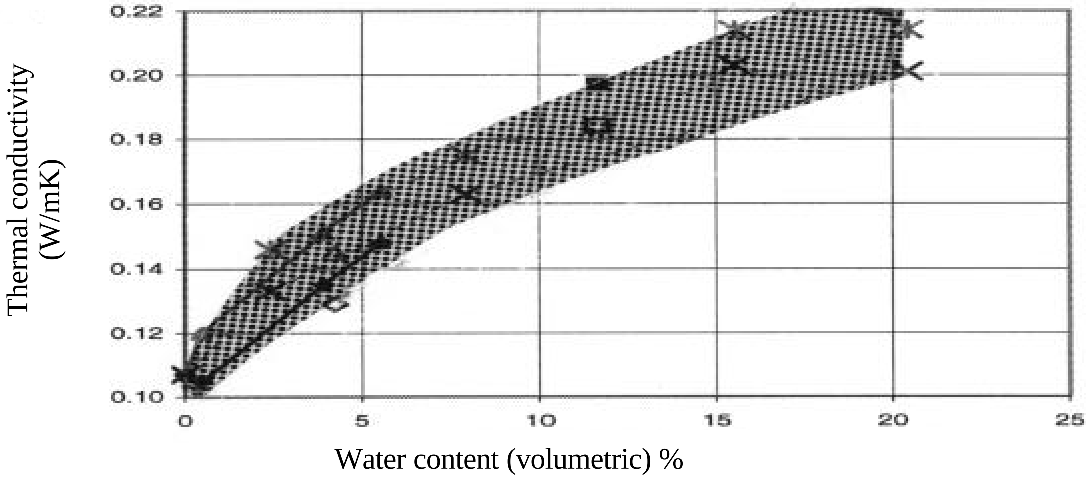

Figure 2 Thermal conductivity for LWA – material as a function of water content

2.2 *Physical properties*

The LWA – material consist of spherical grains of relatively single size. Table 1 show density for different gradings of LWA under different conditions.

Table 1. Some typical material properties for the LWA – material from laboratory tests

Grading	Loose density (kg/m^3)	Density after compaction (kg/m^3)	
		Dry	25 % water content (weight) (≈6 % volume)
LWA 0-32	335	370	460
LWA 4-20	295	330	410
LWA 10-20	280	310	390

2.3 *Mechanical properties*

The grains are quite weak compared to normal rock particles. However, as can be seen from the tests the elastic stiffness and resistance against permanent deformations are quite good as long as the stress levels are low enough to prevent crushing of particles. In Table 2 the stiffness and strength properties from different laboratory tests listed.

Table 2 Results from stiffness testing in laboratory

Test	Parameter	Results
Oedomenter	Modulus	15 – 20 MPa for stress 0 – 100 kPa
Monotonic loading triaxial test	friction angle tanϕ_b	1.02
	characteristic friction angle tanϕ_k	0.85
	attraction a	0
Repeated load triaxial test	Elastic limit angle :	18 ^{o}
	Failure limit angle :	11^o
	Apparent attraction :	100 kPa
	Resilient stiffness:	110 – 210 MPa depending on stress level. (Figure 6)

3 INSTRUMENTED FIELD TESTS

3.1 *Overview*

To test the material in a realistic situation it was decided to build an instrumented test field with real loads from heavy vehicles at Sandmoen, a weight control station close to Trondheim. Dr. ing. student Jostein Aksnes at Norwegian University of Science and Technology (NTNU) has at the same time been studying the stress and strain distribution close to the edge of the road to be able to improve design practice for this part of a pavement structure (Aksnes 2002). The test field was therefore built with four sections whereof two was made using LWA and the two others was build to investigate the edge situation. An overview of the test sections is presented in Figure 3.

