trend can be explained as follows. The fiberglass has the properties of a hollow tubular material. The short-chopped fibers are distributed evenly in the slurry, and packed densely by the slurry layer [24]. Thus, the alkali-resistant fiberglass is tensioned in all directions, forming a disordered support system, in which the cementitious materials are bound into a dense 3D network with enhancement effect [25-27]. The disordered support system inside the foam-concrete consists of countless fiber monofilaments. Together, these monofilaments hinder the separation of aggregates and ensure the uniform bleeding of the foam-concrete in the early phase. In this way, more pores are formed and the concrete strength is improved [28]. The excessive growth of fibers may suppress the compressive strength, because the fibers cannot disperse evenly but agglomerate when the fiber density is too high in the foam-concrete.

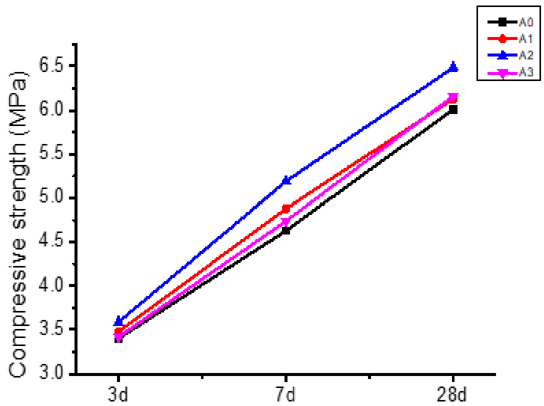

Figure 2. Influence of proportion of fiberglass on strength of concrete

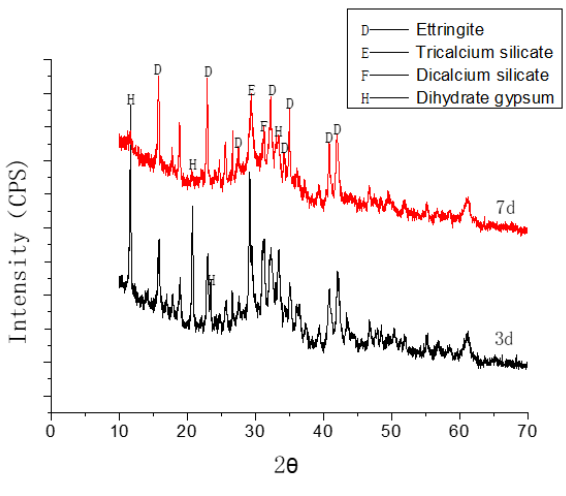

Figure 3. XRD pattern of pastes at different ages

The foam-concretes cured for 3d and 7d were subjected to X-ray diffraction analysis, aiming to clarify the strength enhancement mechanism of foam-concrete made purely from solid wastes. The results show that the peak strength of ettringite was higher on the 7th day than the 3rd day, indicating that the ettringite was not fully generated on the 3rd day. With the elapse of time, more and more ettringite was produced through hydration in the system of steel slag (SS), blast furnace slag (BFS)and desulfurized gypsum (DG). Meanwhile, the peak strengths of C_2S and C_3S were smaller on the 7th day than the 3rd day. This means the C_2S and C3S in the steel slag powder were hydrated, forming the C-S-H gel. For $CaSO_4 \cdot H_2O$, the main component of FGD gypsum, the peak strength was obviously lower on the 7th day than the 3rd day. This trend reveals that the Ca^{2+} in FGD gypsum were involved in the hydration reaction, and reacted with the AlO_2^- from the mining slag, producing ettringite. As shown in the fig.3, undecomposed gypsum was observable on the 3rd day, but almost disappeared on the 7th day, indicating the involvement of decomposed gypsum in hydration. In the later phase, the compressive strength grew slowly, because the growth was mainly driven by ettringite in the system. The formation of ettringite was confirmed by the XRD analysis and scanning electron microscopy (SEM), as shown in the Figure 4.

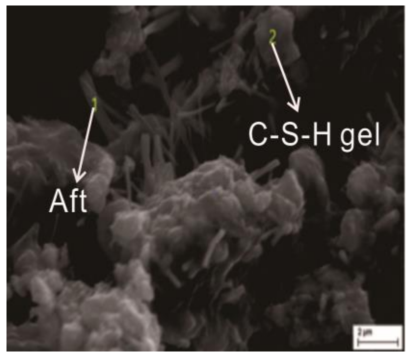

Figure 4. SEM images of hydration products cured for 7d

Next, foam-concretes were prepared without fiber, and with 1 %, 3 % or 5 % of fibers, and measured by standing-wave tube method. The sound absorption coefficients of all specimens were obtained and presented in Figure 5. It can be seen that the cementitious materials foamed without fiber were comparable to ordinary foam-concrete in sound absorption. With the addition of fibers, the foam-concrete did better in absorbing high-frequency noises but poorer facing low-frequency noises. This is because fibers enjoy strong ability to absorb high-frequency sound waves [29]. The addition of fibers made the foaming system more viscous and harder. What is worse, the fibers could not disperse evenly in the specimens [30]. In the foaming process, the fibers impeded the formation of pores, and thus suppressed the absorption of low-frequency sound.

