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# Lightweight aggregate concrete with an open structure and a porous matrix with an improved ratio of compressive strength to dry density

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## HIGHLIGHTS

- Successful combination of foam concrete and lightweight aggregates.
- Lightweight aggregate concrete with open structure and porous matrix.
- Nanoscale view on the texture of the lightweight aggregates.
- Improved ratio between compressive strength and dry density/thermal conductivity.
- Reduction of drying shrinkage due to the aggregates of almost 80%.

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## ABSTRACT

In this study the combination of foam concrete and lightweight aggregates was investigated in order to develop a lightweight aggregate concrete with open structure and porous matrix (LACPM). For this purpose the recipe of a foam concrete was combined with the following lightweight aggregates: pumice, expanded glass, foam glass, expanded clay, and expanded perlite. The successfully produced concretes showed a homogenous microscopic structure and arrangement of the aggregates. A nanoscale view on the texture of the aggregates helped to understand the different embedding in the foamed cement paste matrix and their interaction at the interface. The best embedding was shown by pumice, expanded perlite and expanded clay. The ratio between compressive strength and dry density as well as the ratio between compressive strength and thermal conductivity has been improved respectively. Compared to conventional foam concrete an improvement of the compressive strength by almost 40 % was measured. The same applied for the drying shrinkage, the change in length was reduced by the addition of the aggregates to almost 80 %.



## 1. Introduction

Lightweight concrete is an important field of concrete technology, because it combines constructive and insulating properties of building materials. Normally the reduction of weight is implemented by the intrusion of air, either into the matrix, into the aggregates or both. One kind of lightweight concrete has an open structure, which can be obtained by normal or lightweight aggregates. A possibility to enhance the properties of such a concrete with lightweight aggregates is to fill the cavities with a porous cement paste matrix, which provides the opportunity to decrease the dry density while keeping the compressive strength constant [1,2,3]. This is due to the more homogeneous stress distribution. In concrete with open structure stress transfer is just from one aggregate to another in the contact points, but if the voids in between are filled the transfer area is higher and the stress is evenly distributed [3]. An additional advantage is the improved workability for the concrete with an open structure. The consistency is not stiff anymore and the use of a roller compaction which is unusual equipment for precast plants is unnecessary. In addition the production process is less complicated, since there is only one silo necessary for the aggregate and one for the cement.

Another type of lightweight concrete is foam concrete, which consists of a cement paste with a large quantity of air pores inside [4,5]. One way to produce such a foam concrete is the addition of preformed foam to a cement paste or mortar. To reduce the dry density of foam concrete different approaches can be chosen, e.g. aerogel foam concrete [6,7]. A serious problem of foam concrete is the high degree of drying shrinkage, due to the lack of inert admixtures [8,9]. The addition of lightweight aggregates could pre-

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vent the shrinkage behavior, depending on their properties, mainly their stiffness.

Therefore the combination of lightweight concrete with open structure and foam concrete to produce a porous matrix between the aggregates is advantageous for both. On this kind of concretes just few research has been done and most investigations dealt only with the usage of expanded clay as lightweight aggregate [3,8–12]. The ways of manufacturing vary in every research. Often concrete is mixed first and air pores in form of wet foam are added in the last step. In this research different kinds of aggregates are applied to determine their influence on several concrete properties, in order to create a broad database for LACPM[1]. For the production a well-known foam concrete recipe just made from cement is used, which is mixed with the different aggregates after completion to fill the gaps.

## 2. Experimental

The objective of the experimental program was a combination of a foam concrete with lightweight aggregates in order to develop a concrete with an open structure and filled gaps. First the foam concrete was analyzed and subsequently concretes with the different lightweight aggregates were produced and their influence on the foam concrete's properties was examined.

### 2.1. Raw materials

In this study a rapid hardening ordinary Portland cement CEM I 52.5 R was used as basic binding material. The water/cement ratio (w/c) from the paste is set for all mixtures to 0.25 and in order to ensure a sufficient workability 0.5 % of a polycarboxylate-based superplasticizer was added. The foam is produced by using a synthetic foaming agent and a foam generator. The ratio of paste/foam was set to 30/70, according to the volume.

Different types of lightweight aggregates were used: pumice (P), expanded clay (EC), foam glass (FG), expanded glass (EG), and expanded perlite (EP). The physical properties of these aggregates are given in Table 1.

### 2.2. Mix proportions

The consistency was a decisive factor to ensure an easy handling for a practical implementation of the developed recipes. The aim was to achieve good workability leading to self-flowing concrete, without the need of compaction. Another important factor was to ensure the simplicity of the recipes by using only a few common materials as well as using conventional equipment.

Initially a cement paste from cement, water and superplasticizer was mixed. Then the foam was added and the mixture was stirred until it was homogeneously distributed. In the last step the foam concrete slurry and the pre-wetted aggregate were mixed together, filled into molds without compaction and cured in a climate chamber at 23 °C with a relative humidity (RH) > 95 %. After 24 h the samples were stripped and further stored in the climate chamber according to [18]. The proportions of the mixtures are shown in Table 2.

### 2.3. Methodology

#### 2.3.1. Surface structure

To get a clear view of the surface and the air void structure of each sample optical microscopy (OM) was applied with a magnification of x6.4 (Wild M38 from Heerburgg Switzerland). For determining the microstructure of the aggregates and the specimens, scanning electron microscopy (SEM) was used applying a Quanta FEG 250 SEM from FEI with detectors for backscattered-electron (BSE) imaging. Furthermore the interaction of the foam concrete and the aggregates and their contact zone were examined. For the optical microscope small pieces were cut out of the samples to get a flat surface. Whereas for the SEM investigation a fresh fractured surface was used by breaking the samples.

