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Lightweight foamed concrete with foam agent addition

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Abstract. Lightweight foamed concrete with foam agent addition varied from 0 to 7wt% was fabricated and the influence of foam stabilizer and polypropylene fiber (PPF) addition on mechanical performance of lightweight foamed concrete was researched. The experimental data revealed that the density, thermal conductivity, flexural and compressive strength exhibited a rapidly downward trend with the increase of foam agent content due to generation of a large number of pores by decomposition of foam agent. The samples with foam stabilizer addition possessed better mechanical properties and lower thermal conductivity compared to the samples without foam stabilizer addition due to the improvement of pore structure. Besides, an appropriate amount of PPF could enhance flexural and compressive strength of specimens, while excess PPF was proven to be counterproductive.

1. Introduction

In recent years, light thermal insulation materials have been widely used in construction industry because their use can reduce weight of building itself and decrease building energy consumption depending on their low density and excellent thermal insulation performance [1, 2]. In the past period of time, organic thermal insulation materials such as polyurethane foams [3] and expanded polystyrene (EPS) [4] and have been extremely popular on building market by right of their low cost and high efficiency in heat preservation. However, their application is severely limited owing to their poor fire resistance which tends to give rise to safety accident such as occurrence of fire accidents in the buildings [5, 6].

As a kind of the most important inorganic thermal insulation materials, lightweight foamed concrete has attracted much interest of researchers because of its many superior capabilities such as outstanding sound insulation, light weight, superior thermal insulation performance and good fire resistance [7-9]. Lightweight foamed concrete is usually prepared by introducing foaming agent such as hydrogen peroxide and plant surfactants [10, 11] into cement paste to form high volume of pores and voids in the matrix. Because of high porosity, density and thermal conductivity substantially decrease which is beneficial to lightweight thermal insulation materials, while the mechanical properties such as flexural strength sharply decline which has a negative impact on its application and in order to enhance mechanical properties some measures can be taken such as addition of fibers. In addition, the pores are an important part of foamed concrete and it is very significant for foamed concrete to improve pore structure. The main way to improve pore structure is to introduce foam stabilizer such as polyvinyl alcohol, calcium stearate and polyethylene [11, 12]. In addition to pores, cementitious materials such as ordinary Portland cement (OPC) are another main component of foamed concrete. In recent years, it has become a trend to find a substitute for OPC due to a large amount of CO₂ emission and energy consumption in the production process of OPC. Therefore,



exploitation of fly ash (FA) and flue gas desulfurized gypsum (FGD) has been paid much attention due to their low energy consumption [13, 14]. However, little research about preparation of lightweight foamed concrete with these industrial solid wastes has been carried out.

In this paper, lightweight foamed concrete was prepared with FGD, FA, OPC and foaming agent and the effects of foaming stabilizer and PPF addition on its mechanical properties of lightweight foamed concrete were researched.

2. Experimental section

2.1. Materials

FGD and FA were derived from a power plant in Laiwu China and OPC was obtained from a cement factory in Jinan China. These materials were used as cementitious materials in this study and the chemical compositions were exhibited in Table 1. H_2O_2 with a concentration of 37.5% was used as foam agent to decrease the density and thermal conductivity. NaOH was used as activator to improve the hydration rate of FA. PPF with a length of 25 mm and foam stabilizer mainly composed of polyvinyl alcohol were added to enhance the mechanical strength of samples.

Table 1. Composition of the materials (wt%).

	SO ₃	MgO	SiO ₂	CaO	Al ₂ O ₃	Fe ₂ O ₃
FGD	43.11	2.01	1.45	31.80	0.53	0.21
FA	0.64	0.93	47.13	4.13	40.33	-
OPC	3.52	3.26	19.67	55.81	6.48	3.19

2.2. Samples preparation and test

Table 2. Mixture proportions of samples (wt%).

