Development strategies for foamed cement paste

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ABSTRACT: For several decades numerous research projects dealt with foamed concrete. Although foamed cement-bound materials have very useful properties, for example low density and low thermal conductivity, they are not often used as construction material, because predefined properties are difficult to attain accurately. Therefore the intention of this research work is the unerring production of cement-bound foams. Based on technical and scientific basics of foam technology and concrete technology, special attention is paid to the rheological behaviour, mixture stability and the hardening process of cement paste as the dominating factors for its optimisation as liquid phase for foamed cement paste. From these considerations a comprehensive model for stable cement-bound foams is developed. Within this model the complex interaction of different components of cement pastes and their influences during the phases of production, workmanship and hardening are described. According to the before mentioned aspects, a stable composition for a foamed cement paste was developed. Modifications of this composition have been tested, in order to prove the reliability of the theoretical model.

1 INTRODUCTION

This article gives a review of our research work on the unerring production of cement-bound foams. Basics of the foam technology are shown, and approaches from concrete technology are pointed out, showing how to adjust cement-bound foams in order to stabilize them.

2 BASICS

The background for the unerring production of cement-bound foams is the understanding of the “foam” system. Especially the stabilizing forces, as well as the processes leading to the collapse of liquid foams, are of particular importance. But before describing details of foams, the first step is the differentiation of different kinds of foams. KERN 2002 distinguishes between three kinds of foams, depending on the gas content of the fluid gas dispersion. This is pictured in Figure 1.

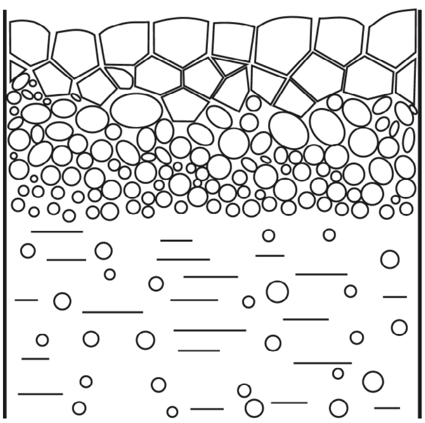

Figure 1. Different types of foam, characterized by the gas content ε, based on KERN 2002.

All further particulars refer to spheric foams. These spheric foams are a good compromise between foam stability and air content, respectively density. Polyhedral foams are not robust enough to outlast the workmanship and the period until hardening without significant changes of structure or total collapse. Bubble systems are less interesting, due to their lower air content and higher density.

The determining factor for the bubble-stability in a fluid is the balance between the internal pressure of the bubble, being always a bit higher than the ambient pressure, and tensile stresses absorbed by the bubble shell (Fig. 2). The maximum size of these tensile stresses depends on the inner cohesion of the fluid and the interfacial tension.

The stability of foams depends not only on the stability of its single bubbles but also on other effects. The most important one, especially for the production of cement-bound foams, is drainage. This means that air and fluid separate. The air bubbles up while the fluid flows out under the influence of the gravitation (Fig. 3). The most important influences on the drainage are the density and viscosity of the

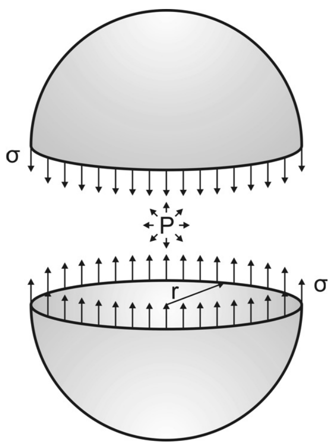

Figure 2. Schematic diagram of a bubble.

fluid. If the fluid-film between two bubbles thins out so far that the tensile stresses corresponding to the internal pressure can no longer be absorbed, the fluid film breaks and the bubbles affiliate. This is called coalescence.

Provided that the air entrainment works as well as possible, the maximum air content of the foam depends on geometrical aspects, like bubble diameter distribution and the minimum thickness of the fluid films between the bubbles. For this a higher viscosity of the fluid would be better. Nevertheless the viscosity has to be limited, because a high viscosity interferes with the air entrainment and the dispersion of the air in the fluid.