#### 2.3.2. Compressive strength

The determination of compressive strength was carried out as specified in [19] for concrete with open structure. Cubes with an edge length of 150 mm were tested after 28 day of curing and the results were calculated from the mean of six specimens.

#### 2.3.3. Shrinkage

For measuring the degree of drying shrinkage of the foam concrete and the influence of the lightweight aggregates a strain gauge was used [20]. From each concrete three samples 40 mm·40 mm·160 mm were produced. After 48 h of curing covered with foil in a climate chamber (23 °C/RH > 95 %) in order to prevent a premature drying, the samples were stripped and further stored in a climate chamber (20 °C/RH = 56 %). After 2, 7, 14, 28, 56 and 90 days two surfaces of the three samples were measured, respectively.

#### 2.3.4. Thermal conductivity

Thermal conductivity was measured by means of a unidirectional heat flow meter HFM 446 Lambda from NETZSCH-Gerätebau GmbH with the plate method for insulators in accordance with [21]. The samples were cured for 28 days and then oven-dried, to eliminate the internal moisture [20].

## 3. Results and discussion

### 3.1. Structure and density

The dry densities from the different lightweight concretes as well as the foam concrete are summarized in Table 3. The foam concrete with a foam volume of 70 % in the fresh paste showed a dry density of 690 kg/m$^3$. The addition of the lightweight aggregates lowers the dry density of the concretes due to their low bulk density, as shown in Table 1. The concrete densities vary from 450 to 660 kg/m$^3$.

To compare the air-void and the aggregate distribution of the different concretes, images of all samples with a magnification of x6.4 were captured with an optical microscope.

The reference foam concrete shows a uniform pore arrangement and a homogenous pore size distribution (Fig. 1a), what also appears in the porous matrices between the aggregates (Fig. 1b–f). The homogenous pore arrangement among the aggregates confirmed that their addition did not influence the structure of the foamed concrete and the uniformity of the air voids is preserved. Just the samples with the expanded glass (Fig. 1c) show few bigger sized pores in between the aggregates. On the one hand, this could be due to the omitted compaction of the samples. On the other hand, it is possible, that the amount of foam concrete was not enough, to fill all the gaps between the aggregates.

### 3.2. Microstructure of the aggregates

In order to understand the coaction of lightweight aggregates and foam concrete or rather the cement paste it is essential to study the aggregates and their structure more closely.

[1] Lightweight Aggregate Concrete with open structure and Porous Matrix

**Table 1**
Physical properties of the different lightweight aggregates.

| Type of aggregate | Bulk density in kg/m$^3$ | Particle density in kg/m$^3$ | Water absorption in % *w*/*w* | Grain size in mm | Porosity in % *v*/*v* | Thermal conductivity in W/(mK) |
|---|---|---|---|---|---|---|
| P | 594 | 385 | 20 | 2–4 | 76 | 0, 14 [13] |
| EC | 577 | 353 | 24 | 4–8 | 78 | 0, 10 [14] |
| FG | 418 | 230 | 40 | 4–16 | 83 | 0, 10 [15] |
| EG | 301 | 204 | 38 | 2–4 | 88 | 0, 07 [16] |
| EP | 203 | 104 | 65 | 2–6 | 93 | 0, 05 [17] |

**Table 2**
Mixture compositions of the different LACPMs.

| Component aggregate type | Aggregate in kg/m$^3$ | Foam concrete in l/m$^3$ |
|---|---|---|
| Pumice (P) | 385 | 774 |
| Expanded clay (EC) | 353 | 582 |
| Foam glass (FG) | 230 | 675 |
| Expanded glass (EG) | 204 | 644 |
| Expanded perlite (EP) | 104 | 903 |

**Table 3**
Dry densities of the LACPMs and the foam concrete as reference system (Ref).

| Type of aggregate | Dry Density in kg/m$^3$ |
|---|---|
| - (Ref) | 690 |
| Pumice (P) | 660 |
| Expanded clay (EC) | 600 |
| Foam glass (FG) | 560 |
| Expanded perlite (EP) | 550 |
| Expanded glass (EG) | 450 |

Lightweight aggregates are categorized by their origin and their production process [22]. Pumice is a natural volcanic rock that is mined in quarries, thus the particle shape is crushed and has a relatively open porosity. From the aggregates used in this study, pumice shows the highest bulk density and therefore the lowest porosity with 76 % *v*/*v*. The structure is demonstrated in Fig. 2 by a SEM picture at a magnification of x1.000. The surface is rough with a lot of capillary pores (0.03–10 μm).

Contrary to the quarrying of pumice, the expanded and the foam glass are made of industrial by-products in a thermal process. The expanded glass displays aggregates with a spherical shape and an outer layer of a sintered skin, which is much denser then the inner part (Fig. 3a). The sintered skin seems smooth with pores in a capillary range whereas the inner structure looks totally different with a lot of air pores (>10 μm) and thin lamella widths (Fig. 3b). This explains the low bulk density and a porosity of 88 % *v*/*v*. Due to their different manufacturing, the foam glass has no sintered skin and the structure contains of a lot of air voids. The cell connectors between the air pores show a dense and smooth microstructure (Fig. 3c). Both bulk density and porosity (83 % *v*/*v*) are in the middle range.

