Granulated Foamed Glass for Civil Engineering Applications

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ABSTRACT: Granulated foamed glass (10-60 mm) produced by recirculating waste glass, is being investigated as a material for road construction purposes. With its insulating properties and light weight (350 – 400 kg/m^3 design density), the material may both be used as a light weight filling material and frost protection layer/thermal insulation in roads or also for other civil engineering applications. Foamglass LWA (lightweight aggregate) is an industrial produced product, using an environmentally friendly recycling technology for contaminated and toxic material.

KEY WORDS: Recycled materials, lightweight fill, foamglass, cellular glass, field monitoring

1 NORWEGIAN ROADS RECYCLED MATERIALS R&D PROGRAM

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. The Norwegian Public Roads Administration (NPRA) has initiated a programme in order to promote the use of recycled material in road structures. This includes incorporating secondary materials in the design guidelines and standards. Environmental issues and concerns need to be addressed during the entire life cycle from the design phase through maintenance to demolition. NPRA has a long tradition in applying various types of lightweight filling materials for road construction purposes such as, sawdust and bark residue, waste material from the production of cellular concrete blocks, Light Weight Clay Aggregate and blocks of Expanded Polystyrene for a variety of applications also including blocks produced from recirculated EPS material.

2 PRODUCTION OF FOAMGLASS

Presently a new option is being investigated involving the use of granulated foamed glass produced by recirculating waste glass. In Europe vast heaps of glass products are accumulating. At the same time as being a waste product it also constitutes a raw material for possible reuse. Foamglass LWA is produced in a 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 and recycled to metal melting plants. The powder is spread on a steel belt conveyor running through high temperature ovens whereby the powder expands, to leave the oven as a glass foam material. When the product leaves the oven it will crack and separate into smaller fragments due to the temperature shock.

Figure 1: Typical foamglass particle

The Miljøtek HASOPOR AS plant in Meråker, Norway, processes 7 million tubes and lamps per year, along with 8,000 tonnes of waste glass, to produce 45,000 m^3 of foamglass aggregate. With a typical loose bulk density is in the range of approximately 180 - 250 kg/m^3 and the normal grain size is in the range of 10-60 mm (nominal sizes d/D), see Figure 1. Transportation could be done with large trucks as shown in Figure 5.

3 MONITORING PROGRAMME

With its favourable drainage and insulating properties and light weight the material may both be used as a light weight filling material and/or frost insulating layer, see Figures 2 and 3, respectively. Monitoring programmes have been initiated in order to investigate the long term performance of foamglass LWA. Data relating to water content and densities measured in the field by the Public Roads Administration are shown in Table 1. The test sites will be monitored with more tests over time in order to observe changes in deformations, water content and density.

Table1: 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

Figure 2: Foamglass used as insulation material

Figure 3: Road E6 at Klemetsrud. Foamglass as light weight material

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 if the foamglass LWA fill is used as general access road or not. After being placed in the fill and compacted, only small further deformations may be expected from road pavement and live loads, in the short term about 1-2 % of the layer thickness. Observations over time (3 years) indicate that further crushing and deformations tend to be negligible or up to 1.5 %.

Table 2: Observed deformations in fills

Site	**Max height of fill in m**	**Com-paction factor %**	**Deforma-tions, % short term**	**Deforma-tions, % long term**	**Deforma-tions on slopes %**	**Layer thickness for compaction**
Lodalen	2	1.25	1.5 – 2. 5	+ 0.5 – 1.0	4	2 m
Rv 120	3	1.60	1	+ 0 – 0.5	2 - 3	1 m
E 6 Mule	3	1.25				
E6 Eggemarka	4		1	+ 1.5	2-3	1-1.5 m
E6 Rosendal	2.5	1.40				0.5 m
E6 Klemetsrud	3	1.20	1			Up to 4 m

The material has been tested in a large cyclic loading triaxial apparatus to find the resistance to develop permanent deformation when exposed to repeated loading. For repeated loading applications the cyclic stress is recommended to be limited to 75 kPa. For use in road structures the material has elastic properties comparable to ordinary gravel commonly used as a roadbase material.

The freeze-thaw resistance for HASOPOR foamglass is tested based on the European standard EN 12091. Before testing, the material was submerged in water for 4 weeks and during the test exposed to 300 cycles of freezing and thawing. After the freeze-thaw test both wet and dried material were tested in a giant oedometer and the results showed no reduction in compressive stiffness compared with earlier performed tests on virgin material. There were also no visual cracks or disintegrations on the material.