Samples	TCC	Water	Activator	Foam agent
0A	100	53	1.5	0
1A	100	53	1.5	1
2A	100	53	1.5	2
3A	100	53	1.5	3
4A	100	53	1.5	4
5A	100	53	1.5	5
6A	100	53	1.5	6
7A	100	53	1.5	7

The FGD was calcined at 155 °C for 200 min and placed at room temperature for 7 days before using it in order to convert it into hemihydrate gypsum. The ternary cementitious composites (TCC) were composed of FGD, FA and OPC with a mass ratio of 6:2:2. The ratio of water-to-binder (TCC) in this study was 0.53. Mixture proportions of samples were shown in the Table 2. FGD, FA and OPC were added into admixtures containing water, activator and foam stabilizer to mix evenly. Foam agent was added into mixed homogeneous paste to mix at a stirring speed of 120 rpm for 1 minute and then the paste was injected into the mold to foam (temperature of the mold was about 40 °C). The samples were demoulded after placed for 6 hours and cured in standard curing box for 28 days.

The density of lightweight concrete was acquired by dividing mass by volume. The flexural strength and compressive strength were evaluated by an electromechanical universal testing machine (CMT5105, China) on the basis of the GB/T 5486-2008. The samples were taken shape and thermal conductivity was obtained through operating a double-plate thermal conductivity tester (IM-DRY3001) on the basis of the GB/T 10294-2008.

3. Results and discussion

3.1. The effects of foam agent in foamed concrete

The density, thermal conductivity, flexural and compressive strength of foamed concrete with different mass percentages of RPP foam agent are exhibited in Figure 1 and 2. It can be found that addition of

foam agent provides tremendous effects on density, thermal conductivity, flexural and compressive strength. All of these properties rapidly decrease with the increase of foam agent addition from 0 to 5wt% which is mainly attributed to generation of high porosity in the sample matrix with foam agent addition. For lightweight foamed concrete, decline of thermal conductivity and density is beneficial to its application. The decrease of density tends to reduce the load of composite materials and the decline of thermal conductivity can reduce the heat loss and improve the efficiency of heat preservation and energy conservation. However, the density and thermal conductivity exhibit a slowly upward tendency when the addition of foam agent ranges from 5wt% to 7wt%. The reason is that the gas produced by the decomposition of foaming agent gradually increases and the total volume of bubbles in slurry largens when content of foaming agent becomes more and more in the specimens, resulting in the decrease of density of materials. When the content of foaming agent is more than 5wt%, the bubbles can not be stable in the slurry due to the generation of excessive gas that is prone to overflow from cementing material pastes leading to the increase of density and thermal conductivity. As exhibited in the Figure 2, flexural and compressive strength of lightweight foamed concrete still show a decline tendency with the increase of foam agent addition from 5wt% to 7wt% which is different from the trend of density and thermal conductivity. When a large amount of gas runs out from the matrix, connected pores and large pores tend to increase in the matrix of composite materials which can give rise to a decrease in mechanical strength. For lightweight concrete, addition of foam agent is disadvantageous to mechanical strength of specimens and in order to overcome the above-mentioned defects caused by foam agent addition, foam stabilizer and PPF are added with different mass percentages into the samples with 5wt% foam agent addition, as shown in Section 3.2 and 3.3.