Natural raw materials are converted in a thermal process to produce expanded clay or perlite. Expanded clay also exhibits a spherical shape with a sintered skin, but with less pores and especially less capillary pores than the expanded glass (Fig. 4a). Furthermore the surface seems rougher than the surface of the glass, but the inner buildup is similar (Fig. 4b). As a result of a porosity of 78 % *v*/*v* the bulk density is comparatively high (Table 1).

Perlite has the lowest bulk density and with 93 % *v*/*v* the highest porosity of the applied lightweight aggregates. The structure exhibits a lot of capillary and few air pores with very thin and filigree lamella widths (Fig. 4c).

### 3.3. Microstructure of the concrete

Pumice seems to be connected to the foam concrete by crystal growth, a clear boundary is not visible (Fig. 5a). The rough surface

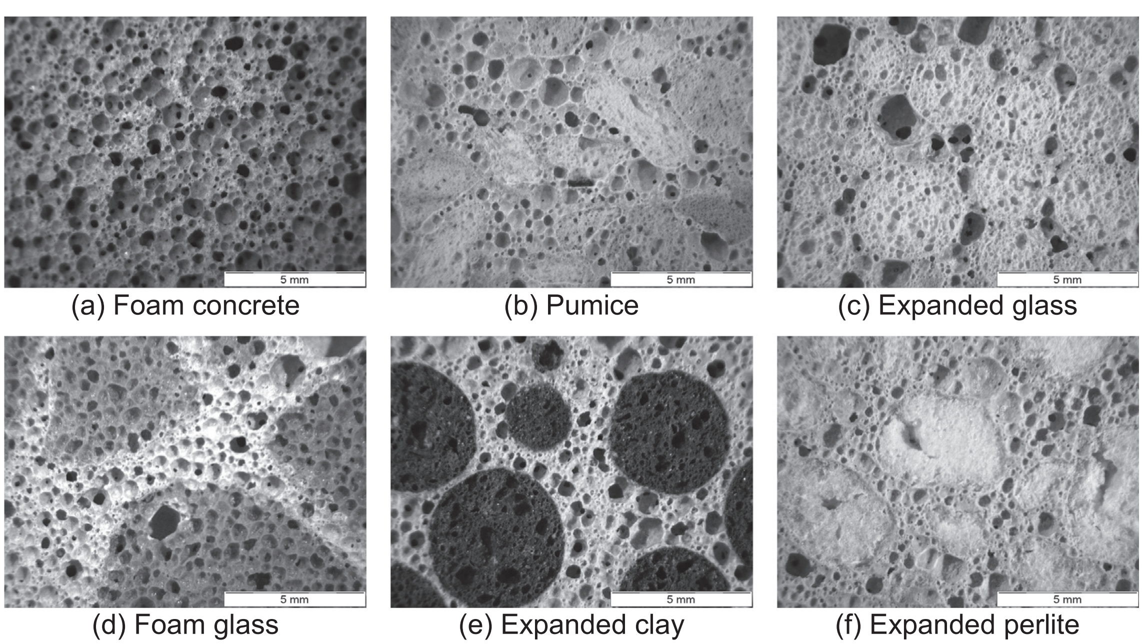



**Fig. 1.** Images from the foam concrete (a) and LACPMs (b to f); OM, magnification x6.4.

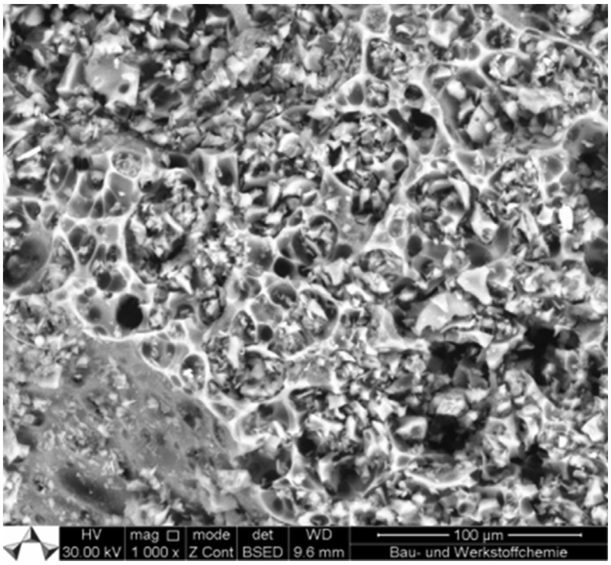



**Fig. 2.** Structure of the pumice; SEM magnification x1.000.

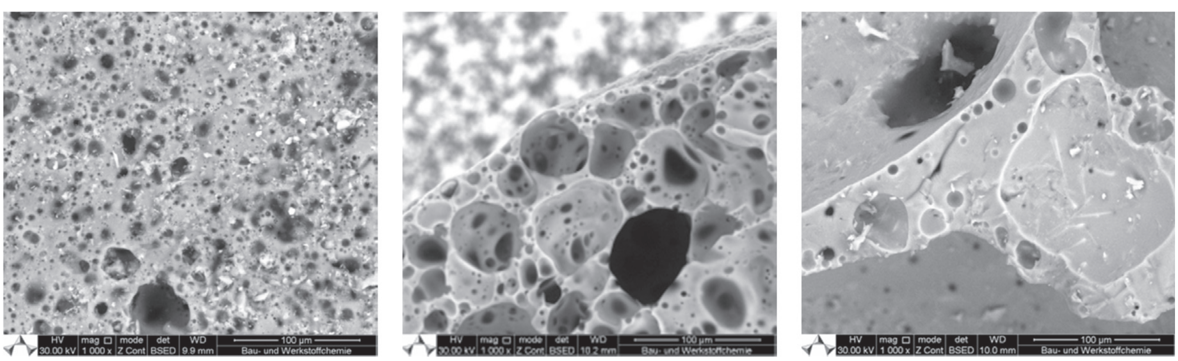
with capillary pores, act as interlocking sites for the cement paste. With a higher magnification hydration products (HP) are visible in the pores (Fig. 5b). No weak interfacial transition zone around the aggregates is visible and the pumice is closely embedded.