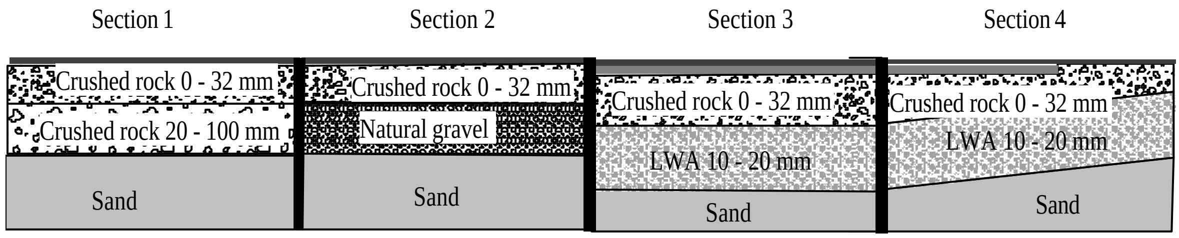

Figure 3 Overview of the different sections at Sandmoen test field.

3.2 *Structures for the LWA sections*

The instrumented section (section 3) was designed approximately as a reasonable design for a Norwegian road with medium traffic density. The structure in section 3 was:

- 100 mm Asphalt Concrete (AC)
- 300 mm crushed rock (0 – 32 mm)
- 400 mm LWA (10 – 20 mm)
- 350 mm sand (single sized)

The intention of the wedge out section (section 4) was to build a structure that would expose the LWA – material to high stress levels and give large deformation and possible failure of the LWA – material. This was intended to give information on minimum required thickness of material covering the LWA –material. The asphalted gravel layer was ended in the middle of the section. At the end of the section the total overlay thickness above the LWA – material is only 20 cm.

3.3 *Instrumentation of section 3*

Section 3 of the test field was instrumented to measure the deformations and stresses in the LWA - material. Temperature sensors and a frost depth indicator were also installed. Table 3 lists the different sensors installed. All of the sensors survived the installation and reasonable results were recorded. One of the deformation sensors for horizontal deformation went out of measuring range the first year. Except for this all sensors was working when the test field was excavated August 2001.

Table 3 Sensors installed in section 3

Measuring property	No of sensors	Location	Sensor type
Vertical stress	6	top, middle and bottom of LWA – layer	GEOCON Earth pressure cell ø = 225 mm h = 7 mm
Longitudinal stress	2	middle of LWA layer	Kulite soil cell type 0234 ø = 55 mm h = 22 mm
Transversal stress	3	middle of LWA layer	Kulite soil cell type 0234 ø = 55 mm h = 22 mm
Vertical deformation	4	from top to bottom of LWA - layer and base layer	LVDT between metal plates
Transversal deformation	2	middle of LWA layer	LVDT between metal plates
Temperature	11	Above and below layer interface	Thermocouple
Frost depth	1	Through the structure	Tube filled with ice indicator fluid.

3.4 *Loading of the test field*

The test field is trafficked by heavy vehicles when the weight control station is operating. A total of approximately 90 000 axles has passed over the test field during the two years of service. For each passing vehicle a data file has been generated with stress and strain measurements. The surface rutting has also been measured regularly. These measurements give valuable information of the long-term behaviour of the structure. However, it is not possible to use these data for analyses because the weight and driving path of these trucks are not systematically registered.

In addition to this occasional traffic special load tests have been carried out:

- Heavy vehicles with known axle load, tire pressure and driving paths.
- Falling Weight Deflectometer (results are presented only in technical reports)
- Plate loading tests

3.4.1 *Controlled loading with heavy vehicles*

To be able to analyse the stress and deformation distribution it is necessary to have good control of the applied loads. This was done by simply weighing the vehicle at the nearby weight control station, measuring the tire pressure and visually inspect the wheel path relative to target lines that were painted on the test field. After some training the driver was able to hit the target lines with very good accuracy.

Figure 4 show results from one passing of a truck directly over the sensors. This truck was overloaded according to Norwegian regulation (100 kN axle load) and gave quite high stress levels on top of the LWA layer.

The stress and strains measurements will be analysed further and used for calibration of a finite element model of the structure. Such a model will be a very helpful tool when a design procedure for this type of materials is going to be developed.

