Cellular Glass Aggregate Serving as Thermal Insulation and a Drainage Layer

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ABSTRACT

Factory-made aggregates of cellular glass with a typical lump size of 10 to 75 mm represent a new type of thermal insulation with drainage properties being applied in Switzerland, Germany, and other European countries. Cellular glass aggregates are used as insulating filling material at the perimeter of buildings as well as under load-bearing foundations. They can serve as insulation drainage layers of garden roofs. The insulation material is manufactured from recycled glass and mineral additives in a thermal process. The aggregates form when slabs of cellular glass crack while cooling down. In order to obtain the required hygrothermal properties, the manufacturing process must be carefully controlled. Despite its low density of approximately 120 to 250 kg/m³, cellular glass aggregate has a high pressure resistance, absorbs hardly any water, and is fireproof. The expected service life is at least 50 years.

Since its first appearance on the market, this insulation material has been thoroughly tested and the effect of water clinging to the aggregate has been investigated in the laboratory. To confirm the assumptions, the average moisture content and the thermal conductivity of the material in service was also determined by material sampling on existing buildings. This paper gives an overview of the different tests that must be performed in order to obtain a German and European Technical Approval. It summarizes the aggregate properties of different manufacturers and reports the practical experience gained by in-situ investigations.

INTRODUCTION

Ever increasing requirements concerning the thermal insulation of exterior building envelopes in Germany and worldwide demand constantly better exterior thermal insulations of building components which are in contact with earth (soil). For the insulation of load-bearing foundations and ground slabs (starting plates or raft foundations, for example) special requirements exist for the compressive strength and resistance against the influence of water and frost. There are German Technical Approvals, mainly for insulations made of extruded polystyrene (XPS) and foamglass in the form of panels. For this application, XPS-insulations dominate in Germany. The application of such insulations in the form of panels requires flat bedrock and takes a lot of time, especially if pipes have to be shifted in the insulation layer. Here the advantages of a pressure-resistant insulation that can balance surface unevenness like aggregates of cellular glass can be significant.

PRODUCT DESCRIPTION

For the industrial manufacturing of cellular glass, there are two different technologies, the wet-foaming procedure and the dry-foaming procedure. However, both procedures are based on similar operational sequences.

Fabrication

For both procedures, the wet-foaming procedure and the dry-foaming procedure, recycling glass is the base material. Waste glass from industrial flat glass production as well as glass from sorted domestic waste and other available glasses are used. The condition for the usability of glass is that it not be contaminated. That means the glass should not contain

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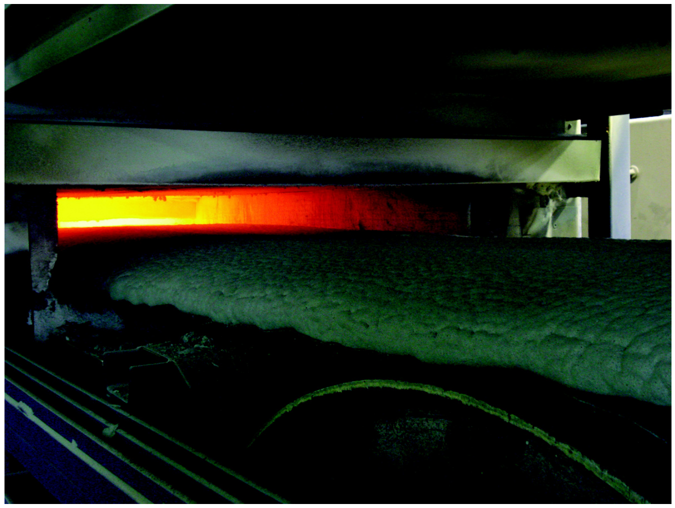


Figure 1 *Exit point of the glass foam "cake" from the furnace. The expanded compound cools down from about 900°C to ambient temperatures. (Reproduced by permission of Misapor AG.)*

heavy metals or other substances posing a health risk. In several stages of crushing and cleaning, the recycling glass is milled to the size of dust. The powder is stored temporarily in silos already mixed with mineral additives. From there it is forwarded to continuous industrial furnaces via conveyor belt. The thickness of the powder layer put onto the conveyor belt defines the resulting lump size. The furnace temperatures and the speed at which the glass powder goes through the furnaces, together with the additives (and their relative proportions) influence the properties of which is to become the insulation material. In the passage through the 10–15-m-long furnaces with temperatures of 900°C–1000°C, the glasspowder expands and bakes to an endless "cake" with a height of about 50–80 mm.