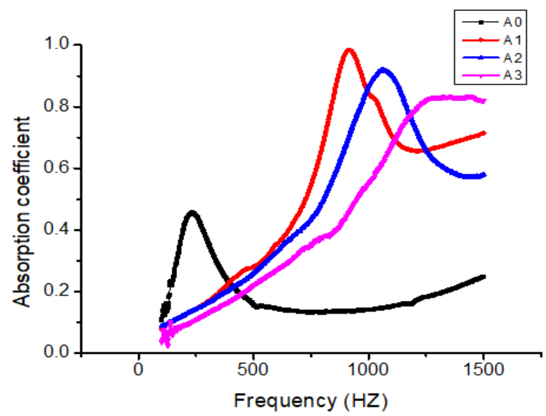

Figure 5. Influence of proportion of fiberglass on sound absorption coefficient of concrete

The above analysis shows that the material boasted a high compressive strength and good sound absorption performance at the fiber content of 3 %: the 28d strength amounted to 6.26 MPa and the mean sound absorption coefficient reached 0.346.

3.2 Effects of physical-chemical combined foaming on the strength and sound absorption of foam-concrete

As shown in the Figure 6, after adding 0.5 % aluminum powder, the strength of foam-concrete increased by 3.53 %, 5.40 %, and 8.49 %, respectively, on the 3rd day, 7th day and 28th day, from the level of the specimen prepared without aluminum powder. The possible reasons of the strength growth are as follows. With the addition of aluminum powder, the nano-sized aluminum powder reacted rapidly to form microbubbles, making the slurry system more uniform. Meanwhile, the Al^{3+} replaced the tetrahedron of silicon in the C-S-H gel, turning the latter into a geopolymer [31-32]. The cement slurry between the large bubbles was not severely lost, and many small pores were embedded in the large pores. This integrated two-layer structure enhanced the pore walls, and thus the foam-concrete.

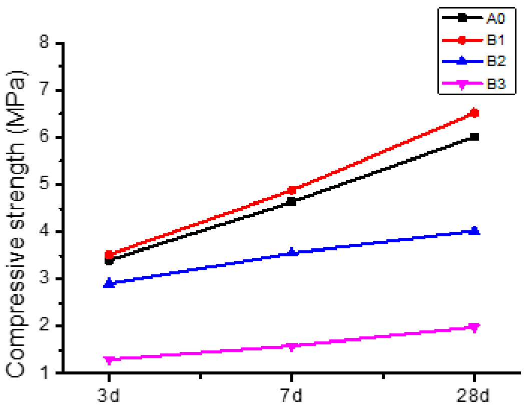

Figure 6. Influence of proportion of aluminum powder on strength of concrete

By contrast, the compressive strength of foam-concrete prepared with 1 % aluminum powder decreased by 14.7 %, 23.32 % and 66.89 %, respectively, on the 3rd day, 7th day and 28th day, from the level of the specimen prepared without aluminum powder. This is because the growing amount of aluminum powder accelerated the gas generation in a short time. Then, the original foam bubbles expanded, and the pores became interconnected. The heavy presence of interconnected pores is detrimental to the compressive strength.

When the aluminum powder content reached 1.5 %, the compressive strength of the foamed cementitious materials was reduced by 61.76 %, 65.66 % and 67.05 %, respectively, on the 3rd day, 7th day and 28th day. The dramatic decline in compressive strength was accompanied by the large expansion of the materials [33], the obvious increase in slurry temperature, the thermal expansion of bubbles and the drastic reduction of material density.

When the aluminum powder content was below 1.5 %, the sound absorption of the material was improved obviously with the increase of the dosage as shown in the Figure 7. This is because the closed circular pores prepared by physical foaming were re-opened by the micro-air flows from chemical foaming. The ensuing secondary agglomeration is a recombination of the gas phase, the liquid phase and the solid phase [34-35]. Due to the surface free energy effect, the micro- and small bubbles formed tiny facture zones, in which bubbles of different diameters continuously clustered into large bubbles, eventually forming interconnected pores. Further addition of aluminum powder and other materials sped up the exothermic chemical reactions [36]. Thus, the foams started to expand irregularly in size and diameter, narrowing the range of effective sound absorption.