3 REQUIREMENTS OF CEMENT PASTE AS LIQUID PHASE OF FOAMS

As aforementioned in the basics, there are a lot of contradictory requirements for cement pastes to be foamed. Therefore two phases can be distinguished:

- Production of cement paste, foaming and processing
- Foam stability until hardening

During the first phase, method and requirements of air-entraining as well as the workability are the determining factors for the specification of the cement paste and its properties. To enable the entraining of air into the cement paste with an acceptable effort relating to energy and machines, relatively low viscosities are necessary. Furthermore the inserted air has to be well dispersed and covered in strong bubbles. Therefore a quick stabilization of the interface between air and cement paste is essential. This can be managed by surfactants (air-entraining admixture or foaming agent) in high dosage. But important for the stabilization of the interface is also its geometrical form. To absorb tensile stresses, the interface has to be as plain as possible. This can be achieved by a higher water content above the saturation point. Under these conditions the interstices between the solid particles at the interface can be filled. This filling of interstices can be supported by the addition of very fine particles like silica-fume. They can be placed in the space between the larger (cement) particles and reduce the volume which has to be filled with water (Fig. 4).

In the second phase the focus is on foam stability. It is important to reduce drainage. Therefore the separation of air and cement paste by bubble up or flow out has to be reduced to a minimum. In spite of the higher water content to allow the foaming process, a high viscosity is necessary for the foam stability between processing and hardening. In order to handle this contradiction, the cement paste has to be described as a 2-phase-system with a liquid and a solid phase. The motion of solid particles always causes a motion of the circumfluent liquid phase. Thus the drainage can be effectively reduced by controlling the mobility of the water. In tests this could be achieved by using organic stabilizers, polycarboxylic ethers (superplasticizers) and very fine particles like silica fume.

Characterizing the situation inside a water filled interstice between several cement particles the respective mode of operation can be easily described (see Figs. 5 a-d).

Within the initial situation only a small proportion of the water is bound to the surfaces of the cement particles. The predominant proportion of the water can move free and flow out of the interstice under the influence of gravitation. With the addition of polycarboxylic ethers (PCE) much more water can

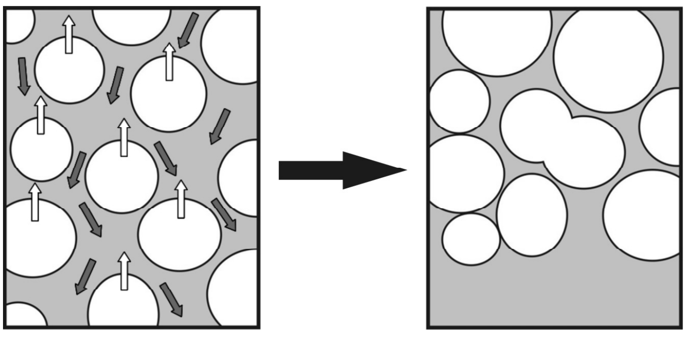

Figure 3. Schematic diagram of drainage and coalescence.

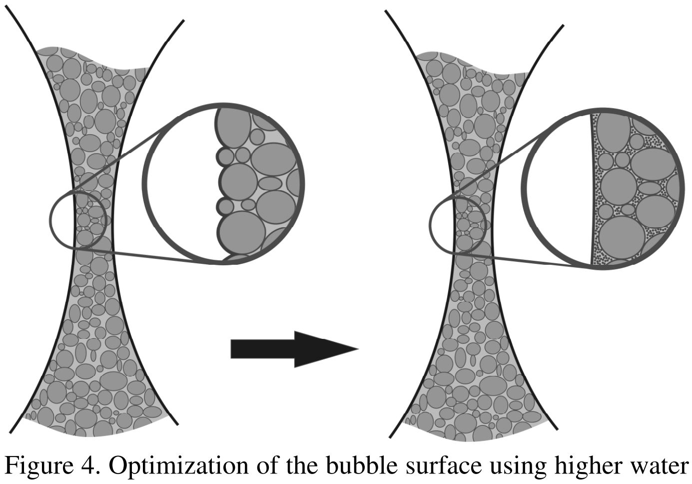

Figure 4. Optimization of the bubble surface using higher water content and silica fume.

