FOAMED GLASS – AN ALTERNATIVE LIGHTWEIGHT AND INSULATING MATERIAL

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ABSTRACT. Granulated foamed glass (cellular glass) is produced by recirculating waste glass. A research project lead by the Norwegian Public Road Administration (NPRA) is presently investigating the possible use of this lightweight material for road construction applications. Foamglass is produced using an environ-mentally friendly recycling technology for contaminated and toxic material. The normal grain size is in the range 10 – 60 mm. When placed and compacted in a drained fill the unit density of the lightest version will be 300 – 350 kg/m^3 depending on the compaction machinery and compaction efforts. With its insulating properties and light weight the material may be used as a lightweight fill material, as frost protection layer/thermal insulation in roads or other civil engineering applications. NPRA has initiated a programme in order to promote the use of recycled material in road structures where a monitoring programme is one of several activities. This paper presents results from the monitoring programme on 6 recent road projects and results from performed laboratory tests. It also gives recommendations regarding design criteria and construction procedures related to foamglass granulate.

Keywords: Waste materials, Lightweight fill, Foamglass, Cellular glass, Field monitoring.

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INTRODUCTION

The Norwegian Public Roads Administration (NPRA) has a long tradition in applying various types of lightweight fill materials for road construction applications. During the last 50 years wooden materials like sawdust and bark residue from the timber industry have been applied for such purposes. Also LWA (Light Weight Clay Aggregate) and waste material from the production of cellular concrete blocks have been widely used. Since 1972 blocks of Expanded Polystyrene have been used extensively in road projects for a variety of applications also including blocks produced from re-circulated EPS material. In this connection monitoring programmes have been initiated in order to investigate the long term performance of these materials.

Presently a new option is being investigated involving the use of granulated foamed glass produced by re-circulating waste glass. The foamglass has a maximum grain size of about 60 mm with angular edges and the material may be produced in various densities. When placed and compacted in a drained fill the unit density of the lightest version will be some 300 – 350 kg/m^3 depending on the compaction machinery and compaction efforts. On recent road projects deformations and possible variations in moisture content, unit density and grain size distribution have been monitored. The application of foamed glass in road construction is part of a larger programme in order to enhance the use of re-cycled material in road construction in general.

Norwegian Roads Recycled Materials Programme

Ambitious environmental politics, international treaties and agreements, and a general change of attitude and awareness considering generating and handling waste has encouraged the development of national policies, codes, routines and contract clauses that motivate more extensive use of recycled materials. NPRA has in this connection initiated a programme in order to promote the use of recycled material in road structures. The programme is aiming at incorporating secondary materials in the national design guidelines and standards of Norway. One aim of the programme is to enhance the reuse of foamglass, whole or shredded car tyres, EPS, slag/ash and broken glass as lightweight fill materials. For NPRA it is important to define quality specifications for these materials including environmental considerations and incorporate these in the general design specifications. In addition to physical and mechanical properties the environmental issues and concerns need to be addressed during the entire life cycle from the design phase through maintenance and to demolition.

FOAMGLASS

Concept

The amount of glass products used in the western hemisphere is huge. This comprises various sorts of glass waste originating from light bulbs and other lighting fixtures like mercury lamps, bottles, windowpanes, car windshields etc. and industrial waste. In Europe the average annual glass consumption is about 30 – 40 kg/per inhabitant. At the same time as being a waste product it also constitutes a raw material for possible reuse. Some of the glass waste may be used directly in the production of bottles and other products but some of the glass waste also contains toxic materials that need to be removed in the recycling process.

In this connection a production process has been initiated based on the recycling of waste glass in the middle region of Norway. A patented process originating in Switzerland (Misapor) is used in Norway under the trade name of Hasopor. The cost of foamglass delivered on site in Norway is at present approx. $ 35 - 40 per m^3. In Norway about 4 million mercury lamps are used every year and the aim is to recycle about 40 % amounting to an annual production of some 50 000 m^3 of foamglass. In the production process lighting fixtures and other toxic glass waste is treated in order to remove heavy metal components and other environmentally difficult matter. The product has now been used as a lightweight filling material on about 25 road projects in Norway and NPRA has initiated a monitoring program in order to evaluate the material properties and the structural performance. A similar product has been produced in Switzerland for some time and it is also reported to have been used in road structures. Regarding material quality and behaviour in this connection only sparse information has been obtained.

