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Fly Ash-based Geopolymer Foam Technology for Thermal Insulation and Fire Protection Applications

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ABSTRACT

In this article, geopolymer foams prepared by 3 different foaming technologies have been used based on fly ash from a Shenhua thermal power plant. They are: Aluminum (Al) powder activated foam, hydrogen peroxide (H_2O_2) activated foam, and combined Al powder activated with physical pre-mix foam. Key properties of these fly ash-based geopolymer foam panels, such as dry density, thermal conductivity, and compressive strength, were measured and compared with foamed cement. Both geopolymer foam panels using H_2O_2 and Al powder-physical foam technologies meet the key requirements of the China Industry Standard JC/T2200-2013 Type II foam and exceed the foamed cement performance (0.065 W/m/K, 220 kg/m^3, <0.5 MPa). Fly ash-based geoplymer foam panels also passed the lab-scale simulated GB/T16810-2006 fire test (test for fire resistance of record protection containers, similar to the UL-72 test) for fire protection applications and showed excellent resistance to the fire temperature up to 1150°C for 2 hours. The “burned” geopolymer foams showed higher compressive strength than the compression strength of the original geopolymer foams measured at the ambient temperature.

INTRODUCTION

The origin meaning of geopolymer is a class of aluminosilicate materials polymerized by the geochemical action to form a three-dimensional structure.[1] In the late 1990s, van Deventer etc. prepared geopolymer using solid industrial wastes, such as fly ash, to immobilize toxic metal ions.[2,3] Recently, geopolymer materials have been foamed to achieve good thermal conductivity and light weight as a new type of thermal insulation materials.[4] The methods used to make geopolymer foams are the pre-foaming or mixed-foaming methods.[5,6] However, the geopolymer foams by the pre-foaming method always get low porosity, high dry density and thermal conductivity.[7, 8] The porosity and the thermal insulating property of geopolymer foams prepared by the mixed-foaming method are also not better than those of traditional porous materials such as glass foam or autoclaved aerated concrete. Those issues limit the use of geopolymer foams as the thermal insulation materials to compete with traditional porous inorganic materials.

In this study, 3 different foaming methods were used to make geopolymer foams based on fly ash from a Shenhua thermal power plant: hydrogen peroxide activated foam, Al powder activated foam, and combined Al powder activated with physical pre-mix foam. Key properties of these fly ash-based foam panels, such as dry density, thermal conductivity, and compressive strength, were measured and compared with foamed cement by the China Industry Standard JC/T2200-2013 for foamed products used for external wall thermal insulation materials. Fly ash-based geoplymer foam panels were also evaluated by the lab-scale simulated GB/T16810-2006 fire test as well as in an oven set at 3 different temperatures of 950, 1150, and 1250°C for fire protection applications. The results show fly ash-based geopolymer foams activated by hydrogen peroxide meet the JC/T2200-2013 type II requirements and exceed the performance of foamed cement, and pass the lab-simulated fire tests for fire protection applications.

FLY-BASED GEOPOLYMER FOAMS FOR THERMAL INSULATION APPLICATIONS

Key properties of organic material foams, inorganic material foams, and organic/inorganic composites used for insulation materials are compared in Table 1. As we all know, the advantages of organic foam materials are light weight and excellent thermal insulation performance, but their disadvantages are ease of aging and poor fire safety performance, leading to fire accident. Especially, when EPS sheet is burned, “flashover" phenomena release smoke and toxic substance. Due to high water absorption, high energy-consumption manufacturing process, and low strength, inorganic foam materials, such as rock wool, glass wool, ceramic foam, etc., are not widely used in China. Recently, foamed cement that is considered as a new thermal insulating inorganic material, was developed and commercialized in China due to a new regulation for an “A” rating according to GB 8624-2006 fire test required for all external wall insulation panels published on March 14, 2011. However, foamed cement still has low strength and high water absorption issue.

In this study, 3 different foam methods were used to make geopolymer foams based on Shenhua’s fly ash as the key raw material: hydrogen peroxide activated foam, Al powder activated foam, and combined Al powder activated and physical pre-mix foam. These fly ash-based geopolymer foams were developed to replace existing inorganic foam materials including foamed cement for external wall thermal insulation applications in China. Dry density, compressive strength and thermal conductivity of these geopolymer fomas were measured and compared with foamed cement according to the China industry standard, JC/T2200-2013, as listed in Table 2.