In contrast to pumice, expanded glass shows a clear boundary to the foam concrete matrix (Fig. 6). It looks like cement paste's hydration phases grow against the aggregates, but not into them. Hydration products could be rarely found inside the glass, due to the smooth surface and the low amount of open porosity. However no gap or weak interfacial transition zone are visible.

The smooth surface of the foam glass results similar, almost no hydration products can be found in the aggregates (Fig. 7a). Additionally a gap between the two materials is often visible (Fig. 7b). Even though the microscopic structure of foam glass and foam concrete is similar, the aggregates are not well embedded in the matrix. This could also be due to the large amount of air pores in the glass, since these are too large for the glass to offer many connection options for the attachment of the cement particles ($d_{50}$ = 10 μm).

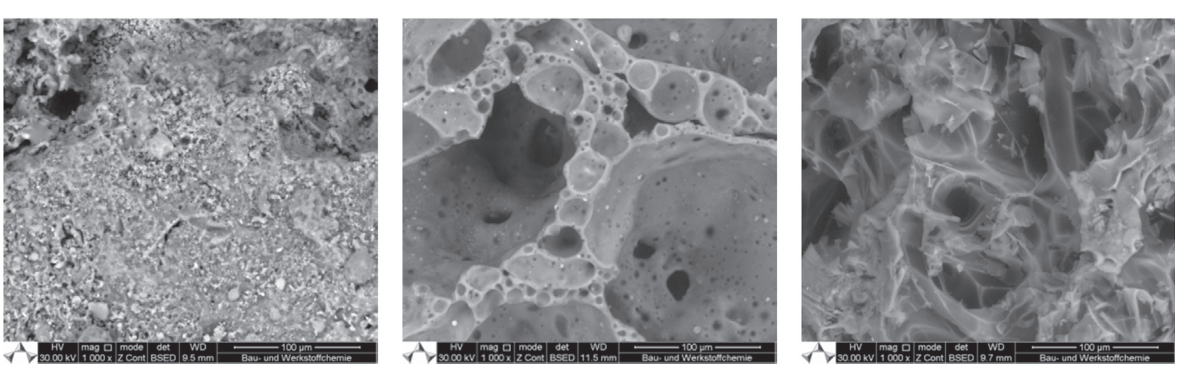
Just like with expanded glass, the expanded clay has a sintered skin, but unlike the glass, clay shows a good embedding in the foamed concrete. The boundary is less clear discernible (Fig. 8a) and hydration products are visible in the outer part of the aggregates (Fig. 8b). The improved embedding could be based on the rougher and therefore also larger surface and the higher amount of possible connection sites for the cement paste. Additionally the expanded glass exhibits an open porosity of 5 % *v*/*v* and the expanded clay of 69 % *v*/*v* that explains why the amount of hydration products is comparatively low in the expanded glass.

As it can be seen in the SEM images (Fig. 4c), the microstructure of the expanded perlite is totally different from those of the other ones. Due to the open-pored and rough surface, the perlite is very



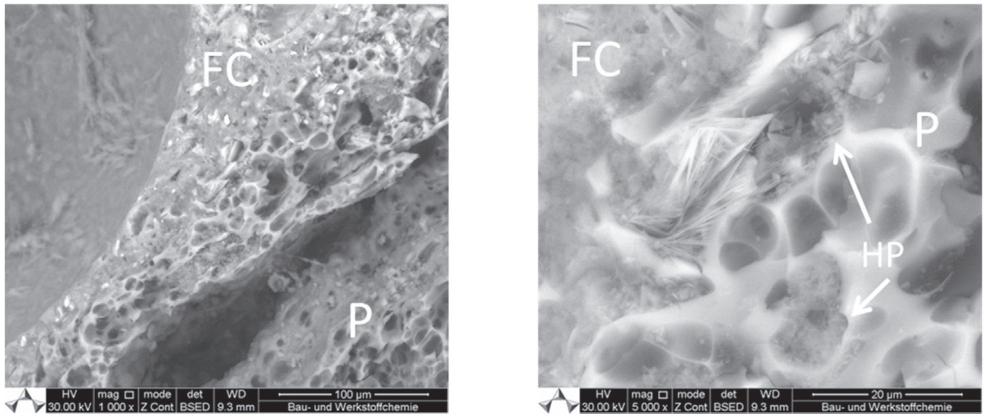
(a) Sintered skin of the expanded glass (b) Inner structure of the expanded glass (c) Structure of the foam glass