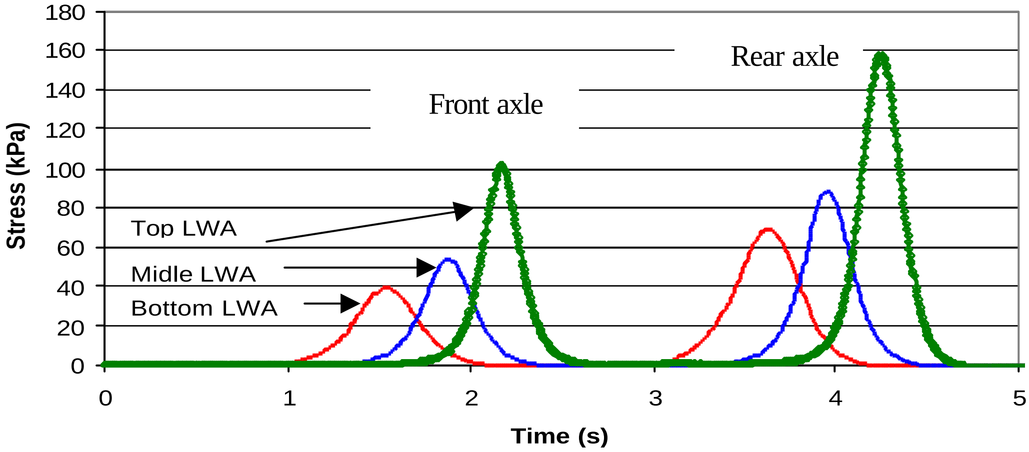

Figure 12 Sample of vertical stress measurements of a passing truck (front/rear axle 63/ 123 kN, 750 kPa)

3.4.2 *Plate loading tests*

When the test field was excavated plate loading tests were performed on all layers. During construction plate load 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 and it is very difficult to place a truck to take the reaction forces from the plate loading test. During excavation of the test field the LWA had a very stabile structure and with some load spreading plates under the wheels we managed to move a truck directly on the LWA material and perform the test.

Figure 5 shows E1, E2 and E2/E1 values for plate loading tests on different levels. Average values are summarised in table 4. The E2 values for the LWA material is surprisingly high considered the lack of stabilising material on top of the material.

Table 4 Results from plate loading tests

Plate loading test	E1	E2	E1/E2
On crushed rock (first construction)	64	182	2.86
On asphalt	104	234	2.25
On crushed rock (excavation)	129	240	1.86
On LWA (excavation)	43	139	3.6