Table 1. Comparison of various thermal insulation materials

Various insulation materials	Material	K (W/m.K)	Denisty (kg/m^3)	Compressive strenght (MPa)	FR ranking	Advantages	Concerns
Organic material foams	EPS	≤ 0.03	≥ 32	-	B2	lower density and K, lower water absorption, low production cost	poor flame resistance
	XPS	≤ 0.041	15-30	0.2-0.25			
	PU	≤ 0.025	≥ 35	≥ 0.1			
	Phenolic Resin	0.035	≤ 55	≥ 0.1	B1	Better FR, low water absorption	High price
	Polyimide （PI）	≤ 0.035	≤ 55	≥ 0.1			
Inorganic material foams	Rock wool	0.04	-	-	A	High FR	high water absorption, shorter life
	Glass wool						
	Glass foam	≤0.066	≥ 150	≥ 0.4			high energy process
	Ceramic foam	0.03	-	-			
	Perlite	0.048					
	Cement foam	0.045	150-250	≥ 0.25			High water absorption, low strength
Organic/inorganic composites	Layer structure				A or B1	High to better FR	
	Composite						

Table 2 Key properties of JC/T2200-2013 vs. geopolymer foams and foamed cement

Products/Properties	Foam methods	Dry Density (kg/m3)	Compressive Strength (MPa)	Thermal Conductivity (W/m•K)
JC/T2200-2013 Type I	NA	≤180	≥0.30	≤0.055
JC/T2200-2013 Type II	NA	≤250	≥0.40	≤0.065
Geopolymer foam 1	H_2O_2	201	1.20	0.057
Geopolymer foam 2	Al powder	515	1.49	0.084
Geopolymer foam 3	Al powder/ physical pre-mix	249	0.84	0.053
Foamed cement	H_2O_2	220	<0.5	0.065

Obviously, fly ash-based geopolymer foam using the Al power foam method had higher density, thermal conductivity, and compressive strength than those made by hydrogen peroxide or Al power combined with physical foam methods, and did not meet the JC/T2200-2013 requirements. However, fly ash based geopolymer foams using H_2O_2 and Al powder-physical foam methods met the Type II foam requirements and exceeded the performance of foamed cement (0.065 W/m/K, 220 kg/m^3, <0.5 MPa).[9-11] Dry density, compressive strength and thermal conductivity values of fly ash-based geopolymer foams using hydrogen peroxide method can be obtained in the range of 180 to 250 kg/m^3, 0.1 to 1.5MPa, and 0.055 to 0.065 W/m.K, respectively.

FLY ASH-BASED GEOPOLYMER FOAMS FOR FIRE PROTECTION APPLICATIONS

One of fly ash based geopolymer foams (NICE-1#) was made and compared with the commercial gypsum foam (0#CSD) as the reference sample for fire protection applications. The key properties of NICE-1# and 0#CSD samples are compared in Table 3. Apparently, the geopolymer foam has lower density and thermal conductivity than the reference sample.

Table 3 Performance comparison between foam geopolymer and the reference sample

Sample	Thickness	Density	Thermal conductivity	Compressive strength
	（mm）	（kg/m3）	（W/m. k）	(Mpa)
0#CSD	40	500	0.150	-
NICE-1#	40	370	0.084	1.17

Three fire protection material classes are based on the GB/T16810-2006 test: Class P, D, or DIS container under a 1000°C fire with its inside temperature at any point not higher than 177°C, 66°C, or 52°C during the fire test time of 0.5, 1.0, 1.5, and 2.0 hours. Lower temperature rise and longer testing time has better fire protection rating.

Our lab-scale simulated fire test uses a flame temperature of 800°C and the distance between the fire gun and sample's surface is about 30 mm. Temperatures on the back of the sample surface are periodically measured in-situ by an infrared thermometer during the fire test. Figure 1 shows the temperature rise profiles of geopolymer foam and reference samples under the lab-scale fire test simulated to the Chinese fire test standard, GB/T 16810-2006, for fire protection applications.

The fly ash based geopolymer foam reached its steady state with the temperature no higher than 52°C within the first 10 minutes during the test, and had temperature lower than the reference sample as shown in Figure 1. The reference sample showed the deep second temperature rise about 23 minutes due to sample crack during the fire test.