**Fig. 3.** Structure of the expanded glass and the foam glass; SEM magnification x1.000.



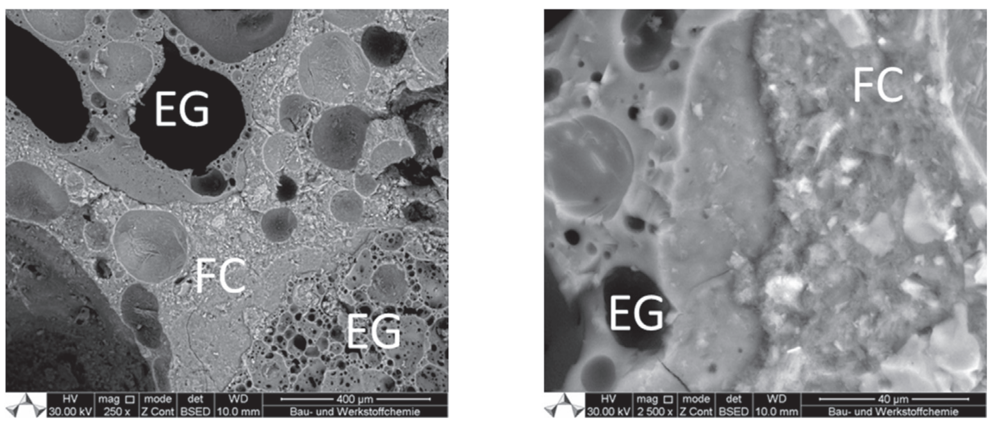
(a) Sintered skin of the expanded clay (b) Inner structure of the expanded clay (c) Structure of the perlite

