Behavior of foam glass aggregate under static loads

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ABSTRACT

Foam glass aggregate is produced in a controlled production process. Due to its low density and thermal conductivity foam glass aggregate offers a broad variety of applications. Based on extensive laboratory tests foam glass aggregate is investigated in the scope of a joint research project performed at Vienna University of Technology and University of Innsbruck. The mechanical properties of single grains are investigated by uniaxial compression tests on cut foam glass prisms. The uniaxial compression test shows both a linear-elastic and a plastic behavior in the stress-strain relationship. A large-scale laboratory test was developed for the determination of the load-deformation behavior of foam glass aggregates taking into account the grain size distribution and the conditions during the compaction process in field. Deformation modulus can be directly derived while for the determination of the stiffness modulus the theory of the elastic-isotropic half space needs to be addressed. The time dependent load-deformation behavior of foam glass aggregate is determined from confined compression tests in an oedometer. Further confined compression tests with foam glass aggregate samples with different grain properties are investigated.

Keywords: Foam glass aggregate, uniaxial compression test, confined compression tests

1 INTRODUCTION

Foam glass aggregate is characterized by high porosity within the grains. This is reflected in a low density and low thermal conductivity. Due to these specific properties the material offers a wide variety of applications. Foam glass aggregate is mainly used as fill material under slabs, frost insulation material, and for light embankments especially for roads and highways.

In a funded joint scientific research project foam glass aggregate is investigated at Vienna University of Technology and University of Innsbruck.

Based on extensive laboratory testing stiffness, time-dependent settlement behavior, shear strength, bearing capacity, frost resistance, as well as permeability of foam glass aggregate layers with different boundary conditions is analyzed.

This paper describes different types of compression tests for the determination of the load-deformation behavior of foam glass aggregate under static loading.

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2 PRODUCTION PROCESS AND GENERAL PROPERTIES OF FOAM GLASS AGGREGATE

Foam glass aggregate is produced in a defined recycling process of waste glass material. In the first step of the production process waste glass is milled to glass powder. Furthermore, the powder is mixed with a foaming agent. The glass powder-foaming agent mix is heated in an oven up to 1000°C. Due to this temperature the glass powder foams up to foam glass. In the end of the production line the hot foam glass is taken out of the oven and cools down to ambient air-temperature. The fast cooling process induces tensile stresses in the sheets that easily let the foam glass break into foam glass aggregates.

The pores inside a single grain are closed. This is shown in a very low water absorption of about 11 vol.%.

The density of foam glass aggregate depends on the grain density, the degree of compaction, and the degree of water content. An overview of the range of the various densities taking into account different boundary conditions is given in Table 1.

Table 1. Density of foam glass aggregate

Boundary condition	Density [kg/m³]
Dry, loose	150 - 210
Dry, degree of compaction 25 % [1]	190 - 260
Wet[2], degree of compaction 25 % [1]	270 - 365

[1] Reduction of the volume of 25 %

[2] At a maximum of water absorption

3 LABORATORY TESTS TO DETERMINE THE PROPERTIES OF SINGLE GRAINS

The following properties of single grains have been determined:

- Grain density
- Uniaxial compressive strength

Both properties are tested on cut prismatic foam glass grains. The measurements of the square prisms are approximately 15 mm in the edge length of the cross-section and comprise a height of about 35 mm. Thus, the proportion factor of the samples H/D (height / coextensive diameter) is about 2 [-].