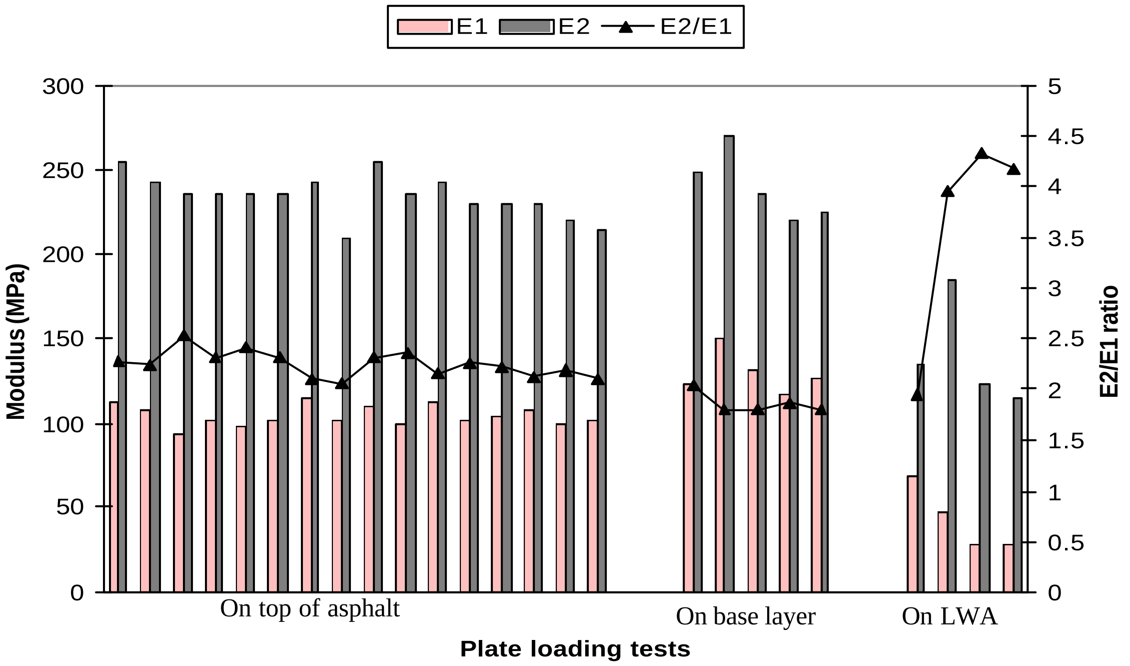

Figure 5 results from plate loading tests under excavation

3.5 *development of surface rutting*

Figure 6 shows final rutting of section 3 and 4 just before excavation. 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 where a total of 80 mm of rutting accumulated after two years of service. The cause for this deformation is not obvious, but it is believed that the major part is due to particle rearrangement rather than crushing of grains.

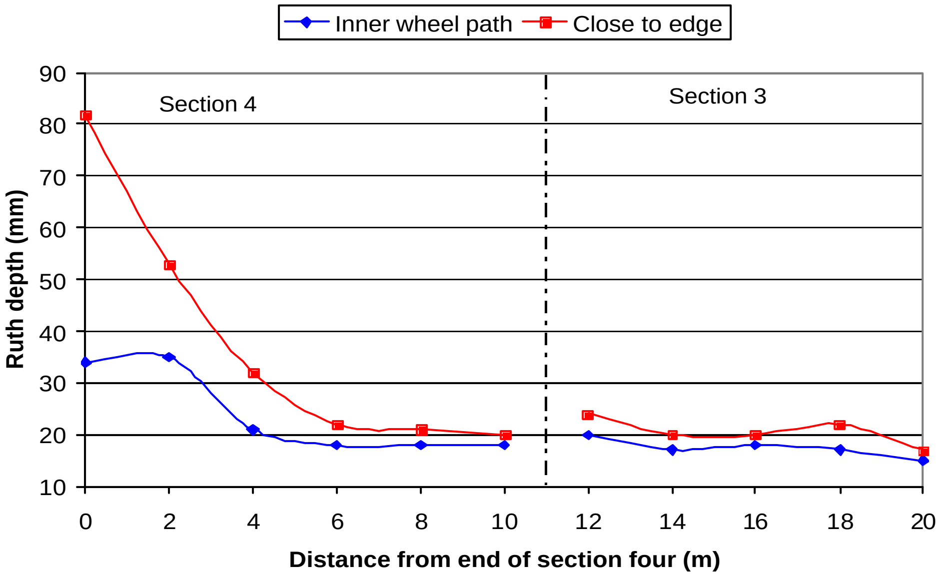

Figure 6. Final rutting measured manually with a 3 m straight beam

3.5.1 *Temperature measurements*

Figure 7 shows air temperature and temperature below the LWA layer for the winter 99/00. The temperature is always above freezing temperature in the sand layer below the insulating layer. The temperature measurements correspond well to the frost depth measurements.

For design of insulated pavements it is necessary to perform a thermal analysis based on the local climate, materials used and consequences of freeze-through.

Formation of hoarfrost on the surface of roads is dangerous because it can be very local and surprise the driver. It has been reported that insulated roads form hoarfrost under different conditions than roads with traditional materials. This tendency is increasing as the insulation is placed closer to the surface. When using LWA as frost insulation in roads this has to be taken into account and a research project on this problem is ongoing.