**Fig. 4.** Structure of the expanded clay and the expanded perlite; SEM magnification x1.000.



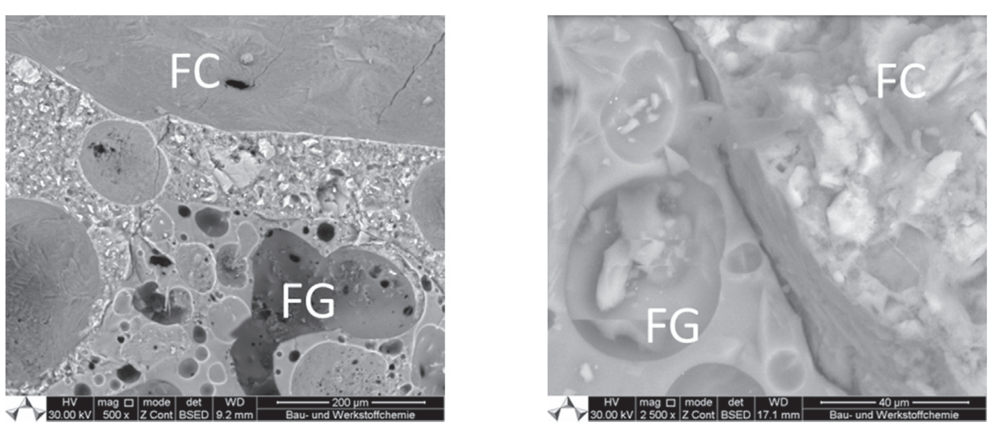

(a) Magnification: x1.000 (b) Magnification: x5.000

**Fig. 5.** Embedding of pumice (P) in the foam concrete (FC); SEM.




(a) Magnification: x250 (b) Magnification: x2.500

**Fig. 6.** Embedding of the expanded glass (EG) in the foam concrete (FC); SEM.

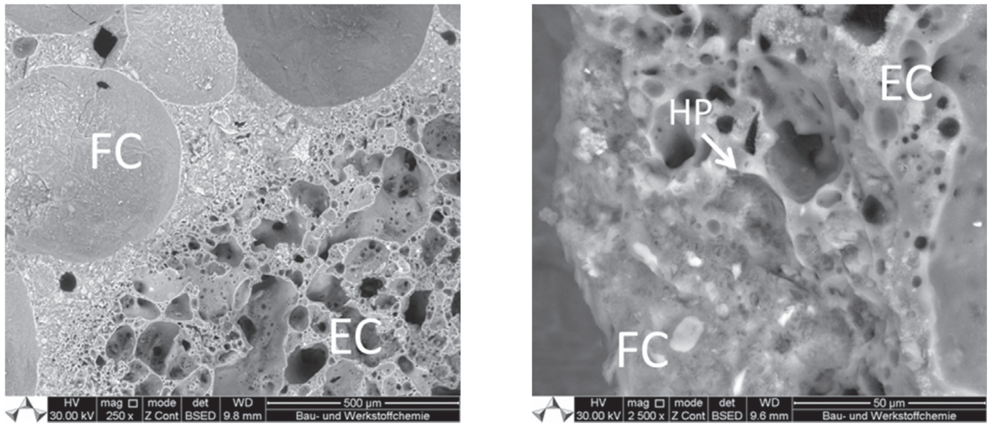



(a) Magnification: x500 (b) Magnification: x2.500

**Fig. 7.** Embedding of the foam glass (FG) in the foam concrete (FC); SEM.

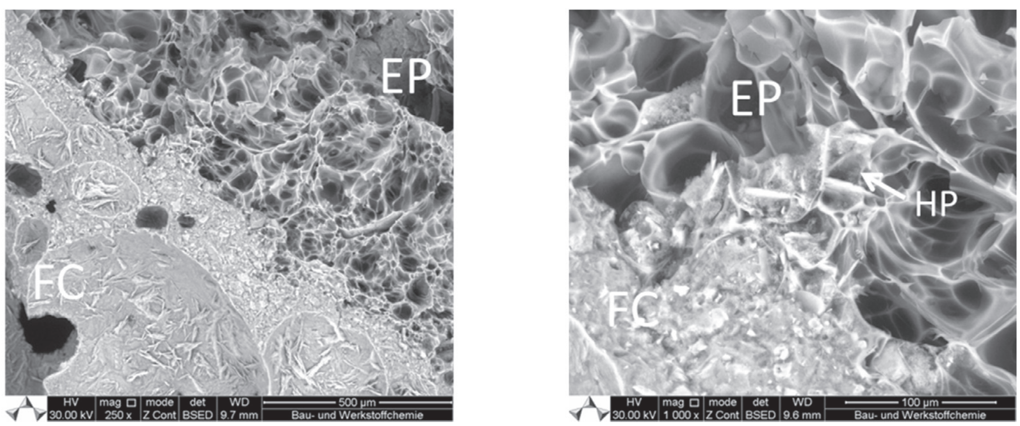
well embedded in the matrix. The transition between aggregates and cement paste seems to be fluent and both are grown together (Fig. 9). The pores inside the filigree cell connectors are filled with hydration products.

Based on the SEM images of the aggregates and their transition zone to the foam concrete matrix the quality of embedding varies between the different types of lightweight aggregates. The influence of a sintered skin, resulting from the production process or the shape of the grains seems to be negligible. More important is the formation of the surface structure concerning roughness and porosity. The best embedding in the foamed cement matrix is visible with the expanded perlite and the pumice followed by the




(a) Magnification: x250 (b) Magnification: x2.500

**Fig. 8.** Embedding of the expanded clay (EC) in the foam concrete (FC); SEM.




(a) Magnification: x250 (b) Magnification: x1.000

**Fig. 9.** Embedding of the expanded perlite (EP) in the foam concrete (FC); SEM.

expanded clay. They are similar with respect to the rough surface, which offers a lot of connection sites. The embedding of the glasses in the matrix is weaker, due to smoother surfaces.

### 3.4. Compressive strength

The compressive strength from lightweight materials is mostly depending on the density and therefore the results are plotted against the dry density of the concrete with a regression curve presented as a continuous line (Fig. 10). These results are based on several mixtures with different amounts of wet foam to vary the density and the strength accordingly. The black rectangle represents the foam concrete mixture that was base for the lightweight aggregate LACPMs. It is obvious that the addition of lightweight aggregates reduce the dry density of all concrete samples due to their bulk densities, which are with a range of 200 to 600 kg/m$^3$ lower than the dry density of the reference foam concrete mixture with 690 kg/m$^3$. The highest compressive strength of 6.8 N/mm$^2$ was reached by the samples prepared with pumice, which at once showed the highest density of 660 kg/m$^3$ similar to the pure foam concrete. The second highest compressive strength of 4.7 N/mm$^2$ is reached by the samples containing expanded clay at a dry density of about 600 kg/m$^3$. Similar results were achieved by addition of foam glass (560 kg/m$^3$) and expanded perlite (550 kg/m$^3$) with 4.6 and 4.5 N/mm$^2$, respectively. The lowest dry density of 450 kg/m$^3$ is achieved by concrete with integrated expanded glass and an associated strength of 3.6 N/mm$^2$.

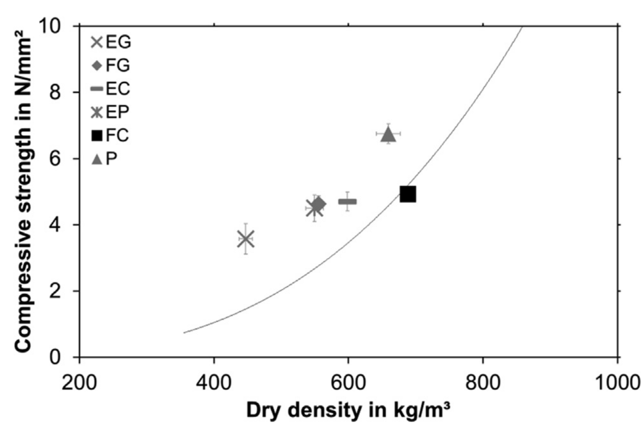



**Fig. 10.** Compressive Strength of LACPMs and reference foam concrete.

Fig. 10 shows that the compressive strength of the concrete with open structure as well as for the reference foam concrete depends on the density. But the samples including aggregates showed consistently lower densities at the same strength level as pure foam concrete. The best relationship between strength and density was exhibited by samples containing pumice, which also

**Table 4**
Characteristic strength of LACPMs.

| Type of aggregate | Pumice | Expanded glass | Foam glass | Expanded clay | Expanded perlite |
|---|---|---|---|---|---|
| $f_{ck}$ in $N/mm^2$ | 5,2 | 2,2 | 3,5 | 3,5 | 3,1 |

showed a good embedding in the foam concrete matrix. The same phenomenon appeared for expanded clay, which is also good embedded and has a similar bulk density, but the strength is lower. This could be explained by the shape of the aggregates. In contrast to the round grains of the expanded clay pumice has edged crushed particles that can become wedged, which means that they do not slide off each other leading to a higher internal stability. Proportional to their low bulk density the expanded perlite achieved a high concrete density of 550 $kg/m^3$, due to their good embedding and the high amount of cement paste that could penetrate into the aggregates because of the open-pored structure. Likewise, the low density of the expanded glass concrete could be explained by the low bulk density of the glass in combination with their closed pore structure and the low degree of connection.