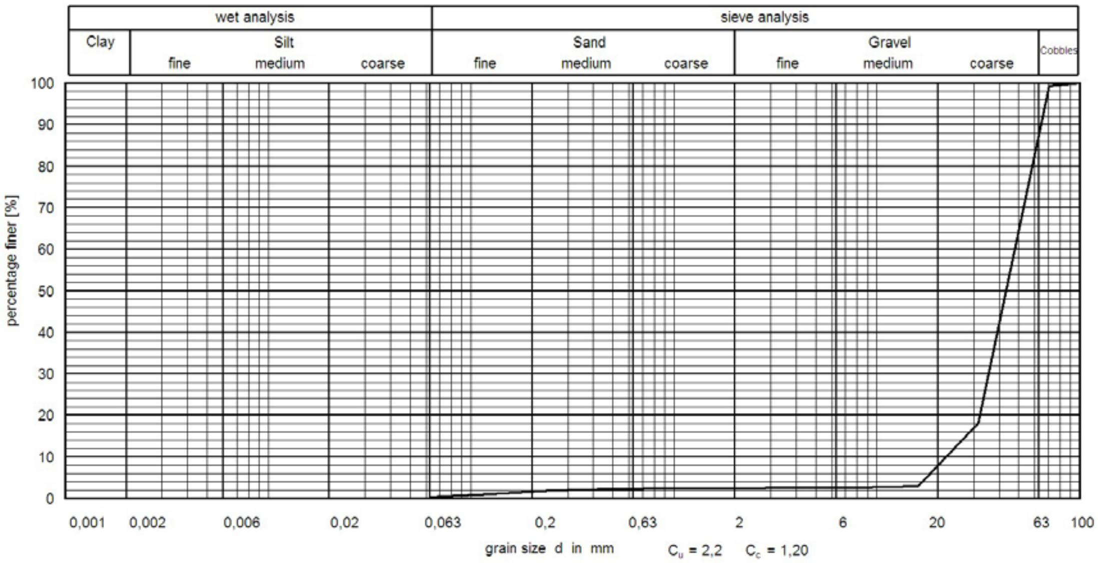

Figure 1. Grain size distribution of foam glass aggregate.

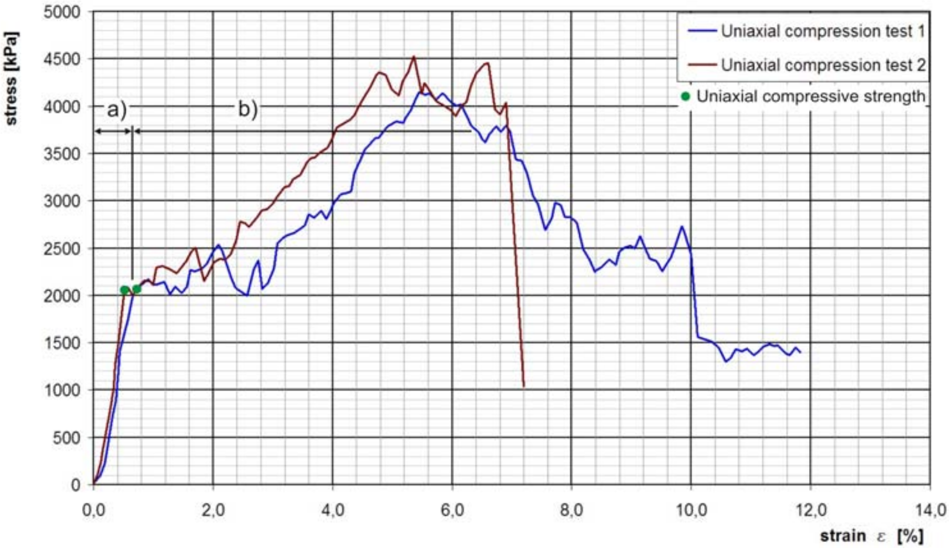

Figure 2. Load-deformation behavior of two foam glass prisms from uniaxial test: phase a) Linear elastic load deformation behavior, phase b) plastic load-deformation behavior.

3.1 *Grain density ρ_S*

The grain density was determined on foam glass prisms based on the particular measurements and weight of each sample and results in a range of 0,202 – 0,433 g/cm³.

