IMPACT OF SETTING RETARDER INCORPORATION ON FOAM CONCRETE PROPERTIES

Adéla Kapicová, *

Katedra betonových a zděných konstrukcí, Fakulta stavební,
České vysoké učení technické v Praze, Thákurova 7/2077, 166 29 Praha 6, Česká republika.
`adela.kapicova@fsv.cvut.cz`

ABSTRAKT

Tato studie řeší problematiku nedostatečné stability předem připravené pěny určené pro výrobu pěnobetonu. U pěny dochází po jejím vmíchání do čerstvé betonové směsi k rychlé degradaci; proces degradace následně vede k příliš nízké pórovitosti pěnového betonu.

Na základě amerického patentu bylo navrženo řešení v podobě přidání zpomalovače tuhnutí betonu do navržené směsi. Byly vyrobeny čtyři sady vzorků – referenční směs a tři směsi obsahující 0.1, 0.3 a 0.4 % zpomalovače tuhnutí. Pro tyto vzorky byla změřena objemová hmotnost, pevnosti a zvuková pohltivost. Na základě výsledků bylo rozhodnuto, že zpomalovač tuhnutí zvyšuje stabilitu pěny a napomáhá tedy vyšší výsledné pórovitosti. Nejvyšší pórovitosti dosáhl vzorek obsahující 0.3 % zpomalovače, toto množství zpomalovače lze tedy označit za nejvýhodnější.

KLÍČOVÁ SLOVA

Pěnový beton • Pórovitost • Stabilita pěny • Zpomalovač tuhnutí • Zvuková pohltivost

ABSTRACT

This study deals with the low stability of the pre-made foam used for foam concrete manufacturing. Previously, it was observed that foam mixed with fresh concrete quickly deteriorates. Such a process in general results in insufficient foam concrete porosity.

Based on a US patent, the following solution has been suggested: adding setting retarder into the concrete composition. Four sets of samples were manufactured – a reference sample and three samples containing 0.1, 0.3, and 0.4 wt. % of setting retarder. For those samples, bulk density, strength, and sound absorption were measured. Based on the obtained results, it was decided that setting retarder addition results in better foam stability and therefore in higher total porosity. The best results were provided by the sample containing 0.3 wt. % of retarder.

KEYWORDS

Foam concrete • Porosity • Foam stability • Setting retarder • Acoustic absorption

1. INTRODUCTION

Foam concrete is a lightweight material, in general consisting of cement, water, and fine aggregate. It is characterized by the presence of a large number of pores in its structure, where the porosity is induced e.g. by the incorporation of foaming agents or pre-made foam.

This material is known and widely used for its advantageous properties. Its exceptional thermal performance minimizes building energy losses; such material behaviour is nowadays desired, as the requirements for building energy efficiency keep increasing. Foam concrete is therefore successfully used in the form of thermal insulation and in some cases even fire insulation. Moreover, thanks to its sound-absorption potential, it can be used for manufacturing structures that are dealing with excessive noise. The use of foam concrete is also desired for its low weight that not only lowers the dead weight of the construction, but also reduces the transportation costs of such material (Fu et al, 2020).

Despite its mechanical characteristics being insufficient for structural applications, foam concrete seems to be, especially in the form of non-structural members, an environmentally- and cost-efficient ordinary concrete alternative with a great impact on the interior building environment, which could even be used for concrete 3D printing (Liu et al., 2021). However, its proper performance is dependent on the character of the gained porosity, as all the mentioned properties are significantly affected by the character of the matrix porous system. Specifically in the case of acoustic absorption, there are several important factors to take into account – the porosity character (open versus closed porosity), the size of pores, the distribution of pores etc. (Luo et al., 2011). These factors are affected e.g. by the method of pore development/ air introduction into the matrix and its steps and specifics. In the case of using separately produced foam, porosity depends on the foam quality, bubble size distribution, foam density, and foam amount. Moreover, porosity is affected by used admixtures.

---

* Školitel: doc. Ing. Petr Bílý, Ph.D.

This experiment focuses mainly on foam quality and the impact of admixtures. It is a part of an ongoing research analysing the impact of material composition on the resulting foam concrete properties, with acoustic absorption being the main factor of interest. In previous research (Kapicová, 2021), the desired composition in terms of cement, water, aggregate, and foam amount has already been set. However, the quality and stability of the used foam seemed to be unsatisfactory, with most of the separately made foam quickly deteriorating and being destroyed during the process of foam mixing with concrete. Such behaviour resulted in quite low porosity and high bulk density of the manufactured foam concrete despite the expectedly sufficient amount of used foam. As acoustic absorption depends on open porosity, the acoustic performance of the samples was also worse than expected. Therefore, it was decided that it is necessary to develop some method of foam stabilization that would result in higher porosity and better sound absorption.