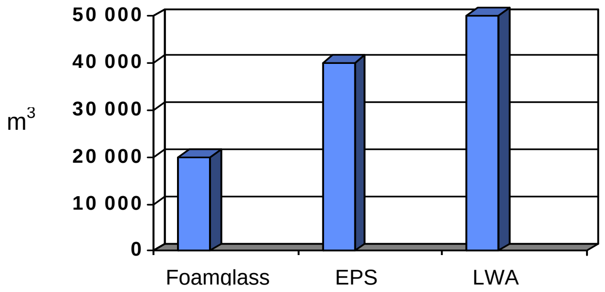

Figure 1 – Annual use of lightweight fill materials for roads in Norway

Figure 2 – Typical foamglass particle

Production Process

Foamglass is produced using an environmentally friendly recycling technology for contaminated and toxic waste ranging from mercury lamps, industrial slag and flyash, PC- and TV-tubes, and laminated glass to batteries. The process is based on the concept of transforming finely ground glass powder from different glass sources mixed with an activator like silica carbide into glass foam. In the grinding process heavy metals are separated out and recycled to metal melting plants.

The powder is spread on a steel belt conveyor running through high temperature ovens whereby the powder expands about 4 times, to leave the oven as a glass foam material. When the product leaves the oven it will crack and separate into smaller units due to the temperature shock. Normal grain size will be in the range of 10 – 60 mm (Figure 2).

The production process is free of dust and any harmful gases and does not need water at any stage.

The principles behind this system are very simple: To separate and to clean the waste in fractions for further treatment down the process line. During this process the toxic components are reduced below the detecting limits. In this connection a certificate has been obtained for the material confirming that possible leaching products from a fill will have toxic contents well below normal environmental requirements.

Foamglass generally consists of 8 per cent of glass by volume and 92 per cent gas bobbles. A thin impervious glass wall encloses each bobble.

Material Properties

Material qualities listed by the producer is as follows:

- Low unit bulk density, the product is delivered in two qualities: (Light) 180 kg/m^3 and (standard) 225 kg/m^3.
- High thermal insulation qualities
- High material strength, 60 – 120 kN/m^2
- Low moisture absorption
- Chemically and thermally stable
- The natural slope angel for uncompacted foamglass seems to be 45°.

With its light weight and good drainage and insulating properties the material may both be used as a lightweight fill material and/or frost insulating layer. A continuous work to improve the material since the start of production in 1999 has resulted in a material that has a different pore structure, density and strength today with improved structural performance compared to the original product.
In order to investigate physical and mechanical properties various monitoring programmes have been initiated both for field and laboratory testing.


Figure 3. – Installing steel tube

On 6 of the existing foamglass fills a thin walled steel tube (with typical diameter 400-570 mm) was pressed / vibrated into the foamglass (Figure 3). The particles contained within the steel tube were removed and the excavated material weighed wet and dry. The test sites will be monitored with more tests over time in order to observe changes in deformations, water content and density.

Data relating to water content and densities measured in the field by the NPRA are shown in Table 1.

Table 1 – Field tests on foamglass material placed in road structures.

Road project	Mat. type	Year	Field test	Volume m^3	Water cont. % (by weight)	Density kg/m^3	Fines < 8 mm (%)
Lodalen	Light	2001	2001	1500	3 -18	325	
Rv 120	Light	2001	2001	2900		500 [1)]	15 - 65
E 6 Mule	Light	2002	2002	550		295	25 - 35
E6 Eggemarka	Std.	2002	2003 2004	1000	15 – 20 ?	345 384 [2)]	20 7-14
Postterminalen	Std	2000	2000	2750			30
E6 Rosendal	Std	1999	2002	310	18	530 [3)]	30
E 6 Klemetsrud	Light	2003	2003	1100	0,5	271	5 - 20

[1)] Average density based on delivered material and theoretical installed volume is about 300 kg/m^3.
[2)] Average density for 2 tests in the upper layer based on measured dry density and assumed water content 15 %.
[3)] Average density based on delivered material and theoretical installed volume is about 350 kg/m^3.

Water Absorption

Laboratory water absorption tests have been performed by the Norwegian Building Research Institute (NBI). The result is shown in table 2. As can be seen the revised production procedures have improved the material properties from year 2000 to 2003.