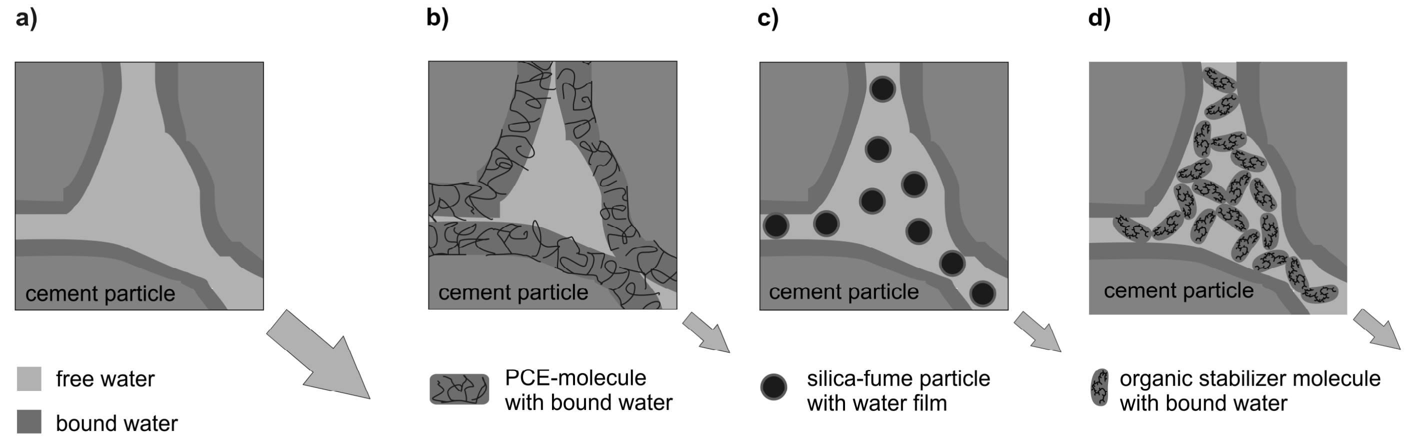

Figure 5. Options to control the drainage.

be bound to the solid particles. The molecules of the PCE contact the particles with their backbone and adsorb water molecules at their side chains. With this effect the film of bound water around the particles becomes thicker, the proportion of bound water increases and the remaining cross-section for the flow of unbound water decreases. The back pressure rises. A similar effect can be achieved by the addition of very fine particles. Due to their immense largeness of surface they can bind a lot of water and they downsize the remaining cross-section for waterflow, too. Another possibility to bind the water is the use of organic stabilizers. These are large organic molecules. They can adsorb a lot of water molecules. These emerging molecule packages are more inert and immobile. If their long molecule chains intertwine they can even evolve into a sort of net-structure, which limits the mobility of both the bound and the free water molecules. As a result of all these three effects the drainage can not be stopped completely, but it can be significantly slowed down. This is the basis for a foamed cement paste being stable until hardening with minimal symptoms of decline.

The before mentioned ideas are combined and illustrated in Figure 6.