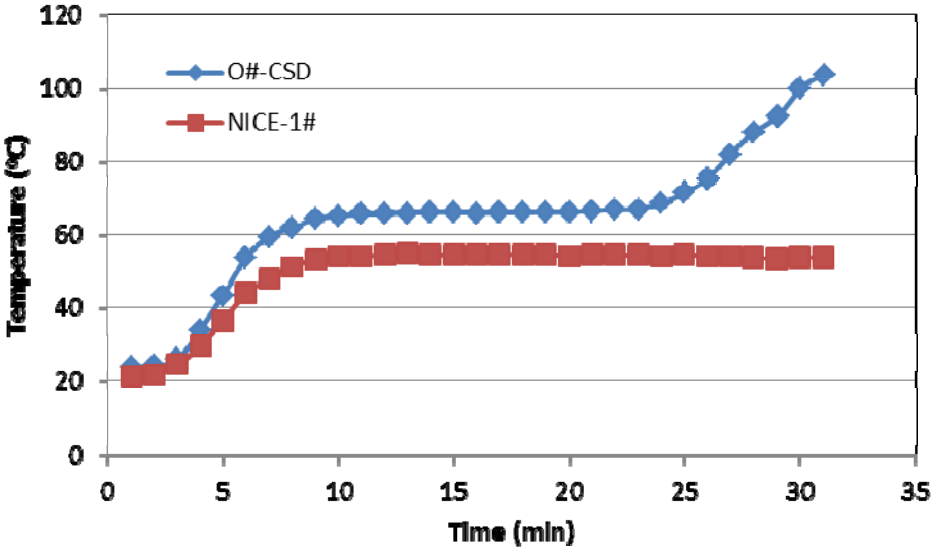

Figure 1 Temperature profiles of geopolymer foam vs. gypsum foam

Fly ash-based geopolymer foams with 3 different foam densities of 250, 330, and 770 kg/m^3 were made and placed inside an oven for 2 hours at 3 evaluated temperatures of 950, 1150, and 1250°C. As expected, geopolymer foams with higher density had higher compressive strength. However, compressive strength of geopolymer foams aged after 2 hours at the oven temperature of 950°C was increased to at least 2 – 4 times higher and then decreased at the oven temperature of 1150°C, both higher than the original strength as shown in Figure 2. Geopolymer foams aged after 2 hours at the oven temperature of 1250°C melt and had no strength. Obviously, fly ash-based geopolymer foams have excellent resistance to temperature up to 1150°C for the fire protection applications.[12]

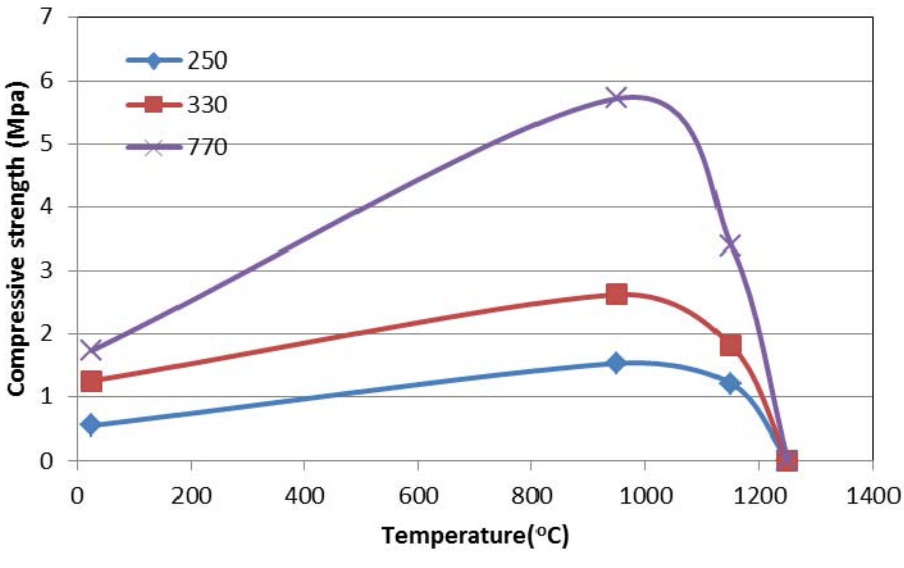

Figure 2 Compressive strength of geopolymer foams after 2-hrs at various temperatures

CONCLUSION

Fly ash-based geopolymer foams prepared by the hydrogen peroxide or Al power combined with physical foam methods had lower density, thermal conductivity, and compressive strength than those prepared by the Al power method alone, and met the key JC/T2200-2013 Type II foam requirements and exceeded the performance of foamed cement for thermal insulation applications. Fly ash-based geoplymer foam panels can keep the temperature not higher than 52°C in the lab-scale simulated GB/T16810-2006 fire test and have excellent resistance to temperature up to 1150°C for 2 hours with compressive strength higher than the original value without melt for fire protection applications.

REFERENCES

[1] Davidovits, J. Concrete International, 1987, 9, p.28-39.

[2] Van, Jaarsveld J.G.S., Van Deventer, J.S.J., Lorenzen, L. Mineral Engineering, 1997, 10, p.659.

[3] Van, Jaarsveld J.G.S., Luckey, G.C., Van Deventer, J.S.J. et al. Publications of the Australasian Institute of Mining and Metallurgy, 2000,5, p.363.

[4] Zhang, Z., Provis, J.L., Reid, A., Wang, H. Construction and Building Materials, 2014, 56, p. 113.

[5] Henon, J., Alzina, A., Absi, J., et al. Ceramics International, 2012, 38, p.77.

[6] Prud'Homme, E., Michaud, P., Joussein, E., et al. Journal of the European Ceramic Society, 2010, 30, p. 1641.

[7] Bourret, J., Prud'Homme, E., Rossignol, S., et al. Journal of Materials Science, 2012, 47, p.391.

[8] Al Bakri Abdullah, M. M., Hussin, K., Bnhussain, M., et al., International Journal of Molecular Sciences, 2012, 13, p.7186.

[9] Jow, J., Zhao, Y. B., Dong, Y., Lai., S. Y. Chinese patent, CN201210458125.x.

[10] Lu, D. Y., Xu, Z. Z., Yang, G. J., Zhao, Y. B., Jow, J., Li, Q. Chinese patent, CN201310148098.0.

[11] Zhao, Y. B., Jow, J., Cui, H., Li, Q., Zhai, J. P. Chinese patent, CN201410601488.3.

[12] Zhao, Y. B., Jow, J., Cai, X. L. Chinese patent, CN201410687378.3.