Upon leaving the furnace, the expanded compound cools down from about 900°C to ambient temperatures. The thermal stresses in the foam "cake" lead to cracks and then successively to a breakup into the final product—aggregates of cellular glass. Bigger lumps of cellular glass break to smaller pieces because of the stress in the material and through mechanical influences like transport on the conveyor belts, loading, vibrations on the trucks, unloading, and compaction to a minimum lump size. Lumps of this minimum size no longer carry thermal stress. Therefore, they are only breakable under extremely heavy loads and thus provide a loadbearing insulation layer.

Logistics

After production, the cellular glass aggregate is typically transported to outdoor storage. From there the insulation material is sometimes taken into silos, is filled directly into polypropelyne bags (FIBC, flexible intermediate bulk container) up to a size of 3 m^3, or is transported as loose fill on a truck. At the building site, the glass foam pieces are usually lifted into place by crane. The cellular glass, which is transported as loose fill on the truck, is dumped onto a sheet before it can be lifted by the crane. The compression of the cellular glass is then done by a vibration-plate-compactor or a small steamroller.

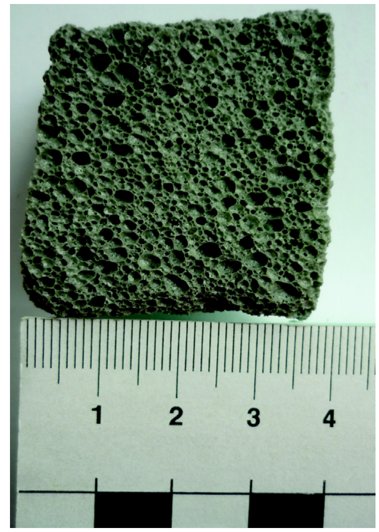
PROPERTIES

The cellular glass produced by the wetfoaming procedure usually appears black, whereas dryfoaming results in grey aggregates. The form of the lumps is similar to normal rock ballast. A more detailed inspection shows a spongy appearance but with a closed porous cell structure (Figure 2). The size of the single lumps of the loose foamglass ballast ranges from 30 mm up to about 80 mm. Smaller lump sizes are achieved through mechanical crushing if needed.

Hygrothermal Properties

Table 1 shows a set of hygrothermal and mechanical properties of the aggregates of cellular glass (DIBt 2008, 2009a, 2009b, 2009c). The thermal conductivity of the compressed aggregate of cellular glass (1.3:1 compression ratio) is measured with the guarded hot plate apparatus. For the measurements, the insulation is compressed in plastic boxes. The measurement is made using special samples in dry and wet conditions. The thermal conductivity of the dry insulation ranges from about 0.08 W/(mK) to 0.095 W/(mK). The results of measurements made using wet samples of cellular glass insulation that were submerged for 28 days under water reaches maximum values of 0.17 W/(mK). In the time between 2002 and 2008, at five different houses, samples of

(a)



(b)

Figure 2 *(a) Aggregates of cellular glass at outdoor storage directly after the production, and (b) a lump of cellular glass after production. The spongy appearance of the foam glass lump can be seen. The cellular glass has a closed porous cell structure. (Reproduced by permission of Misapor AG.)*