3.2 *Uniaxial compressive strength*

The uniaxial compressions tests have been performed on foam glass prisms with a feed rate H/100 per minute [mm/minute]. Figure 2 shows two typical load-deformation behaviors of foam glass prisms. In the first phase a) a linear elastic behavior of the sample-material can be observed. In this phase no crushing of the foam glass grains occurs. The uniaxial compression test shows a horizontal load level with plastic deformations in combination with stress-rearrangement next to the linear elastic phase. The foam glass sample material is obviously hardening in the plastic range b) up to the fracture. The uniaxial compressive strength is defined by the change of the linear elastic to the plastic behavior. Figure 3 shows the correlation between the grain density and the uniaxial compressive strength.

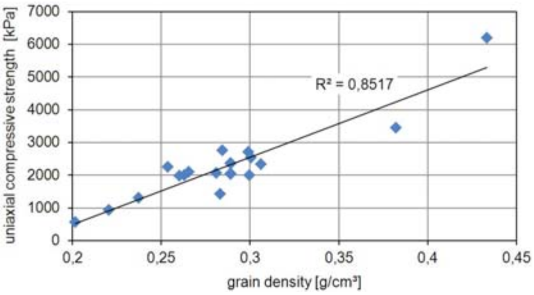

Figure 3. Correlation between grain density and uniaxial compressive strength.

4 EXPLORATION TO DETERMINE THE LOAD-DEFORMATION OF FOAM GLASS AGGREGATE

4.1 *Large-scale compression tests*

At the University of Innsbruck large-scale compression tests with samples in a test box measuring 3.80 m x 0.70 m and a depth of 0.60 m have been conducted to determine the load deformation behavior and ground failure mechanisms as well. The load is applied by a rectangular load plate.

Five types of foam glass aggregate from three manufacturers with varied degrees of compaction were tested.

The compaction process of the material in the test box is achieved with a vibration plate. The boundary conditions in the laboratory are more or less same as in field.

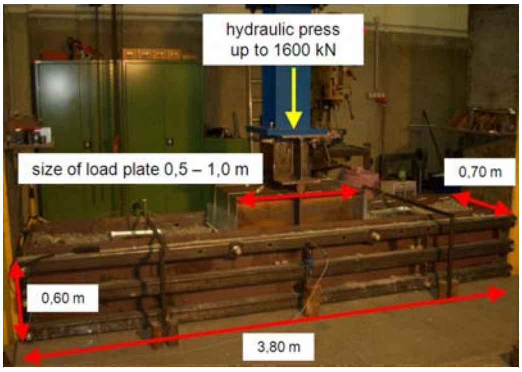

Figure 4. Test set-up of the large-scale compression test in the laboratory of the University of Innsbruck and the geometry of load plate and test box. [1]

The large-scale compression test is performed with a constant load increasing rate of 2 kN per second for initial loading as well as for reloading. The loading is done in cycles with a load increase of 100 kPa per step. In the first load cycle the foam glass aggregate sample is pressurized up to 100 kPa followed by a reloading with a minimum pressure of 10 kPa. The second load cycle has a defined maximum load of 200 kPa. The compression test is finished after eight load cycles respectively at a maximum load level of 800 kPa. One test takes about 20 minutes.

The strain of the foam glass aggregate body in transverse direction (cross to the length of the test box) is comparable to the strain of the samples of the confined compression test [chapter 4.2]. Due to the development of strains in longitudinal direction of the material in the test box the stiffness modulus cannot be derived directly.

The calculation of the stiffness modulus is based on the theory of elastic isotropic half space given in Formula (1).

$$E_S = \frac{2 \cdot b \cdot \Delta q}{\pi \cdot \Delta z} \cdot \frac{(1-\nu)^2}{(1-2 \cdot \nu)} \cdot \left[2 \ln \cot \frac{\beta}{2} - \frac{1}{1-\nu} \cdot \cos\beta \right] \quad (1)$$

E_S	stiffness modulus [MPa]
$2 \cdot b$	width of load plate [m]
Δq	stress [MPa]
Δz	settlements in vertical direction [m]
ν	Poisson ratio [-]
β	arctan(b/z) [°]
z	height of sample [m]

Actually the exact Poisson ratio of foam glass aggregate is unknown.