Long term creep tests are performed in a large oedometer with diameter 500 mm for loads up to 250 kPa. The creep deformation, defined as the deformation that will occur after day one, is interpreted to be less than 0.6 % during the next 50 years for a stress level of 250 kPa, see Figure 4.

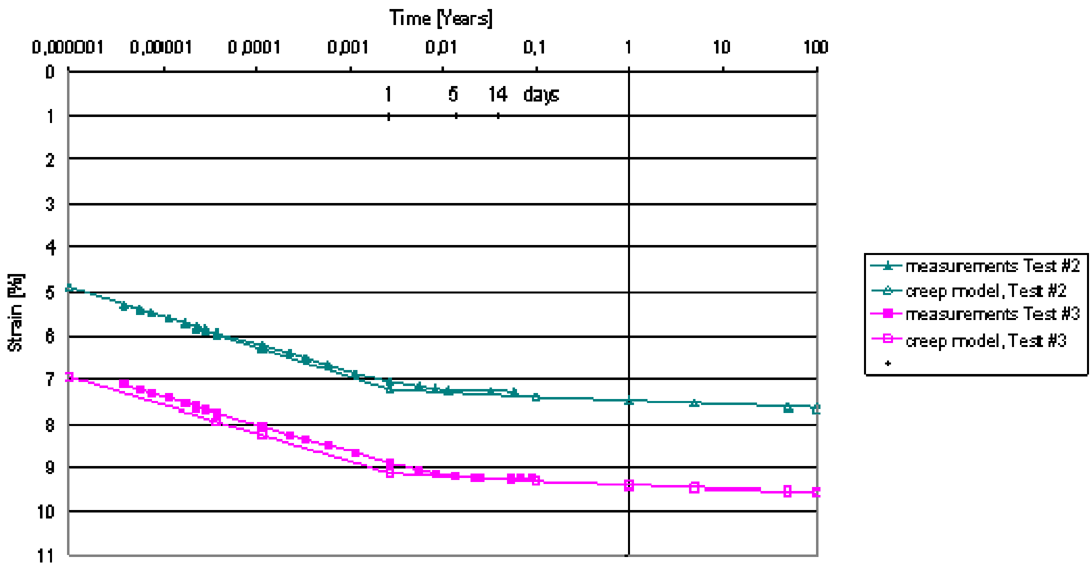

Figure 4: Measured and interpreted creep strains at stress level 250 kPa

Figure 5: Transportation of foamglass LWA

The material is suitable as thermal insulation and frost protection in both building and road application. The insulating properties have been tested in the laboratory. Dry, compacted material has a thermal conductivity as low as 0,10 W/mK at +10 ºC. The latest tests also include tests on wet and frozen material. The results will, together with field experiences, be used to develop a design chart for use as a road insulation material.

From a geotechnical point of view the design unit density is most critical in the competition with other light weight filling materials like LWA (550 kg/m^3) and EPS (50/100 kg/m^3). Tests conducted so far have led to implementation of Hasopor foamglass in the NPRA design manuals with a design unit density of 350 kg/m^3 for the light type of Hasopor. Construction procedures and type of equipment for compaction have been linked to various applications of the material. The requirements and execution concerning compaction are specified in NPRA design manual 018 Vegbygging and in the Norwegian standard, NS 3458.

Figure 6: Foamglass LWA used as a lightweight fill material, building in Trondheim

After being placed in the fill and compacted, only small further deformations may be expected from the road pavement and live loads, in the short term about 1-2 % of the layer thickness. Observations over time (3 years) indicate that further crushing and deformations tend to be negligible (<1 %).

The Norwegian Building Research Institute is preparing a European Technical Approval [ETA] in 2005 for Hasopor based on a Common Understanding Assessment Procedure (CUAP).

The initial type-testing of the product is conducted by Norwegian Building Research Institute (NBI) and SINTEF Technology and Society, Rock and Soil Mechanics. All of the initial type-tests are now finished (April 2005) in accordance with CUAP no. ETA request 12.01/08. The relevant characteristics testes are presented in Table 3.

Table 3: Relevant characteristics to be evaluated in the ETA [*Ref. - CUAP, ETA request N^o^ 12.01/08*].