Table 1. Overview of Properties of Cellular Glass Aggregates

Property	Unit	Test Standard/Source	Insulation under Ground Slabs
Lump size (not compressed)	mm	EN 933-1	10 to 75
Density of the aggregate of cellular glass (not compressed)	Kg/m³	EN 1097-3	120 to 190
Compaction factor (compression)	–	–	1.3:1
Density of the aggregate of cellular glass (compressed)	Kg/m³	–	156 to 247
Moisture content (in situ)	Vol. %	–	1 to 6
Moisture content (after 28 days under water)	Vol. %	–	7 to 15
Thermal conductivity (dry)	W/(mK)	EN 12667	0.08 to 0.095
Thermal conductivity (design value)	W/(mK)	approval	0.11 to 0.14
Specific thermal capacity	J/(kgK)	manufacturer	ca. 850
Installation depth	mm	approval	150 to 600
Compressive stress at 10% deformation	kPa	EN 826	300 to 820
Compressive stress (design value)	kPa	approval	170 to 370
Softening point	°C	manufacturer	ca. 700
Possibility to recycle	%	100	100
Freeze/Thaw resistance	–	approval	yes
Fire resistance	–	assumption	yes

(a)

(b)

Figure 3 *Removal of samples of cellular glass (a) located under the ground slab of a house from outside and (b) through holes in the middle area of the plate. (Reproduced by permission of Misapor AG.)*

the insulation were taken and as far as possible the properties were determined (IBP 2006, 2008a, 2008b). Some of the samples under the ground slabs were taken from outside with a distance of about 10–15 cm to the boundary area of the ground slab, two samples under the ground slab were taken through holes in the middle area (Figure 3) and others in the boundary area outside the ground slab. The main goal of this was to determine the moisture content of the in situ insulation as well as to find out if a change in the cellular glass particles can be observed, which could shorten their durability. The thermal conductivity of these samples was determined on the basis of their moisture content and the measured thermal conductivities of the aggregates of cellular glass on dry and wet samples. According to the moisture contents of about 2–6% by volume at the boundary area of the ground slab, the calculated thermal conductivity was approximately 0.1 W/(mK) under ground slabs in the middle area and up to about 0.12 W/(mK) in their boundary area (Figure 4). From the samples which were taken at the five buildings, a significant change of the material could not be observed. These results correspond to the results obtained in laboratory tests. The single lumps absorb no water due to their closed cell structure. However, because of the rough surface of the lumps, some water remains attached. Freeze/thaw experiments where the samples were exposed for 20 or more cycles (one cycle per day) from –20°C without water, changing to +20°C under water, until now have shown no damage or considerable changes of the properties, neither to aggregates of cellular glass nor to single lumps. The compressed aggregates of cellular glass are assumed to be capillary interruptive. The mean water permeability for cellular glass aggregates is stated to be about 30 li/s/m² by the manufacturers. The research into the thermal conductivity and heat transport behavior of the cellular glass in different application situations under the influence of ground moisture and rain are objectives of a research project of the Fraunhofer-Institute for Building Physics (IBP) together with industrial partners, which should create more practical and theoretical knowledge.

Further Properties

For the control of the compressive stress, a German Technical Approval requires tests according to standard EN 826 on samples which are compacted like the in situ insulation with a compression ratio of 1.3:1. The dimensions of the samples are 170 mm × 200 × 200 mm. The results of such measurements were the compressive stresses at 10% deformation from about 300 kPa up to 820 kPa (Table 1). Figure 5 shows an example of measurement results. The declarations of the manufacturers for the compressive strength of a single granulate goes from about 4 N/mm² up to 10 N/ mm²; the shear strength according to EN ISO 12957-1 is about 0.9 kPa and the friction angle is from approximately 40° to 50°. The cavity space of the consolidated cellular glass aggregate is about 30% according to one manufacturer. Because of the base substance of the insulation glass the durability is assumed to be more than 50 years (CUAP 2003). The insulation is considered to be acid-resistant and alkali-resistant and also resistant to bacteria and vermin.