Figure 5 illustrates exemplary the progress and the value of the stiffness modulus of foam glass aggregate samples at initial loading with different ratios of compaction between 10 % and 25 % of volume reduction with a chosen Poisson ratio of 0.46.

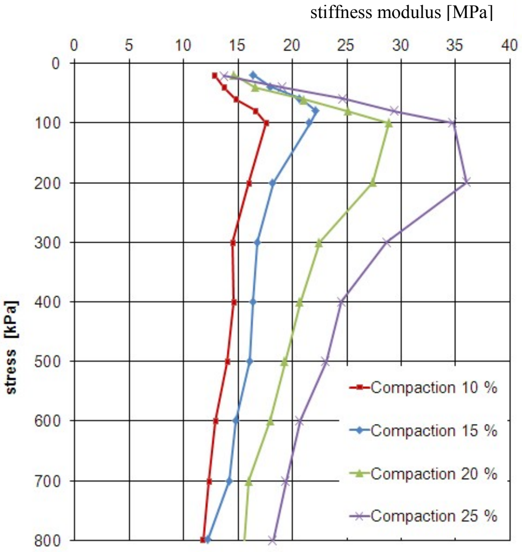

Figure 5. Exemplary depiction of the modulus of stiffness at initial loading with a Poisson ratio of 0.46.

The measurements of the load plate and the test box go conform with the grain size distribution of foam glass aggregate. The compaction in our experiment is selected to reproduce the compaction in field. Due to the high costs of the large-scale compression tests it is not possible to perform long term tests. For the determination of time dependent load-deformation behavior compression tests in small scale are carried out.

4.2 Confined compression tests

Confined compression tests in a large oedometer have been performed at Vienna University of Technology. The oedometer comprises a diameter of 250 mm. The compaction of the sample material is carried out with a proctor hammer. The loading procedure is done similar to the loading of the large-scale tests in the test box. Consequently, the comparability between the results of the large-scale tests and the confined tests is given. Figure 6 shows a comparison of the stiffness modulus with compacted foam glass aggregate samples examined in large-scale and confined compression tests (25% volume reduction by compaction).

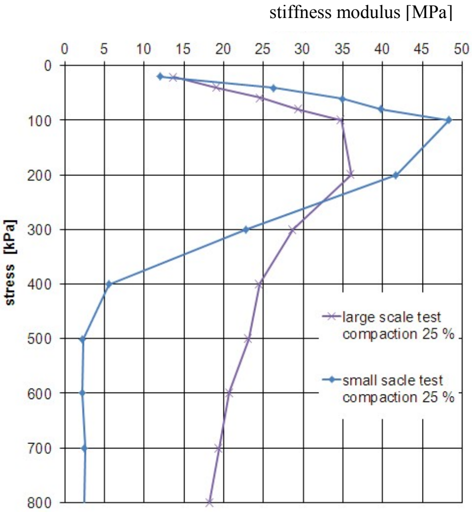

Figure 6. Comparison of the stiffness modulus between confined and large-scale compression tests with sample material with the same ratio of compaction.

The curves in Figure 6 show a similar trend of the progress of the stiffness modulus. Yet their levels are different. The distinct values of the modulus result from various test conditions, mainly from the different size of the oedometer (confined compression test) and the test box (large-scale compression test).

4.2.1 Long-term confined compression tests

Long-term confined compression tests have been carried out over a period of three to five days per test run to evaluate the time-dependent settlement behavior of foam glass aggregate.

The tests are performed in the oedometer with a diameter of 250 mm in accordance with the confined compression tests [chapter 4.2].