Table 2 – Laboratory tests performed on submerged foamglass

Material type	Water absorption (**2000**) % by weight after 22 weeks	Water absorption (**2003**) % by weight after 50 weeks
Light	76	48
Standard	103	45

Strength and deformation properties
The material have been tested at SINTEF in a large cyclic loading triaxial apparatus with diameter 300 mm to find the resistance to develop permanent deformation when exposed to repeated loading. The results are relevant for designing road applications where the material is used in the road structure as part of the base layer or the sub-base layer. For use in road structures the material has elastic properties comparable to ordinary gravel commonly used as a roadbase material. It is, however, important that the stress level is kept below a level that will result in crushing and permanent material deformations. For repeated loading applications the cyclic stress is recommended limited to 75 kPa to reduce the permanent deformations.
A large oedometer with diameter 500 mm is used to measure deformations in the material when exposed to permanent loading. The results are relevant for foundation application (concrete base plate etc.), see Table 3. During the spring 2004 the test programme is expanded to include long term creep tests to find characteristic values for possible long term deformation. The typical use until now has been up to approximately 100 kN/m^2 base pressure and the experience show no damaging long term deformations for any projects. The long term creep tests will make it possible to estimate the long term deformation for different loading conditions. The already performed oedometer tests are used to estimate the amount of long term creep assuming a linear time resistance development. Results are shown in Table 4. However, long term creep test have to be performed to verify these estimates.

Table 3 Deformation/settlements (short term/day 1) in foam glass material (Hasopor)

Quality and compaction level \ Stress level	50 kN/m^2	100 kN/m^2	300 kN/m^2
Light 1.25	1 %	4 %	> 15 %
Light 1.34	0.25 %	1.3 %	> 11 %
Standard 1.24	0.3 %	1.1 %	> 10.5 %

Table 4 Estimated creep deformations after day 1 at stress level* 300 kN/m^2 permanent load

Compaction level	1 year	5 years	25 years	100 years
1.25	2.9 %	3.8 %	4.6 %	5.3 %
1.34	2.0 %	2.6%	3.1 %	3.5 %

*Below stress level 75 kN/m^2 creep deformations are assumed negligible.

During the summer 2004 material exposed to freezing thawing cycles will be tested in the oedometer to ensure that the material retain its characteristics on a long term basis.

Thermal Conductivity
The material is very suitable as thermal insulation and frost protection in both building and road application. The insulating properties have been tested in laboratory and for dry, compacted material a thermal conductivity of 0.11 W/mK at +10 ºC has been found. New tests on wet and frozen material are currently being performed. The results will, together with field experiences, be used to develop a design chart for use as road insulation. Foamglass is in the revised general design specifications evaluated as similar to LWA and the same design chart is used for designing the frost insulation layer. The design of foamglass used as a frost insulation in a road structure has, in addition to the thermal properties, also to take into account the mechanical properties of the material to avoid crushing and shear deformations due to the traffic load. Also the possibility for risk of surface icing has to be evaluated. It is recommended that the pavement structure above the foamglass should be as for a pavement

structure on a chrushed rock fill. Figure 4 shows a typical pavement structure insulated with foamglass.

Asphalt pavement, 2 layers
Base layer: 10-12 cm Asphalt stabilised
Sub base layer: 20-40 cm Chrushed rock
Frost protection: 15-50 cm Faomglass

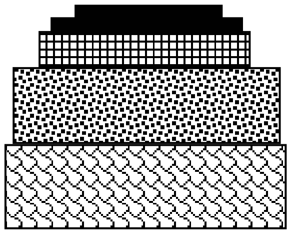

Figure 4 Typical frost protected pavement structure

Density
Foamglass is an alternative to other lightweight fill materials like LWA and EPS. Tests performed so far indicate that unit densities after compaction in the range of 300 – 350 kg/ may be expected. NPRA recommends using a design unit weight in the structure of 3.5 kN/m^3 (light type) and 4 kN/m^3 (standard type). The compaction factor is defined as the actual volume placed in a fill divided by the theoretical volume and is normally recommended in the range 1.2 to 1.3. The relatively higher measured densities in some projects indicate that the material density varies in the fill based on the construction conditions. Design unit densities probably should be linked both to the type of material delivered on site and on construction equipment and procedures.