APPLICATIONS

Cellular glass aggregate is mainly used in German speaking countries as a load- bearing insulation under ground slabs. For this application the German Institute for Building Technique (DIBt) in Berlin has made a test plan (DIBt 2001).

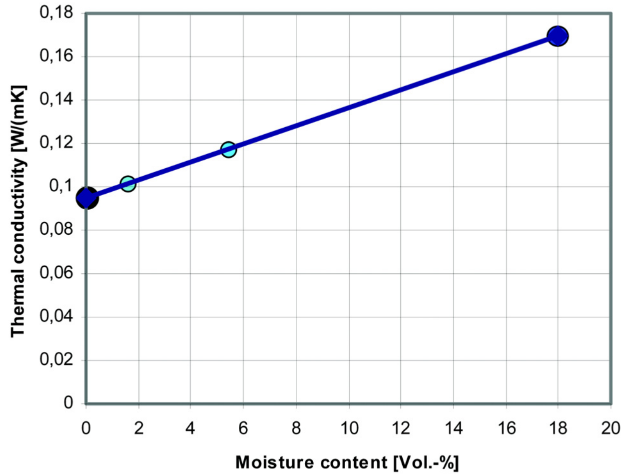


Figure 4 *Thermal conductivity of compacted aggregates of cellular glass as a function of moisture content. P1 and P2 show results of measurements in the laboratory at dry conditions and after 28 days with total immersion. P3 shows the mean thermal conductivity related to the moisture content of in situ samples below ground slabs (at 1.8 Vol.-%), P4 the mean thermal conductivity in the boundary area just outside of the ground slabs (at 5.5 Vol.-%). (Reproduced by permission of Misapor AG.)*

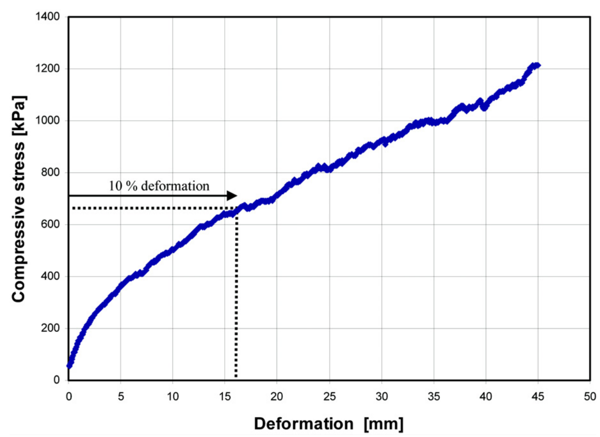


Figure 5 *The compressive stress was measured according EN 826. At 10% deformation the compressive stress was 670 kPa. (Reproduced by permission of TECHNNOpor.)*

According to this test plan, tested products get a German Technical Approval which regulates the use and obligates the manufacturer to a continuous factory production control and inspection and tests by an approved testing laboratory. Besides the test plan of the DIBt on the European level there exists a CUAP (CUAP = Common Understanding of Assessment Procedure) "factory-made cellular glass loose fill", for use as a lightweight fill, thermal insulation, water capillary barrier, and drainage for in-ground constructions like insulation of road constructions and under load-bearing foundations. The tests according to the CUAP and their adaptation and optimization for national requirements are presently under review by German expert groups.

Application as Loadbearing Insulation under Ground Slabs

The test plan from the 16th November 2001 of the German Institute for Building Technique (DIBt) for the application of load-bearing insulation under ground slabs comprises the following tests (DIBt 2001):

a. loose bulk density
b. particle size distribution
c. density of the material itself
d. compression at deformations of 10%, 20%, and 25% of
    i. dry material,
    ii. wet material after freeze and thaw cycles, and
    iii. material dried after freeze and thaw cycles,
e. thermal conductivity in dry and wet conditions (after 28 d of water immersion)
f. water content after water immersion and after freeze and thaw cycles
g. determination of sandy abrasion