Two initial test load applications are investigated:

- loading steps of 20 kPa from 2 kPa to 100 kPa
- loading steps of 100 kPa from 100 kPa to 800 kPa

Every load step is finished when the strain rate is smaller than 0.05% per hour.

The stiffness modulus and the creep value were determined at every load step.

In Figure 7 the results of long-term tests are illustrated by using foam glass aggregate samples with different uniaxial strength and different grain density as well as different porosity. The illustrated curves showing the development of the stiffness modulus were determined with foam glass aggregate compacted to a volume reduction of 25%.

The analysis of the long-term confined compression test results indicates that the maximum stiffness modulus is obtained between 30 MPa and 43 MPa and is nearly independent of the grain density. Material containing fine pores (violet curve) shows high stiffness at higher pressure loads and significant creeping occurs only at higher load steps as well.

A correlation between low creep values and high stiffness modulus is evident.

The extrapolation of the time dependent load-deformation behavior from the long-term confined compression test to the large-scale compression test is given by the comparison of the stiffness modulus between confined and large-scale compression tests [Figure 6]

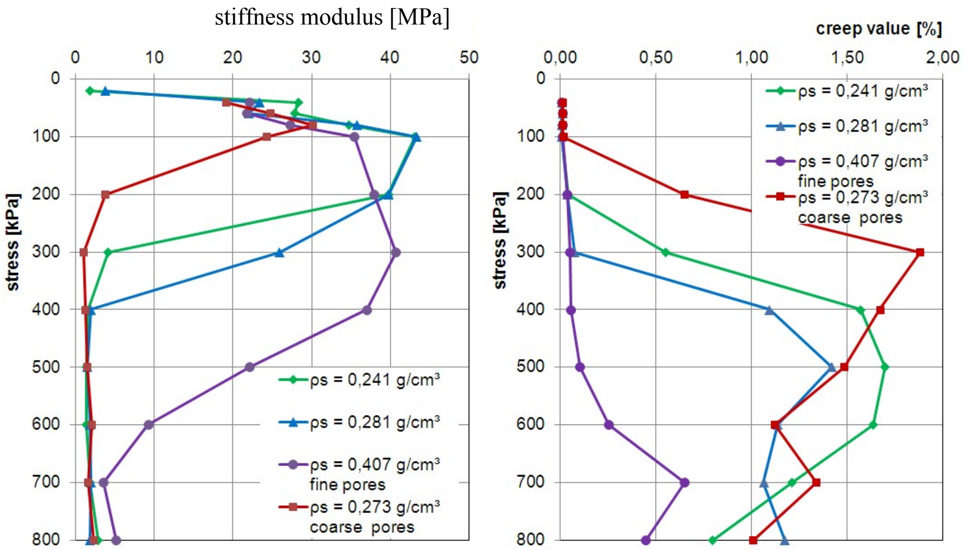

Figure 7. Stiffness modulus and creep value of foam glass aggregate samples as a result of long-term confined compression tests with different grain properties.

Figure 8. Two different types of foam glass aggregate prisms left fine pores, right coarse pores.

5 CONCLUSIONS

In the scope of a funded research project to determine the mechanical properties of foam glass aggregate, laboratory tests have been performed both with single grains and the aggregate. Uniaxial compression tests on single grains disclose a linear-elastic and a plastic range of the material behavior. The intersection of the linear-elastic to the plastic deformation in the stress-strain curve defines the uniaxial compressive strength, which correlates with the grain density.

For the investigation of the load-deformation behavior of foam glass aggregates under static loads different kinds of compression tests have been performed. As expected, the load deformation behavior and stiffness modulus are similar.

Furthermore, the time-dependent deformations of the foam glass aggregates strongly depend on the applied load, the density of the material, the degree of compaction, and the porosity of the grains.

Finally, the tests showed that the stiffness modulus does not depend on the uniaxial compressive strength.

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