In Table 4 the characteristic strengths from the concretes with lightweight aggregates according to [20] are listed. All prepared samples reached strength class LAC2 and even the samples including pumice reached class LAC4.

Except for expanded glass, all the other concrete samples exceeded the required strengths. Therefore a reduction of strength or rather density was investigated. As represented in Fig. 10 the density and the strength of the foam concrete could be adjusted by variation of the amount of wet foam. In order to find out whether the same effect is achieved when aggregates are added to the ratio of paste to foam was decreased from 30/70 % to 25/75 % *v/v*. Because of the comparatively high sample volume just three cubes with an edge length of 100 mm were tested of each mixture after seven days (Fig. 11). The decrease of density as well as of strength is by far strongest for pure foam concrete (Ref) from 690 to 560 $kg/m^3$, means 19 % *w/w*. But also the density of the aggregate concrete samples could be decreased by changing the density of the added foamed concrete. The degree of reduction varied from 3 % *w/w* with pumice to 11 % *w/w* with expanded perlite depending on the share of foam concrete. This decrease although it is weaker due to the smaller share of foam concrete in the samples with aggregates, is possible for all presented concretes. Hence, it can be concluded, that for each kind of aggregate density and compressive strength, which are interdependent, are variable and could be adjusted up to a certain level upon need.

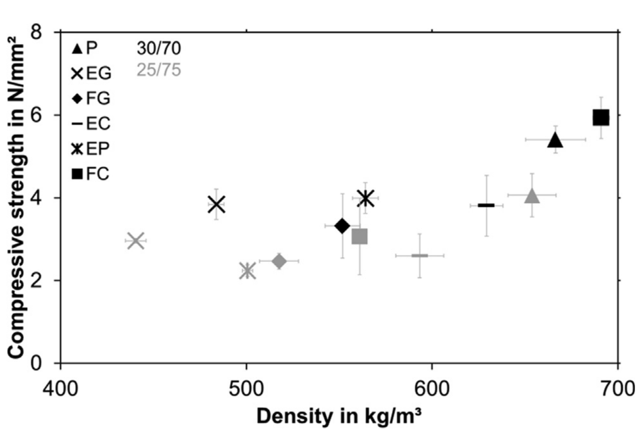



**Fig. 11.** Compressive Strength of the LACPMs and foam concrete with different shares of wet foam.

### 3.5. Drying shrinkage

One concept to reduce the high degree of drying shrinkage of foam concrete is the addition of lightweight aggregates, which was also investigated in this study. Another concept is to replace some of the cement with admixtures, e.g. fly ash [23,24]. To avoid an overlapping of both effects, just the aggregates and foam concrete made of a cement paste were used. The change in length of LACPMs over time as well as of foam concrete is shown in Fig. 12. The degree of drying shrinkage of the foam glass containing concrete could not be measured, as the grain size was too big for the applied specimen dimensions and following some shrinkage cracks occurred.

The high degree of drying shrinkage of foam concrete without any aggregates, additives or admixtures could be confirmed by a reduction of 4.8 mm/m that takes place after 90 days. The same applies for the addition of aggregates as their shrinkage ability could also be confirmed. The incorporation of expanded perlite leads to the highest degree of shrinkage with 3.0 mm/m, which is still an improvement of almost 40 %. The change in elongation is almost the same for concrete with pumice and with expanded glass, respectively. After 90 days both undergo a length reduction of only 1.5 mm/m, which means an improvement of almost 70 %. The lowest degree of drying shrinkage is reached by the application of expanded clay, which resulted in a length reduction of just 1.0 mm/m (1 ‰). The relatively high degree of shrinkage of the expanded perlite could be explained by the very low bulk density and the related low hindrance ability of the aggregate. In comparison the bulk density of the expanded glass is also comparatively low, but because of their sintered skin, the individual grain strength is higher. In addition the growth of the foam concrete into the perlite supports the shrinkage.

Some previous tests showed that the shrinkage behavior of foam concrete is strongly depending on the density. Therefore the degree of drying shrinkage was also measured for the above mentioned recipes with a higher (25/75) and a lower (35/65) share of wet foam. Thus the development is similar and just the comparison of the change in length after 90 days is evaluated (Fig. 13).

The more foam is added, the higher the degree of shrinkage, which means that the reduction in length is more distinctly for lower densities of foam concrete. The same coherence is visible