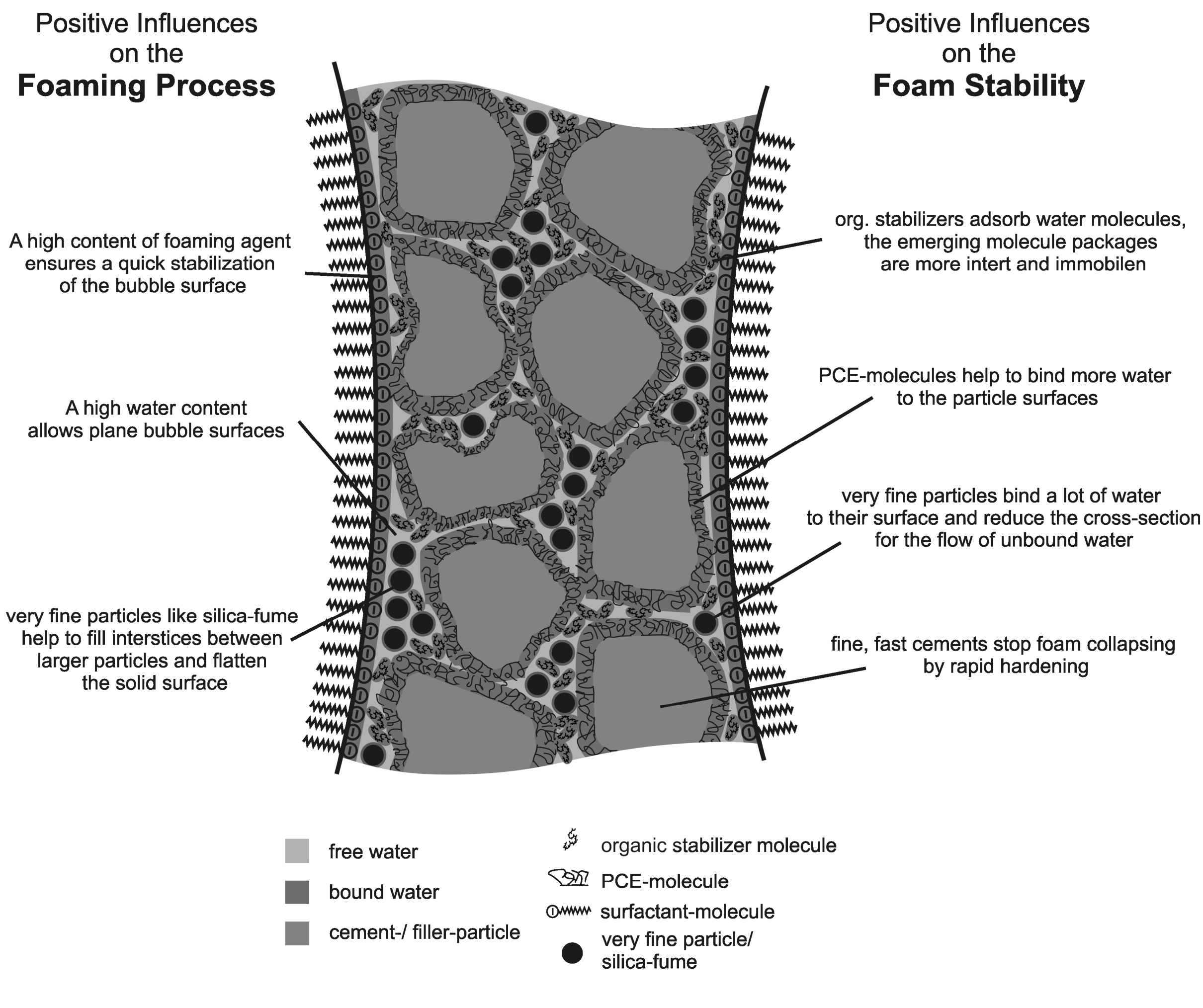

Figure 6. Model of the influences of different components of cement paste on foam processing and foam stability.

4 EXPERIMENTS AND THEIR RESULTS

Within the experimental research program preliminary tests were used to develop a robust basic recipe for foamed cement pastes, based on the described theoretical ideas. In a parametric study more then 150 variants of this recipe were tested to examine the influence of different types of cement, admixtures, additives and different dosages of these substances. Due to the allowed extension of this paper it is not possible to show all the results in detail. They can be looked up at POTT 2006. The diagram in Figure 7 shows exemplarily the influence of different organic stabilizers and their dosage on the foam stability. It becomes apparent that both type and dosage of the organic stabilizer decide about the foam stability. It is obvious that the dependency is not linear. There is a material related marginal dosage which is necessary to keep the foam stable. The influence on the density of the fresh and hardened (stable) foamed cement pastes is small. This sort of analysis does not detect changes of the pore structure inside the foam. They were reviewed by means of fracture surfaces.