According to Gray (2012), the problem with foam quality in foam concrete is caused by low stability of most of the available foaming agents in cementitious media. Foam usually quickly deteriorates after being mixed with concrete due to the mechanical and chemical interaction with cement. For this reason, it is hard to predict sample porosity and therefore come up with an ideal composition of foam concrete.

The solution for this problem was suggested in patent US 8,167,997 B2 (Gray, 2012). This patent recommends adding hydration stabilizer into foam concrete. The stabilizer presence is supposed to allow foam to be mixed with cement properly without being destroyed; such performance is ensured by controlling and postponing the hydration reaction. The reaction usually causes the largest foam deterioration.

The mentioned patent´s solution was chosen for this experiment, as it is recommended for use in combination with firefighting foams. The foam used in this experiment is a firefighting foam as well, and therefore, such solution is a fitting one. For the needs of this study, a hydration stabilizer was replaced by a hydration retarder, as the patent mentions that retarder is usually included in stabilizers.

Other possibilities to improve foam quality, e.g. the addition of surfactants, foam stabilizers, or viscosity modifiers (Gray, 2012) (Liu et al., 2021), were also considered. However, most foaming agents, including the one used, already contain some of these options. Also, the impact of these options on the fresh and hardened concrete properties is harder to evaluate in advance. Therefore, these options have not yet been investigated.

2. MATERIALS AND METHODS

Four types of foam concrete specimens were prepared from portland cement CEM I 42.5 R (Českomoravský cement, a.s. – Závod Mokrá) (C), sand aggregate of the size 0–4 mm (A), water (W), and foam (F) produced by mixing the foaming agent Sthamex 5% with water. Except for the reference sample, the samples also contained the setting retarder Retardal 540 (R). The composition of the examined specimens is shown in Table 1. Sample PR is the reference sample, and samples P6–P8 are the samples containing retarder. Sample numbering starts with 6, as these samples build up on another five sample types from the previous research (Kapicová, 2021).

Table 1: *Sample composition [kg·m^{-3}].*

	C	A	W	F	R
PR	500	850	250	14.9	-
P6	500	850	250	14.9	2
P7	500	850	250	14.9	1.5
P8	500	850	250	14.9	0.5

The composition, specifically the amount of used cement, aggregate, and water/cement (W/C) ratio, was chosen based on the study conducted by Hilal et al. (2014) – concrete mix FC6 described in the study was set as the initial composition for its promising open and total porosity. The appropriate foam amount was decided by a series of experiments closely described by Kapicová (2021). It was set to 14.9 kg·m^{-3}, as such an amount managed to provide a sufficient porosity.

The foam was pre-made before the concrete mixing began. It was created by stirring foaming agent Sthamex 5% with water in the ratio 1:20 (S:W); such ratio was recommended by the manufacturer. It is important to take into account that the water contained in foam was not counted into the W/C ratio (W/C = 0.5). The W/C ratio was chosen independently of the foam amount, and it was set to be high enough to prevent cement from absorbing the water bound in the foam and therefore from causing foam degradation. This approach was recommended by Kearsley et al. (2005).

The setting retarder was used in the case of samples P6–P8. It was added in three different amounts set as wt. % of cement. Sample P6 used 0.4 wt. %, sample P7 used 0.3 wt. %, and sample P8 used 0.1 wt. %. Those amounts were chosen based on the manufacturer´s recommendation.

Figure 1: *Foam preparation setup.*

The mixing process began by preparing foam in a bucket with the use of a drill provided with a special extension (see Figure 1). Subsequently, dry concrete components were mixed for 30 seconds by a laboratory mixer. Afterwards, water (reference sample) or water mixed with setting retarder was added, and the mixing process continued for another 90 s, involving manual mixing in the middle of the process with the purpose of ensuring proper homogenization of the mixture. Subsequently, the prepared foam was added and blended with concrete by hand – such setup was chosen, as mixing by the laboratory mixer resulted in excessive foam deterioration.