Deformations
After being placed in the fill and compacted relatively small further deformations is expected from road pavement and live loads. Deformations of about 1-2 % of the layer thickness are measured in the projects so far, but it should be noted that the measurements have only been lasting for a relatively short time period. Observations over time (3 years) indicate that further crushing and deformations tend to be negligible. Two temporary foamglass fills will be excavated and moved to another location for reuse in 2004 and this is expected to give some more information of the structural behaviour.
Due to the angular shape of the foamglass particles the fill may be placed with rather steep side slopes. However the measured deformations from the traffic load indicate significantly higher deformations close to the edge of the fill, most likely due to lack of lateral restrain of the material.

Table 5 – Observed deformations in fills

Site	Max height of fill in m	Com-paction factor %	Layer thickness for compaction	Deforma-tions, % short term	Deforma-tions, % long term	Deforma-tions on slopes %
Lodalen	2	1.25	2 m	0.5 – 1	+0.5	4
Rv 120	3	1.60	1 m	1	+ 0 – 0.5	2 – 3
E 6 Mule	3	1.25				
E6 Eggemarka	4		1-1.5 m	1	+ 0.5	2
E6 Rosendal	2.5	1.40	0.5 m			
E6 Klemetsrud	3	1.20	Up to 4 m	0.5	+0.5	

Environmental Properties
Reuse of waste material for filling purposes requires a certification that the material is inert and does not have an environmental impact. For this purpose a series of specifications and guidelines from the Norwegian Pollution Control Authority (SFT) must be considered related to the project in question. A material may be defined as inert provided it does not undergo

any appreciable physical, chemical or biological change and any leaching fluid must only contain insignificant amounts of polluting substances.
The composition of the material (a waste material or a product based on a waste material), its leaching effects, environmental properties and the long term behaviour in a deposit must therefore be known before it is deposited. In this connection a technical description of foamglass is prepared by the NBI for the manufacturer of Hasopor. For this purpose a Common Understanding Assessment Procedure is used to make an ETA approval for Hasopor as a non standardised material.

EXAMPLES WHERE FAOMGLASS IS USE IN ROAD PROJECTS

E6 Steinkjer, Eggemarka Cut and Cover Tunnel

A cut and cover concrete tunnel of about 600 m length was constructed as a part of the the relocation of the main highway E6. In order to keep the traffic running during the construction period a temporary diversion road with an embankment height of more than 15 m is constructed above the concrete tunnel. The upper 6 m of the embankment consisted of lightweight fill materials to reduce the weight on the culvert and to improve stability and reduce settlement problems. Both LWA (9000 m^3) and foamglass (Hasopor 1000 m^3) are used. The diversion road was in service for one year until March 2004. The lightweight fill materials are reused as backfill against bridge abutments and in other parts of the road.

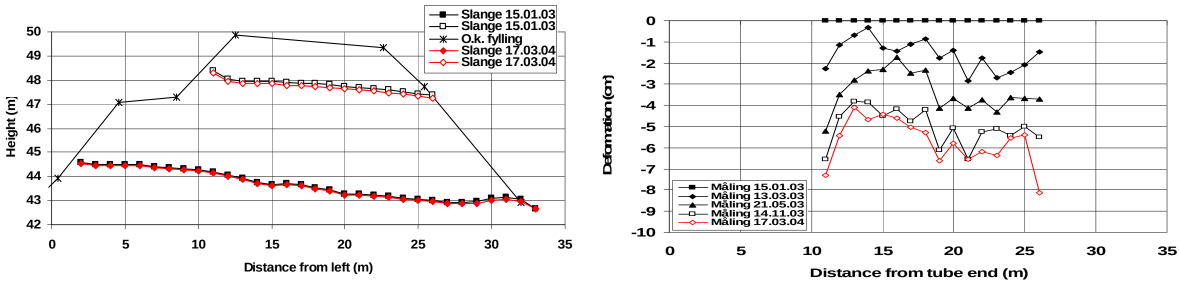

Figure 6 – Observed deformations at Eggemarka

Placing and compaction was performed in 1 to 1.5 metre thick layers using crawler mounted dozers with track loads ≤ 40 kN/m^2 performing some 3 passes over the area per layer. A volume reduction of 25 % was observed. Another 5 % reduction in volume was anticipated due to transport on site from local storage areas. No covering soils were placed on the foamglass slopes on the temporary fill. Density and water content measurements were performed throughout the construction period both on loose material delivered on site and on compacted material in the fill. Average figures from these tests are given in Table 1. Sieving tests were performed on all test samples collected for density measurements. Plate bearing tests and falling weight measurements (FWD) were also performed. So far there seems to be small differences between the rockfill and the light weight material. Settlements are monitored using settlement tubes, one tube on the top and one at the bottom the lightweight filling layer for each material. Observed deformations are shown in Figure 6.