It has also been demonstrated that the surface of robust bubbles in fresh foamed cement paste is always made up of a closed fluid film. Pictures of the inner side of pores in hardened foamed cement paste were made with a scanning electron micrograph (SEM). These pictures show platy crystal structures all over the surface of the pore (Fig. 8). With the help of energy dispersive X-ray analysis a huge amount of Ca-atoms and nearly no Si-atoms could be detected within these platy crystals. This indicates a closed film of calcium hydroxide solution on the inner surface of the bubbles. Solid particles like cement or silica fume are not integrated in the surface structure between cement paste and air.

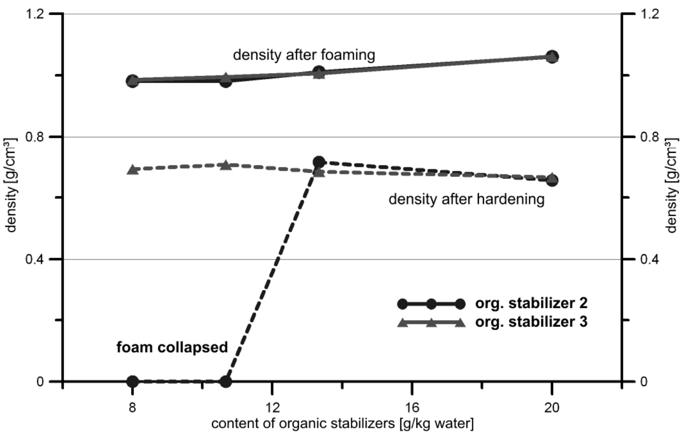

Figure 7. Influence of the dosage of different organic stabilizers on the foam stability.

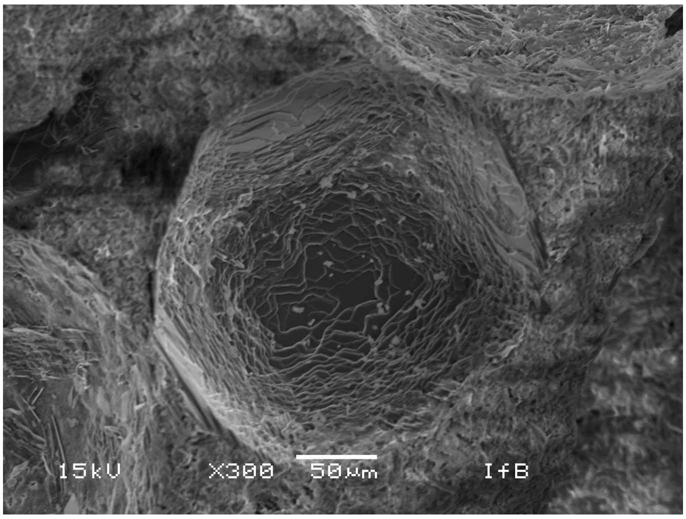

Figure 8. SEM-Picture of a pore with platy crystal structures.

5 SUMMARY

The paper at hand provides an insight into a wide research project for the production of cement-bound foams (see POTT 2006). Some substantial results are described. With the help of optimized recipes for cement pastes it is possible to froth them up and to keep the foam stable until it is hardened. Based on the basics of foam technology and concrete technology some principals for the production of cement-bound foams were derived and experimentally verified:

- Foamed cement pastes should be spheric foams to be robust enough to resist usual effects from processing and while hardening
- The production of cement-bound foams requires relatively high contents of water to allow plane interfaces between cement paste and air (bubble)
- The water in the fresh cement paste should be bound and made immobile. This can be achieved by using very fine particles, organic stabilizers and polycarboxylic ethers (superplasticizers) to minimize the drainage and keep the foam stable until hardening

With these results the further development of foamed cement-bound building materials for different fields of application will be possible.

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