The fresh concrete mixtures were cast into three prismatic steel moulds with the dimensions 40 × 40 ×160 mm, and into four circular moulds – two with the diameter of 98 mm and two with the diameter of 43 mm, both with the thickness of 20

---

* Školitel: doc. Ing. Petr Bílý, Ph.D.

mm. The fresh samples were then kept in the moulds for three days, as their slowed setting did not allow earlier demoulding. Afterwards, the samples were stored in water at 20 °C. The samples for mechanical testing were kept in the water tank until testing; the samples used for acoustic testing were removed from water approximately a week before testing.

The following material properties were tested: bulk density ρ [kg·m^{-3}], compressive strength f_{cm} [MPa], flexural strength f_{ctm} [MPa], and acoustic absorption coefficient α [-]. Bulk density was measured in accordance with the standard EN 12390-7 (CEN, 2019); it was measured in a dry state (ρ_{dry}) and in a wet state (ρ_{sat}) after being withdrawn from water.

The flexural strength test was performed in accordance with the standard EN 196-1 (CEN, 2016) suitable for cement testing – this standard was chosen based on the sample size. The compressive strength test was performed according to the mentioned standard as well; however, because of the low value of foam concrete compressive strength, the loading speed was changed to the one described in EN 12390-3 (CEN, 2019), i.e. from 1.5 ± 0.125 MPa/s to 0.6 ± 0.2 MPa/s.

The acoustic absorption test was performed according to the standard ISO 10534-2 (ISO, 1998); the transfer function method was used. This method was performed in two impedance tubes with the diameters of 100 mm and 44 mm. The frequency range 100–1250 Hz was measured in the wider tube, and the frequency range 630–4000 Hz was measured in the narrower tube. The overall frequency range, 100–4000 Hz, was chosen for its relevance for human hearing, as those frequencies are the most problematic ones.

Due to logistics reasons, only one of each pair of cylindrical samples was used for acoustic performance measuring; the one with a visually better porosity was always examined. The samples were examined in combination with acoustic insulation (mineral wool) with a thickness of 40 mm. The thickness of the total setup was 100 mm, which consisted of a 20 mm thick sample, 40 mm of mineral wool, and a 40 mm thick air gap behind the mineral wool.

3. RESULTS AND DISCUSSION

The gained saturated and dry bulk densities are shown in Figure 2. The saturated values include standard deviations, as those were measured for all three prismatic samples. On the other hand, dry values were usually measured for one sample only; for that reason, standard deviations are missing for the dry samples.

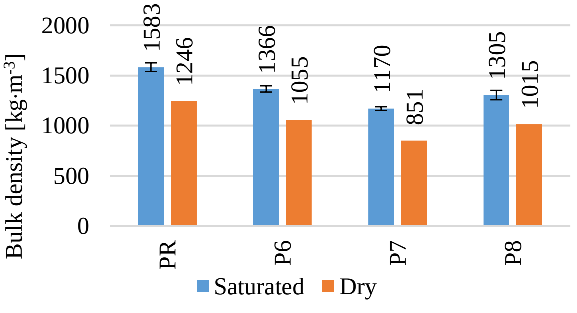

Figure 2: *Saturated and dry bulk density.*

Both sets of bulk density values (dry and saturated) point towards the obvious effect of setting retarder. The reference sample PR provides the highest bulk density; all the samples including setting retarder show lower density. The lowest bulk density was measured for sample P7 containing 0.3 wt. % of setting retarder; in this case, the addition of setting retarder caused a decrease of 31.7% in dry bulk density. The decrease in bulk density for all samples containing setting retarder is shown in Figure 3.

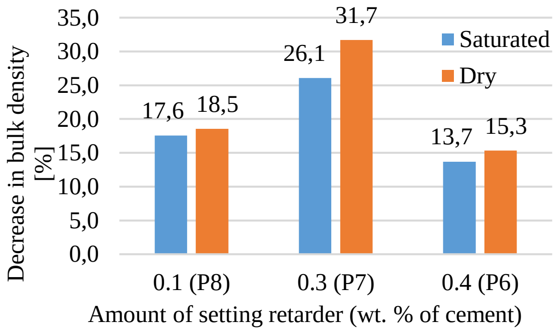

Figure 3: *Decrease in dry and saturated bulk density [%] caused by the addition of setting retarder; expressed in relation to the values measured for the reference sample.*

From the data shown in Figure 3, it is evident that there is no proportionality between the amount of used setting retarder and decrease in bulk density. Although in the first two cases (0.1 wt. % and 0.3 wt. %) concrete density decreases with the increasing amount of setting retarder, the last case containing 0.4 wt. % of retarder disrupts this trend. Overall, the composition containing 0.3 wt. % of retarder is the most advantageous if low bulk density of concrete is needed.