Furthermore, since 2009, release of the following dangerous substances has to be checked four times a year: Arsenic (As), lead (Pb), cadmium (Cd), chromate III (Cr), copper (Cu), nickel (Ni), mercury (Hg), and zinc (Zn) are controlled to avoid contamination of soil and groundwater. For monitoring the durability of the insulation, the cellular glass aggregate insulation at three residential or industrial buildings has to be inspected within a certain number of years. To get a European Technical Approval on the basis of the CUAP guideline, the following properties have to be determined: a) water vapor transmission, b) capillary water suction, c) long term water absorption by total immersion, d) thermal conductivity (dry and wet after water immersion), e) loose bulk density, f) the density for the degrees of compaction, g) particle size contribution, h) resistance to freeze and thaw, i) compactibility, j) load-bearing capacity (declaration), k) tests for resistance to crushing (giant odometer test), l) behavior under cyclic load, m) settling properties, n) reaction to fire, and o) release of dangerous substances. A typical example for the usage of the material under a ground slab can be seen on Figure 6.

In Figure 7, one can see the differences between a conventional solution of an insulated ground slab and a solution with an insulation of cellular glass aggregate. If one compares a conventional construction of an insulated ground slab with one that is insulated with cellular glass aggregate it can be seen that cellular glass aggregate requires an insulation layer that is about twice as thick as conventional insulation material like XPS. At the same time, the drainage and capillary braking

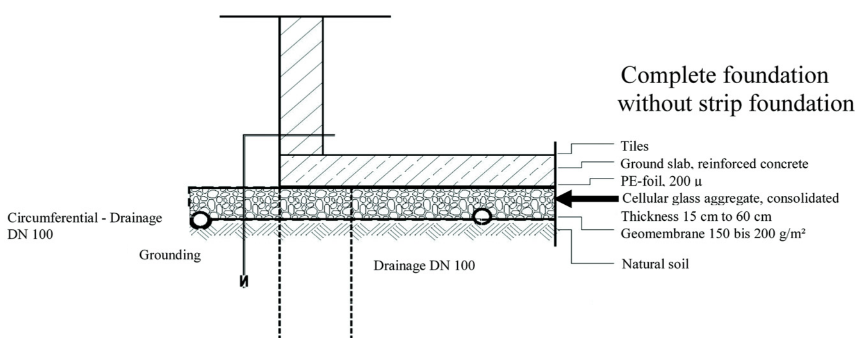


Figure 6 *A typical application of a consolidated cellular glass aggregate insulation as load-bearing insulation below a ground slab. (Reproduced by permission of Misapor AG.)*

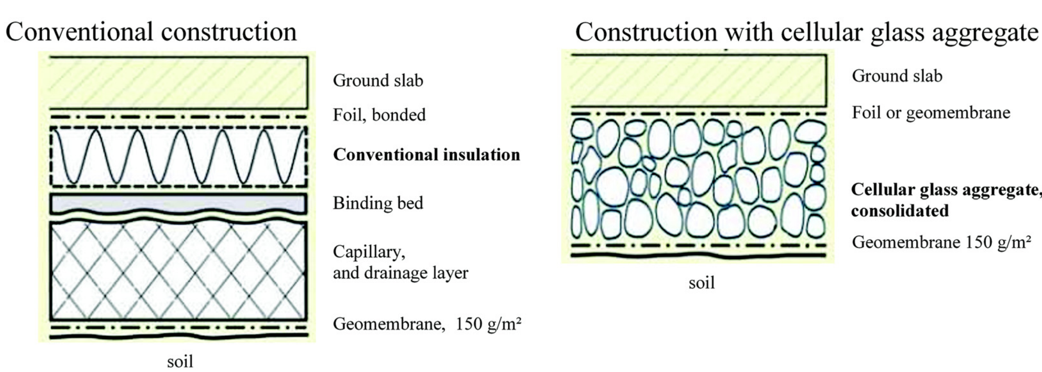


Figure 7 *Construction of ground slab with insulation in a conventional manner and with a layer of consolidated cellular glass aggregate. (Reproduced by permission of TECHNNOpor.)*

layer, a binding bed, and strip foundations are usually not necessary.