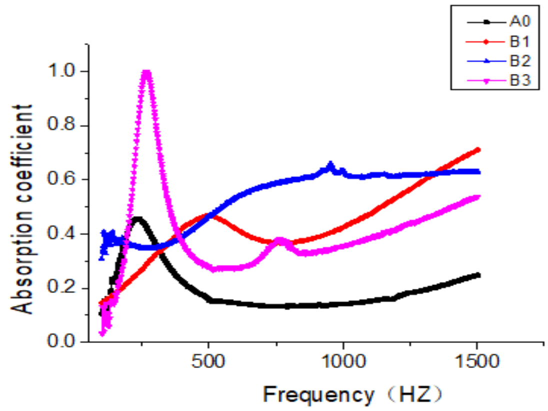

Figure 7. Influence of proportion of aluminum powder on sound absorption coefficient of concrete

3.3 Preparation and mechanism analysis of sound absorbing material based on the optimal mix ratio of steel slag and mining slag

The above analysis demonstrates that physical-chemical combined foaming can effectively improve the sound absorption of foam-concrete. When the dosage of aluminum powder is 1 %, the material can withstand the compressive stress of 4 MPa, which satisfies the standard for ordinary foam-concrete (A40), and the sound absorption coefficient 0.443 is much higher than that of ordinary foam-concrete.

Next, a sound-absorbing material was prepared with 3 % fibers and 1 % of aluminum powder, and subjected to measurements of compressive strength and sound absorption coefficient. The measurements put the 28d compressive strength at 4.99 MPa in the Figure 8, and the mean sound absorption coefficient at 0.457 as shown in the Figure 9. Through SEM observation in Figure 10, it is learned that the addition of aluminum power created micro airflows between the bubbles, resulting in more interconnected pores, and thus improved the sound absorption performance of the material i. For the foamed cementitious materials based on system of steel slag (SS), blast furnace slag (BFS), the enhancement of compressive strength hinges on the massive generation of ettringite (Aft) and C-S-H gel in Fig4 through hydration, which involves both C_2S and C_3S.

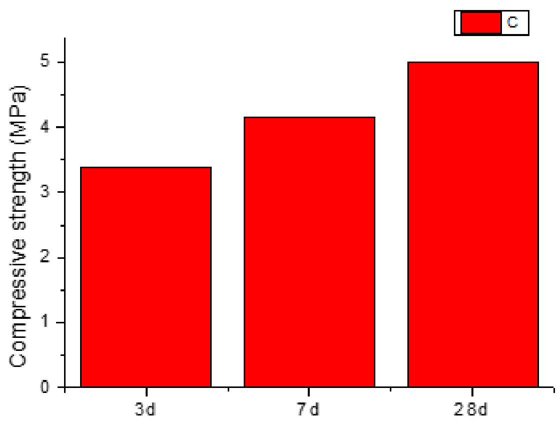

Figure 8. Compressive strength of sample C

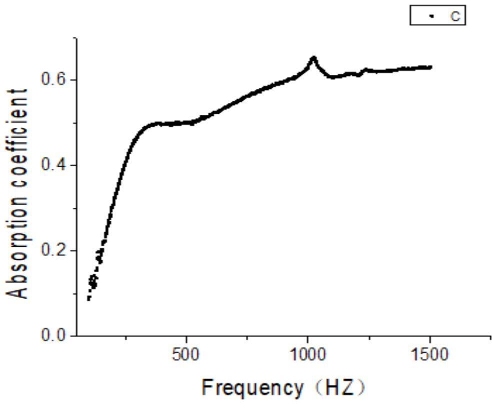

Figure 9. Sound absorption coefficient curve of sample C

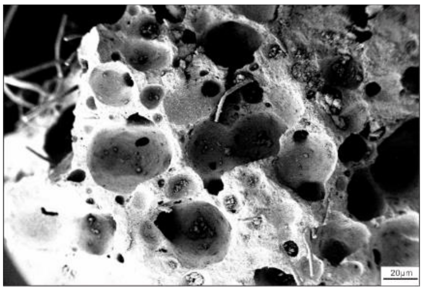

Figure 10. SEM images of pore structure of physical-chemical combined foaming concrete

4. CONCLUSIONS

(1) With the growth in fiber content, foam-concrete based on steel slag and mining slag increased first and then declined. Meanwhile, the foam-concrete did better in absorbing high-frequency noises but poorer facing low-frequency noises, and saw a narrower range of effective sound absorption. Considering the heavy presence of high-frequency noise sources in the industrial and construction fields, the bulk density of fiber-containing material should be properly increased to improve the high-frequency absorption ability of the foam-concrete, without violating the strength requirement.

(2) Physical-chemical combined foaming is an effective way to enhance the ability to absorb noises at different frequencies. For the cementitious materials prepared from steel slag and mining slag of the given SSA, the sound absorption performance is optimized as 0.457 at the dosage of 1% aluminum powder. However, excessive dosage will amplify the heat release of the chemical reactions, leading to a narrow range of effective sound absorption, hurting the sound absorption performance.

Physical-chemical combined foaming creates micro airflows between the bubbles, resulting in more interconnected pores, and thus improves the sound absorption performance of the material. The enhancement of compressive strength of the foam-concrete prepared from steel slag and mining slag comes from the formation of C-S-H gel and ettringite.

ACKNOWLEDGMENT

The authors would like to thank fund project: State Grid Corporation Headquarters Science and Technology Project Funding.

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