As the retarder presence is the only material difference between the reference sample and samples P6–P8, the matrix density of all the samples should be basically identical. This assumption means that the difference between sample bulk densities is caused by their different porosities. Therefore, the addition of setting retarder affects the sample porosity; in general, it causes an increase in porosity. Since the porosity of foam concrete prepared from pre-made foam directly depends on the foam stability and quality, it is reasonable to claim that the higher porosity is caused by better foam stability, which was obviously achieved by the retarder presence.

Overall, the bulk density results are the first confirmation of the corectness of the initial assumption that setting retarder improves foam stability. Higher porosity of the samples containing retarder is also visually observable (see Figure 4).

Figure 4: *Visual difference between the reference sample (PR = P4) and sample P6.*

---

* Školitel: doc. Ing. Petr Bílý, Ph.D.

The porous system of the samples was also observed by optical microscope. Figure 5 shows that the visible surface pores are thoroughly connected with the inside porous system; moreover, the connectivity between internal pores was observed on fractions of foam concrete samples.

Figure 5: *Microscope image of sample P8, magnification 50×.*

The measured compressive and bending strengths are shown in Figure 6. The compressive strength and bending strength provided by the reference sample are the highest ones measured, while the sample containing 0.3 wt. % of retarder provides the lowest values measured. As higher porosity generally leads to low strength, these results imply that sample P7 likely has the lowest porosity of all the samples.

Overall, the strengths provided by all foam concrete samples are very low, showing that foam concrete is not a suitable material for structural applications.

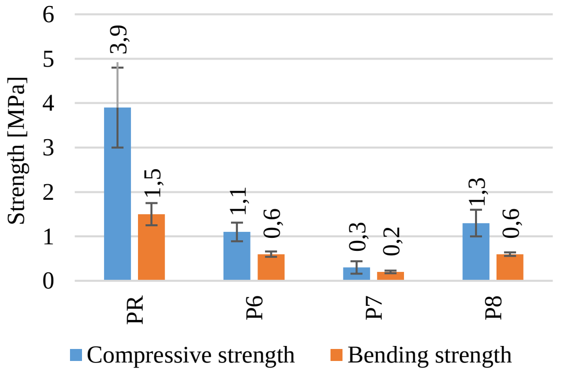

Figure 6: *Compressive and bending strengths of foam concrete samples.*

In Figure 7, the results of acoustic absorption are shown. However, only samples P6 and P7 were examined, as the other samples were visually significantly less porous and were evaluated as samples without any acoustic potential. Hence, the measuring of acoustic absorption of those samples was skipped.

Sample P7 shows higher values of sound absorption coefficient *α* [-] than sample P6 for most of the measured frequencies except for the third octave bands with central frequencies 2500 Hz and 3150 Hz; obviously, sample P7 is a more promising sound-absorbing material. The gained results describe not only the acoustic performance, but also the porosity of the materials. As open porosity is a key value for acoustic absorption, based on the absorption coefficient it is obvious that the open porosity of sample P7 is significantly higher than the open porosity of sample P6. Such claim is in agreement with the previous findings.

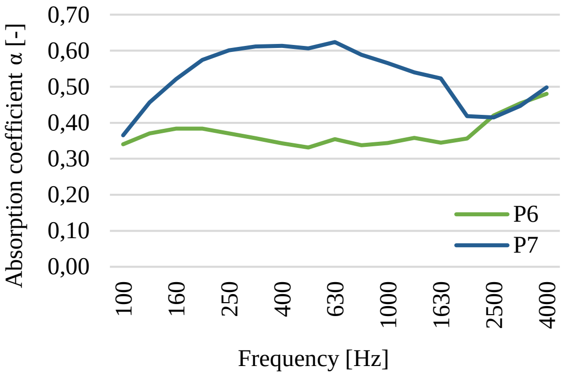

Figure 7: *Sound absorption coefficient of samples P6 and P7, measured in third octave bands.*

Overall, all the measured characteristics show that the total and also open porosity of foam concrete with composition P7 is the highest. Therefore, the amount of setting retarder 0.3 wt. % provides the used foam with the best stability. However, all the samples containing setting retarder showed higher porosity and therefore better foam stability compared to the reference sample.