Figure 8 shows how the loose cellular glass fill is mounted with the help of a special sheet and a crane at the construction site. The truck tips its load onto a sheet with a plug valve in the middle. The valve allows a controlled distribution of the loose fill. The same kind of insulation distribution is possible with the polypropelyne bags which have a plug valve as well, on the lower side.

Further Applications

Besides the above-mentioned applications there are further application possibilities. Advantages of the cellular glass aggregate are best demonstrated in situations where insulation is in contact with soil, requires a high compressive strength and durability, is fire resistant, and has drainage qualities. The possibility of easily insulating all kinds of shapes, like pipes or arched ceilings is another advantage along with the fact that it often takes less time to mount the insulation. The following list gives an overview of the various application possibilities of cellular glass aggregates:

- **Structural engineering**
  Insulation under ground slabs
  Insulation flanking the ground slabs
  Perimeter insulation of basement walls
  Perimeter insulation at industrial and commercial construction
  Drainages (Figure 9)
  Swimming pool insulation
  Terrace insulation
  Light loose fill
  Compensatory loose fill
  Industrial roofs
  Greenroofs and flatroofs
  High load bearing roof constructions (Figure 9)

Figure 8 *Placement of cellular glass aggregate with the help of a crane and a sheet with a plug valve onto which the cellular glass is unloaded from the truck. (Reproduced by permission of Misapor AG.)*

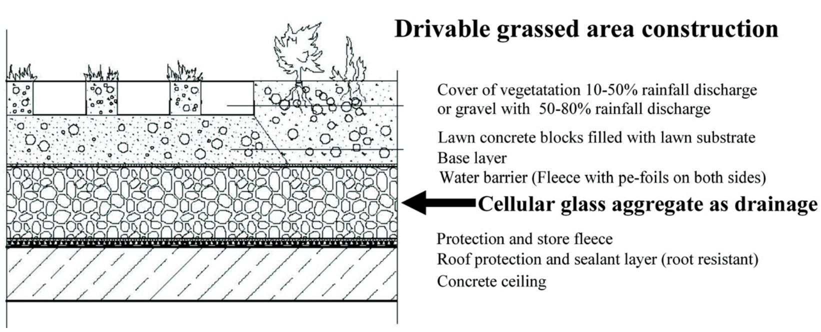


Figure 9 *Drivable grassed area construction used as a parkhouse roof. (Reproduced by permission of Misapor AG.)*

Floor constructions
Wooden and concrete ceilings
Timber frame and timber slab construction

- **Civil engineering**
  Light loose fill
  Road construction – load bearing and frost proof
  Frostfree foundations of paths and building sites
  Soil stabilization
  Slope stabilization
  Drainage
  Water and sewage line construction
  Thermal insulation of district heating lines
- **Special construction projects**
  Sports fields
  Ice skating rinks
  Design of surroundings and landscaping

CONCLUSION

For more than 10 years, cellular glass aggregates have been used in structural and civil engineering. The most common application in the German-speaking countries of Europe is load-bearing insulation under ground slabs. Because of its beneficial properties (light weight, high compressive strength, an assumed durability of at least 50 years, frost resistance, resistance against bacteria and vermin, fire resistance) and its use of recycled glass as its base material, cellular glass aggregate finds a wide spectrum of applications in structural and civil engineering, and for various kind of special building projects. The challenge of the future will be the adaptation of test procedures to the special material properties, the search for further applications, as well as the continuous development of the insulation material itself. A research project of the Fraunhofer-Institute for Building Physics (IBP) together with industrial partners, which is promoted by the German Institute for Building Technique (DIBt) in Berlin should create more practical and theoretical knowledge. The research into the thermal conductivity and heat transport behavior of the cellular glass in different application situations under the influence of ground moisture and rain are objectives.

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