E 6 Klemetsrud

A short temporary diversion road is needed for a period of about half a year. On this section foamglass has been used with a layer thickness of up to 4 metres in order to reduce the load and resulting settlements on a water main. The material will be reused in connection with a ramp at one of the intersections with soft ground conditions. The foamglass has been subjected to light compaction activities with a belt pressure of 45 kN/m^2 in order to reduce particle crushing. The calculated compaction factor is low (1.2). Possible deformations of the road surface and at the top of the foamglass layer will be monitored in order to evaluate the structural behaviour with this light compaction. So far the observed deformations at the top of the foamglass layer do not deviate from deformations registered in other foamglass projects. Sieving tests and density measurements were performed when the fill was placed and similar tests will be performed when the material is moved to its future location. Settlements are monitored using settlement tubes. Observed deformations are shown in Figure 7.

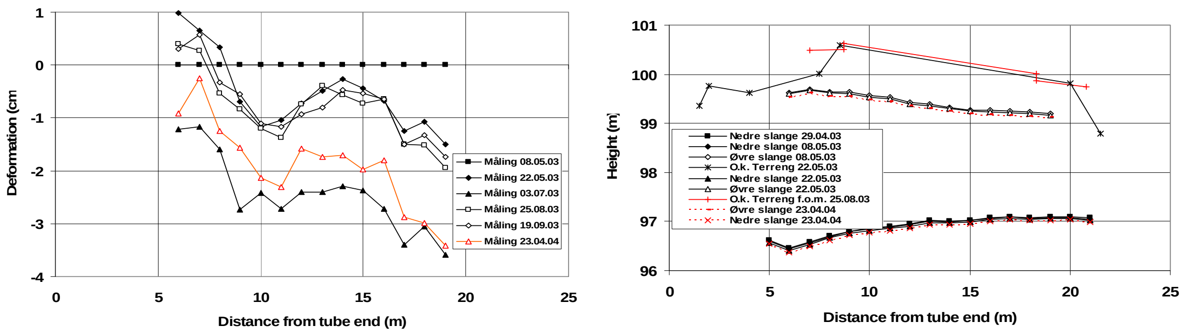

Figure 7 Observed deformations at Klemetsrud

CONCLUSIONS

The material is believed to be an interesting alternative as lightweight fill material and thermal insulation for a number of civil engineering applications. Foamglass granulate has light weight and good insulating and drainage properties. The design densities for foamglass are by NPRA set to be 3.5 kN/m^3 for the light quality and 4.0 kN/m^3 for the standard quality. Foamglass may be used as light weight fill in embankments to improve stability and/or reduce settlements and as frost insulation layer. The material is believed to be fully resistant to possible chemical degrading agents in a road structure. The mechanical strength of the light quality material may require some special handling in order to prevent excessive crushing. Observations so far indicate that fairly light machinery should be used on site for placement, distribution and compaction. In this connection specifications for construction procedures may have to be revised.

ACKNOWLEDGEMENTS

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REFERENCES

1. Aabøe Roald, 1980, “Lette fyllmasser I vegbygging” (lightweight filling materials in road construction – text in Norwegian), Intern rapport 954, Norwegian Road Research Laboratory, Oslo
2. Aabøe Roald et. al., 1995, ”Vegbygging på bløt grunn” (Road construction on soft subsoils – text in Norwegian), Handbook 188 (Code of practice), Norwegian Public Roads Administration, Oslo
3. 2003, Vegbygging (Road Construction – text in Norwegian), Handbook 018 (Standard Specifications), Norwegian Public Roads Administration, Oslo
4. Frydenlund Tor Erik & Aabøe Roald, “Use of waste materials for lightweight fills”, International Workshop on Lightweight Geomaterials, Tokyo Japan March 2002.
5. Bakløkk L. et. al., 2001, "Hasopor skumglass" (text in Norwegian) SINTEF report STF22-F01322.