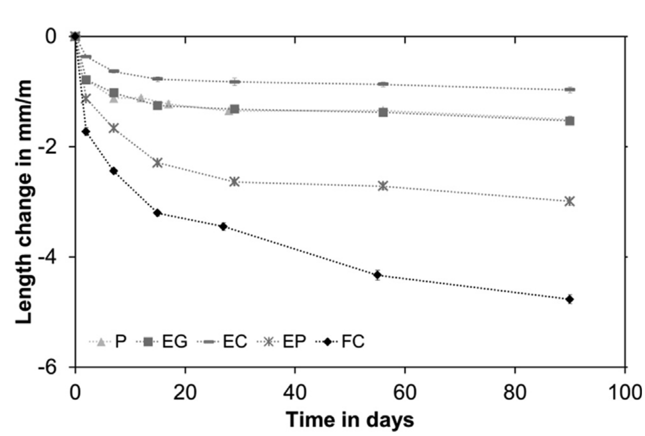



**Fig. 12.** Degree of drying shrinkage development of LACPMs and foam concrete.

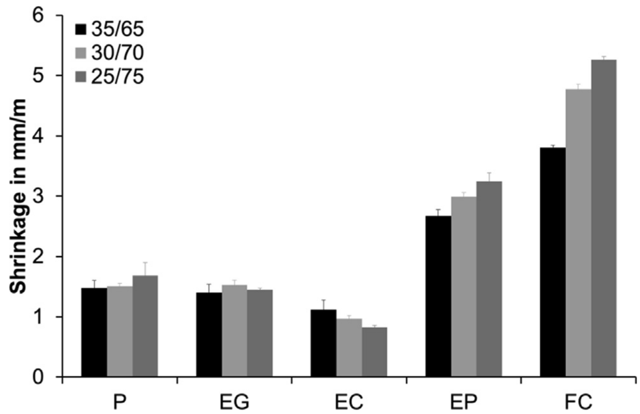



**Fig. 13.** Degree of drying shrinkage of LACPMs and foam concrete after 90 days.

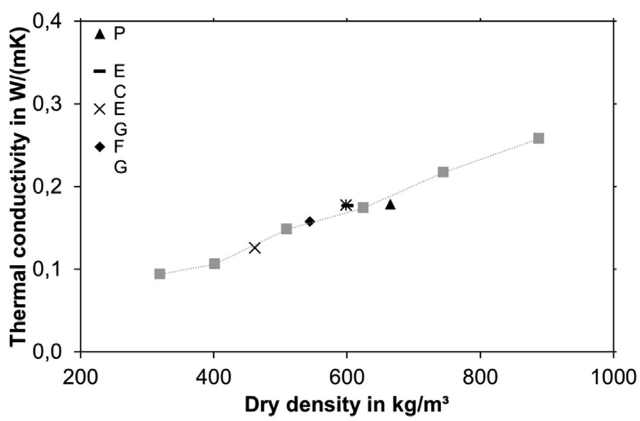



**Fig. 14.** Thermal conductivity of LACPMs and the foam concrete.

for the concrete with the expanded perlite. The lower the density the higher the degree of shrinkage of the concrete mixtures occurs. This proves the low hindrance of the expanded perlite, because the influence of the foam concrete is still obvious. For other aggregates there is no correlation between density and degree of shrinkage. For all samples of one type of aggregate the results are similar, just differing in the range of the error of measurement. Except for expanded perlite, the aggregates show a degree of shrinkage that seems specific for the type of aggregate, which is in average the smallest for expanded clay with 1.0 mm/m. The mean value for the pumice is 1.6 mm/m and for the expanded glass 1.5 mm/m. This also confirms that the LACPMs have an optimal packing density of aggregates. Otherwise the grains would be pushed apart from each other and the difference of the degree of shrinkage would be bigger for different recipes of the foamed concrete.

### *3.6. Thermal conductivity*

For lightweight materials and their related function as insulation materials thermal conductivity is an important property. The thermal insulation capability is just depending on the porosity e.g. the density of a lightweight concrete [25,26]. Due to the different dry densities from concretes with aggregates, various measurements for a wide density range of foam concretes have been performed. The results of the thermal conductivity measurement are plotted in Fig. 14 as a function of the dry density.

The thermal conductivity of foam concrete varies between 0.094 W/(mK) at a density of 320 kg/m$^3$ and 0.26 W/(mK) at a density of 890 kg/m$^3$. All conductivity values of the lightweight LACPMs are in the same range. That means that the thermal insulation is mainly depending on the material density regardless of the origin of the porosity.

## 4. Conclusions

Aim of this study was the development of a lightweight concrete with open structure, where the voids are filled with foam concrete. Different aggregates like pumice, expanded glass, foam glass, expanded clay and expanded perlite were incorporated. The mixing process was successful and the production of the concretes worked with every chosen aggregate.

On the microscopic scale the LACPMs exhibit a homogenous structure and a uniform distribution of the aggregates. The differences between the aggregates became evident on the nanoscale: at the surface as well as in their degree of embedding in the foam concrete matrix. Due to the rough surface, the embedding of the pumice, the expanded perlite and expanded clay was better than of the expanded glass and the foam glass with a relatively smooth surface.

Compared to the reference foam concrete that was used to fill the voids between the aggregates the dry densities of the LACPMs were lower; due to the aggregates' low bulk densities. The application of pumice marginally reduced the density, but increased the compressive strength by almost 40 %. The concretes made with foam glass, expanded clay and expanded perlite had a slightly reduced compressive strength, accompanied with a significant reduction in density. The application of expanded glass led also to a lower compressive strength, but at the same to a strong decrease of density. In relation to their densities, all aggregate concretes reached a higher compressive strength.

The high degree of drying shrinkage of foam concrete could be reduced by the utilization of lightweight aggregates. The best results were achieved by expanded clay, with a shrinkage rate of about 1.0 mm/m followed by pumice and expanded glass. Expanded perlite led to a detectable but weak decrease.

Thermal conductivity is in the same range as foam concrete and mainly depending on the density of the concrete.

All investigated lightweight aggregates could be applied for LACPMs, but all lead to different concrete properties. According to this, the optimal mixture is depending on the application and the required characteristics. These could be achieved by modifying the foamed concrete.

## CRediT authorship contribution statement

**Katrin Schumacher:** Conceptualization, Methodology, Investigation. **Nils Saßmannshausen:** Conceptualization, Methodology, Investigation. **Christian Pritzel:** Methodology, Investigation. **Reinhard Trettin:** Resources.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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