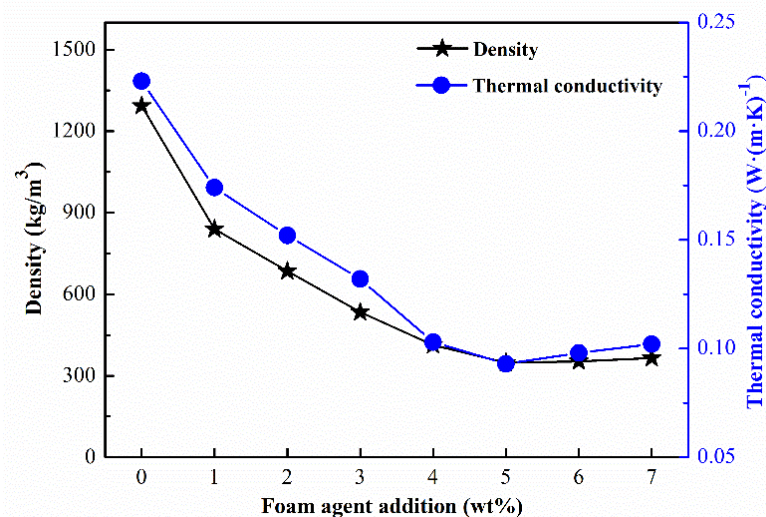


Figure 1. The thermal conductivity and density of specimens with foam agent added.

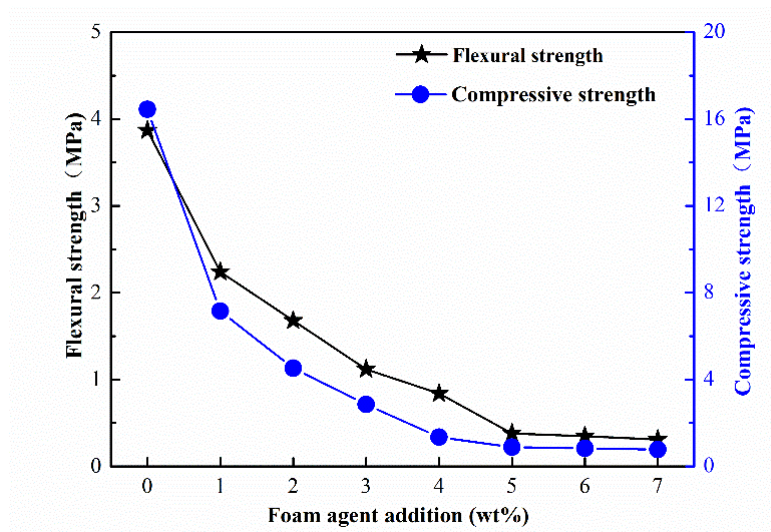


Figure 2. The flexural and compressive strength of specimens with foam agent added.

3.2. The effects of foam stabilizer in foamed concrete

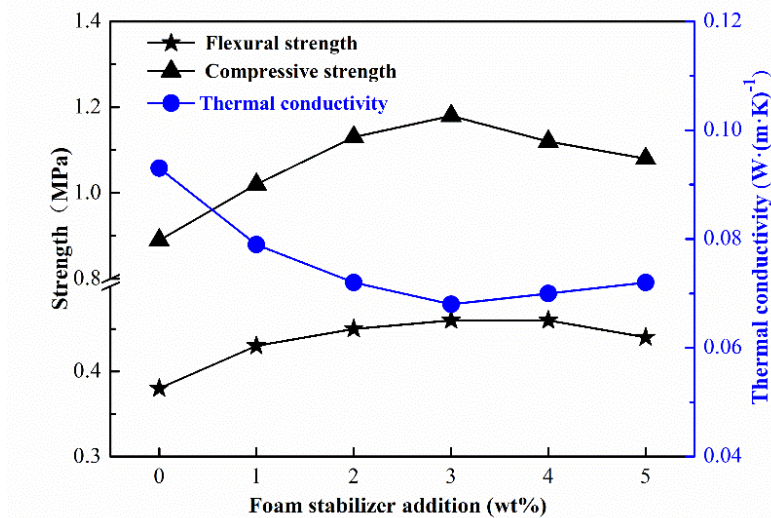


Figure 3. The thermal conductivity, flexural and compressive strength of specimens with foam stabilizer added.