4. CONCLUSIONS

This study examined the impact of setting retarder incorporation on the stability of the pre-made foam added into concrete. The findings are as follows:

- The addition of 0.3 wt. % of setting retarder (sample P7) into foam concrete resulted in concrete with the lowest bulk density. As the composition otherwise remained the same as that of the reference sample and the matrix density therefore did not significantly change, sample P7 obviously had the highest porosity of all the examined samples.
- Stable foam, i.e. foam that does not deteriorate, should provide concrete with better porosity. Therefore, the addition of 0.3 wt. % of setting retarder was proven to be optimal for enhancing foam stability.
- The setting retarder presence made porosity higher and foam more stable compared to the sample without retarder in all cases.
- High porosity is advantageous in terms of acoustic absorption; the sample with the highest porosity provided a high sound absorption coefficient for all measured frequencies. However, both measured samples provided high values of α when compared to ordinary concrete, as α values of ordinary concrete usually do not exceed 0.1.

---

* Školitel: doc. Ing. Petr Bílý, Ph.D.

- On the other hand, high porosity can be a disadvantage in some applications, as it results in low mechanical properties. Strengths of all examined foam concrete samples were considerably low, supporting the claim that foam concrete is not suitable for structural use.
- The gained results confirm that porous concrete is suitable for various non-structural uses. It can be used e.g. as a lightweight sound absorbing cladding.

The use of setting retarder was successful; this method of foam stabilization proved to be valid. In the following parts of this study, the other possibilities of foam stabilization might be examined. Future studies will also put a greater focus on the examination of foam manufacturing process replicability and on ways to obtain foam with uniform properties, as this proved to be a challenge in this experiment. Moreover, the impact of various foam entertaining agents will be examined.

ACKNOWLEDGEMENTS

This research was funded by the TREND programme of the Technology agency of the Czech Republic (TA ČR), project no. FW03010173 “Development of sound-absorbing concrete for interior applications”.

A special acknowledgement goes to doc. Petr Bílý and doc. Josef Fládr for their help with foam concrete manufacturing and for their various innovative ideas.

References

CEN (2016), *Methods of testing cement – Part 1: Determination of strength*, EN 196-1, viewed 7 March 2022, retrieved from ČSN Online.

CEN (2019), *Testing hardened concrete – Part 3: Compressive strength of test specimens*, EN 12390-3, viewed 7 March 2022, retrieved from ČSN Online.

CEN (2019), *Testing hardened concrete – Part 7: Density of hardened concrete*, EN 12390-7, viewed 7 March 2022, retriever from ČSN Online.

Fu, Y., Wang, X., Wang, L., Li, Y. (2020), ‘Foam Concrete: A State-of-the-Art and State-of-the-Practice Review’, in *Adv. Mater. Sci. Eng*. vol. 2020, pp. 1–25

Gray, L. J. (2012), *Concrete mixtures having stabilized foam admixture*, USA Patent US 8,167,997 B2 [Online]. Available at https://patentimages.storage.googleapis.com/c1/2a/c6/100d0278748992/US8167997.pdf.

Hilal, A., Thom, N.H., Dawson, A. R. (2014), ‘Pore Structure and Permeation Characteristics of Foamed Concrete’, in *J. Adv. Concr. Technol.*, vol. 12, pp. 535–544.

ISO (1998), *Acoustics – Determination of sound absorption coefficient and impedance in impedance tubes – Part 2: Transfer-function method*, ISO 10534-2, viewed 10 March 2022, retrieved from ČSN Online.

Kapicová, A. (2021), Concrete for interior acoustic purposes. Master´s thesis. Czech Technical University in Prague.

Kearsley, E.P., Mostert, H. F. (2005), ‘Designing mix composition of foamed concrete with high fly ash contents’, in *Proceedings of the International Conference on the Use of Foamed Concrete in Construction*; Ravindra, K., Dhir, M.D.N., McCarthy, A., Eds.; Thomas Telford Publishing: London, UK, 2005; pp. 29–36.

Liu, Ch., Wang, X., Chen, Y., Zhang, Ch., Ma, L., Deng, Z., Chen, Ch., Zhang, Y., Pan, J., Banthia, N. (2021) ‘Influence of hydroxypropyl methylcellulose and silica fume on stability, rheological properties, and printability of 3D printing foam concrete’, in *Cem Concr. Compos*., vol. 122, pp. 104158.

Luo, X., Li, W., Jin, X., Zeng, L. (2011), ‘Effects of Porosity and Pore Size on Sound Absorption Characteristic of Ceramsite Porous Material’, in *J. Chin. Ceram. Soc.*, vol. 39, pp. 158-163.

---

* Školitel: doc. Ing. Petr Bílý, Ph.D.