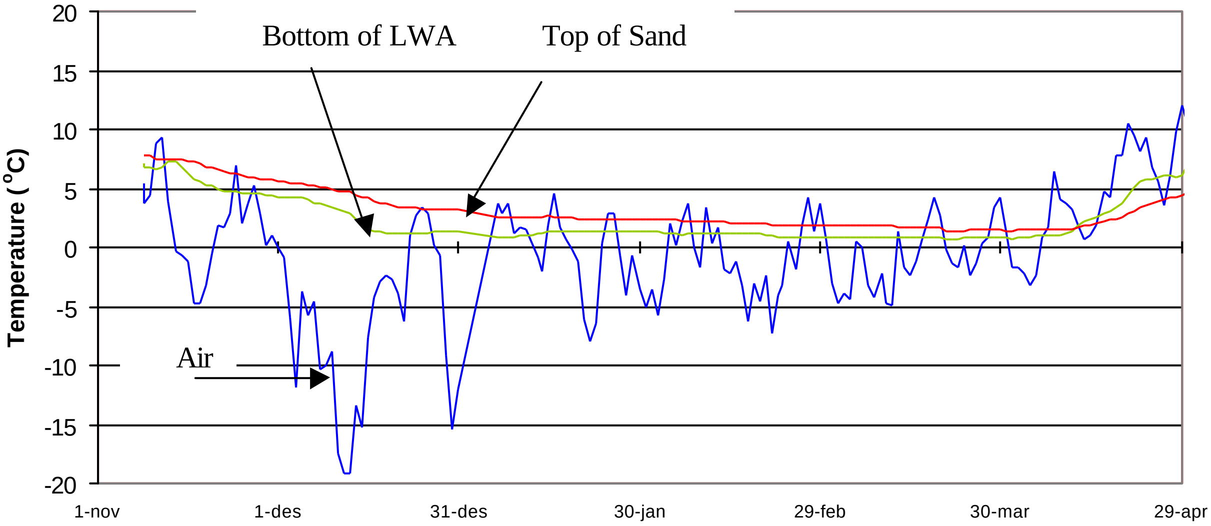

Figure 6 Registered temperatures (daily mean) at different levels in the LWA –section for the winter 99/00

4 DESIGN OF PAVEMENTS WITH LWA

In many countries the design procedure is based on empirical rules and no methods for design of pavements that does not comply with the requirements set to materials. This complicates the introduction of alternative materials and all the responsibility is here given to the design engineer.

LWA is different from traditional granular materials and special care has to be taken to secure a reliable structure. These problems have to be considered with extra care for structures including LWA:

- Stress level in the LWA – material
- Surface icing
- Construction phase
- Risk for freezing through the LWA – layer

Design guidelines and structural solutions for LWA – material as insulation in roads are under development but is not completed yet, but is essential if this type of materials should be taken into common use. Some preliminary recommendations are given in this paper.

4.1 *Stress levels*

As the grain strength of the LWA – material is much lower than for traditional granular materials extra consideration is needed in the design to avoid too high stresses that might cause crushing of the grains.

For a 100 kN axle load on the instrumented section at Sandmoen (10 cm asphalt 30 cm crushed rock) the stress at the top of the LWA is approximately 100 kPa. For the weak end of the wedge-out section the stress levels is calculated to approximately 250 kPa. The last value seems to be too high and unacceptable damages are observed.

The stress level limit for the use of the LWA material is yet to be determined. Some factors might influence on this decision is the grading and properties of the LWA material, traffic volume and consequences of development of rutting. Provisionally we recommend keeping the vertical stress below 100 kPa.

4.2 *Surface icing*

Under special climatic conditions it is observed differences in formation of surface hoarfrost between insulated and traditional pavements. Calculations show that this effect is stronger the closer the insulation is placed to the surface. How, much material that should be placed above the insulating layer has to be considered depending on the local climate and thermal characteristics of all the materials used in the structure. Experience so far indicates that more that 40 cm of material on top of the LWA gives relatively small changes in icing risk.

4.3 *Construction phase*

LWA materials can be placed by normal construction equipment. However, it is not possible to drive directly on a LWA layer with a vehicle on wheels. The construction work should be organised in a way that minimises stress applications to the LWA layer. The stress situation in the LWA – layer should be analysed for all stages of the construction work.

4.4 *Thermal optimisation*

How thick layers of LWA that should be used as frost protection has to be considered depending on the local climate and consequences of freeze-through. Several computer programs for this purpose exist and could be used for this part of the design. It has also been developed design charts for this purpose.

5 CONCLUSIONS AND RECOMMENDATIONS

The laboratory tests performed in this project showed that the resilient stiffness and the resistance against permanent deformations for the LWA material is almost as what has been measured for traditional materials as long as the stress levels are low enough to avoid crushing of the particles.

From the two sections of the test field at Sandmoen we have observed severe damages at the weak end of the wedge-out section and acceptable performance on the instrumented section. This gives information of how large stress levels the LWA material should 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 analyses 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 a high volume road, it should be considered to increase the thickness somewhat to reduce the risk for abrasive wearing of the grains.

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