Figure 3 presents that the effects of foam stabilizer addition on thermal conductivity, flexural and compressive strength of foamed thermal insulation concrete. As can be demonstrated from Figure 3, flexural and compressive strength of foamed thermal insulation concrete progressively increase when content of foam stabilizer varies from 0 to 3wt% in the specimens, while they show a downward trend with the content of foam stabilizer from 3wt% to 5wt%. The flexural and compressive strength of specimens with 3wt% foam stabilizer addition run up to a peak value of 0.46 MPa and 1.18 MPa, far greater than mechanical strength of specimens without foam stabilizer. Connected pores and large pores tend to be formed by adding foam agent. Under the action of external force, the stress will be concentrated at a point in the specimen where connected pores and large pores exist, resulting in decline of the mechanical capabilities of the specimens. The addition of foam stabilizer can improve the pore structure by forming a polymer film in the matrix which can lead to the decrease of connected pores and large pores [11, 12]. Besides, we can also see from Figure 3 that the addition of foam

stabilizer also has a positive effect on thermal conductivity which is mainly attributed to improvement of pore structure leading to the decrease of heat loss from connected pores to outsides.

3.3. The effects of PPF in foamed concrete

Figure 4 presents the effects of PPF addition on mechanical capabilities of foamed thermal insulation concrete. As revealed in Figure 4, the flexural and compressive strength of foamed specimens increase step by step with increase of PPF addition from 0 to 0.9wt% and then reach a maximum value of 0.61 MPa and 1.27 MPa which increase by 32.61% and 7.63% respectively compared to the samples without PPF addition. PPF tends to be distributed randomly in three dimensions to form a network support system which improves the homogeneity of cementitious material slurry. When samples are subjected to external forces, a lot of crack will be generated and then spread rapidly in the lightweight foamed concrete which can give rise to reduction of mechanical properties. As for samples with PPF addition, the development of crack can be impeded PPF scattered in the composites which tends to make the crack propagation path longer leading in more energy consumption [15]. Besides, PPF itself is a material with good mechanical capabilities such as good toughness which is advantageous to the enhancement in mechanical capabilities of foamed specimens. However, it can be also seen from Figure 4 that the curve of mechanical properties is downward when the content of PPF is over 0.9% which is mainly attributed to aggregation of PPF inside the composite matrix which can give rise to the stress concentration in the place where fiber gathers and the decline of mechanical properties.

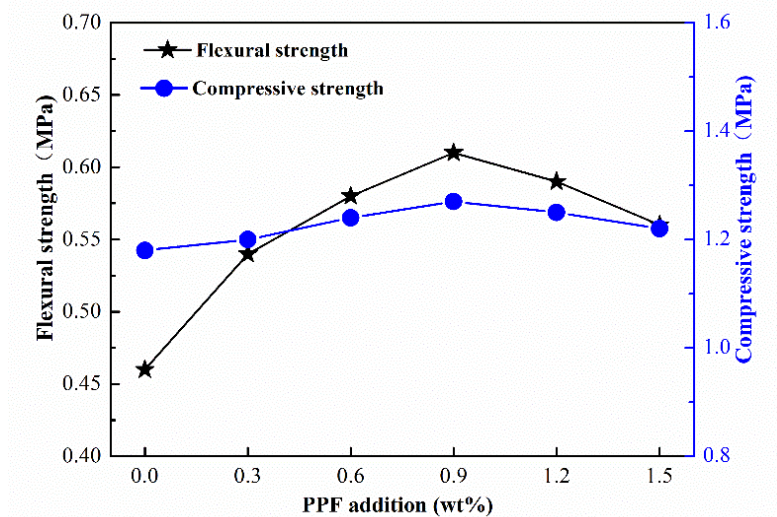


Figure 4. The flexural and compressive strength of specimens with PPF added.