ER	Corresponding ID paragraph for: Works	Corresponding ID paragraph for: Product performance	Relevant product characteristics	CUAP clause for: Verification method	CUAP clause for: Relevant limit value or classification
1	4.2	4.3.1 4.3.2 4.3.3	Load bearing capacity	4.1.1 Load bearing capacity	5.1.1
			Crushing resistance	4.1.2 Crushing resistance	5.1.2
			Behaviour under cyclic load	4.1.3 Behaviour under cyclic load	5.1.3
			Freeze/thaw resistance	4.7.1 Resistance to freezing and thawing	5.5.1
3	3.3.5.2 Release of dangerous substances	3.3.5.3 4.2 4.3	Presence of dangerous substances	4.3.1 Release of dangerous substances	5.3.1
6	4.2 Provision to limit energy consumption	4.3.2.1 Fabric materials Table 4.1	Thermal conductivity	4.6.4 Thermal conductivity	5.4.1
			Liquid water capillary suction	4.6.2 Capillary water suction height	5.4.2
			Liquid water absorption	4.6.3 Water absorption	5.4.3
			Density	4.6.5 Density	5.4.4
			Particle size distribution	4.6.6 Particle size distribution	5.4.5
D 1)	5.1 2) Working life, durability	5.2 2) Working life of construction product in relation to the ER	Freeze/thaw resistance Liquid water absorption Thermal conductivity	4.7.1 Resistance to freezing and thawing	5.5.1
				4.6.2 Capillary water suction height	5.4.2
				4.6.3 Water absorption	5.4.3
				4.6.4 Thermal conductivity	5.4.1

Notes
ER Essential Requirements according to the Construction Product Directive (CPD)
ID Interpreting Document for each of the ER
D Durability (aspects of), common part of IDs
1) Related aspects of durability, serviceability and identification
2) Common part of the Ids

4 ROAD E6 EGGEMARKA

Road E6 at Eggemarka , north of the town Steinkjer includes an embankment, more than 15 m high constructed above a concrete tunnel, with the upper 6 m consisting of light weight filling materials, see Figure 7. Both LWA (9000 m^3) and foamglass (Hasopor 1000 m^3) are used to reduce the weight on the culvert and to improve stability and reduce settlement problems. The fill worked as a diversion road that was in service for one year. Placing and compaction was carried out 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 LWA slopes on the temporary fill.

Density and water content measurements and sieving tests were conducted 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.

Figure 7: Foamglass used in project E6 Eggemarka as light weight fill material

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 of the lightweight filling layer for each material, see Figure 8. Initial measurements were taken when the fills were completed and then again two months later.

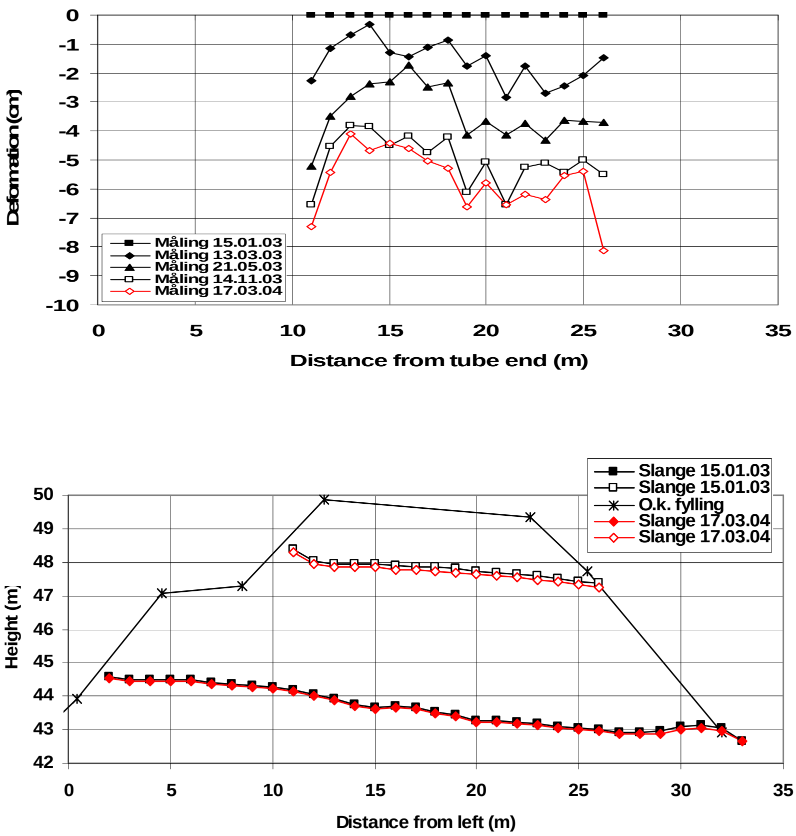

Figure 8: Observed deformations at Eggemarka

5 CONCLUSION

The monitoring programmes together with the laboratory tests have shown that the material may be applied in road construction projects as an alternative to competitive products and solutions.

6 ACKNOWLEDGEMENTS

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