4. Conclusion

In general, the density, thermal conductivity, flexural and compressive strength of lightweight thermal insulation concrete suddenly decreased when content of foaming agent becomes more and more which was chiefly attributed to existence of high porosity in the specimens with foam agent addition by decomposition of foam agent. The existence of foam stabilizer had a positive effect on heat insulation performance and mechanical strength owing to the improvement of pore structure. Besides, flexural and compressive strength of foamed specimens were improved through adding PPF. However, excess fibers had an opposite effect on mechanical properties due to aggregation of PPF inside the composite matrix.

Acknowledgments

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References

- [1] W. Villasmil, L. J. Fischer, J. Worlitschek, A review and evaluation of thermal insulation materials and methods for thermal energy storage systems, *Renew. Sust. Energ. Rev.* 103 (2019) 71-84.
- [2] M. Khoukhi, The combined effect of heat and moisture transfer dependent thermal conductivity of polystyrene insulation material: impact on building energy performance, *Energy. Build.* 169 (2018) 228-235.
- [3] E. Ciecierska, M.J. Kowalska, P. Bazarnik, M. Gloc, M. Kulesza, M. Kowalski, Flammability, mechanical properties and structure of rigid polyurethane foams with different types of carbon reinforcing materials, *Compos. Struct.* 140 (2016) 67-76.
- [4] Z.Z. Wang, S.J. Jiang, H.Y. Sun, Expanded polystyrene foams containing ammonium polyphosphate and nano-zirconia with improved flame retardancy and mechanical properties, *Iran Polym. J.* 26 (2017) 71-79.
- [5] L. Jiang, H.H. Xiao, W.G. An, Y. Zhou, J.H. Sun, Correlation study between flammability and the width of organic thermal insulation materials for building exterior walls, *Energ. Build.* 82 (2014) 243-249.
- [6] L. Zhou, A. Chen, L. Gao, Z. Pei, Effectiveness of vertical barriers in preventing lateral flame spread over exposed EPS insulation wall, *Fire. Safety. J.* 91 (2017) 155-164.
- [7] H.D. Li, Q. Zeng, S.L. Xu, Effect of pore shape on the thermal conductivity of partially saturated cement-based porous composites, *Cem. Concr. Compos.* 81 (2017) 87-96.
- [8] E. Kuzielova, L. Pach, M. Palou, Effect of activated foaming agent on the foam concrete properties, *Constr. Build. Mater.* 125 (2016) 998-1004.
- [9] K. Ramamurthy, E.K.K. Nambiar, G.I.S. Ranjani, A classification of studies on properties of foam concrete, *Cem. Concr. Compos.* 31 (2009) 388-396.
- [10] C. Sun, Y. Zhu, J. Guo, Y.M. Zhang, G.X. Sun, Effects of foaming agent type on the workability, drying shrinkage, frost resistance and pore distribution of foamed concrete, *Constr. Build. Mater.* 186 (2018) 833-839.
- [11] Y. Cui, D.M. Wang, J.H. Zhao, D.L. Li, S. Ng, Y.F. Rui, Effect of calcium stearate based foam stabilizer on pore characteristics and thermal conductivity of geopolymer foam material, *J. Build. Eng.* 20 (2018) 21-29.
- [12] M.S. Cilla, M.R. Morelli, P. Colombo, Open cell geopolymer foams by a novel saponification/peroxide/gelcasting combined route, *J. Eur. Ceram. Soc.* 34 (2014) 3133-3137.
- [13] S. Duan, H. Liao, F. Cheng, H. Song, H. Yang, Investigation into the synergistic effects in hydrated gelling systems containing fly ash, desulfurization gypsum and steel slag, *Constr. Build. Mater.* 187 (2018) 1113-1120.
- [14] Y. Hefni, Y. A. E. Zaher, M. A. Wahab, Influence of activation of fly ash on the mechanical properties of concrete, *Constr. Build. Mater.* 172 (2018) 728-734.
- [15] A. Noushini, M. Hastings, A. Castel, F. Aslani, Mechanical and flexural performance of synthetic fibre reinforced geopolymer concrete, *Constr. Build. Mater.* 186 (2018) 454-475.