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Fabrication of Porous Ceramic-Geopolymer Based Material to Improve Water Absorption and Retention in Construction Materials: A Review

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Abstract. Porous ceramic nowadays has been investigated for a variety of its application such as filters, lightweight structural component and others due to their specific properties such as high surface area, stability and permeability. Besides, it has the properties of low thermal conductivity. Various formation techniques making these porous ceramic properties can be tailored or further fine-tuned to obtain the optimum characteristic. Porous materials also one of the good candidate for absorption properties. Conventional construction materials are not design to have good water absorption and retention that lead to the poor performance on these criteria. Temperature is a major driving force for moisture movement and influences sorption characteristics of many constructions materials. The effect of elevated temperatures on the water absorption coefficient and retention remain as critical issue that need to be investigated. Therefore, this paper will review the process parameters in fabricating porous ceramic for absorption properties.

1. Introduction

Rising temperatures in large cities nowdays poses an increasing environmental threat. This phenomenan arises from the increasing amount of heat generated by human activity (e.g., vehicles and air conditioners). The increasing amount of surface areas covered by artificial materials with a high solar absorption capacity also affected this global warming issues. Some counter measures have been carried out. For example, planting on the building roof to increase the green area, and using water retentive material for construction material to cool surroundings according to the evaporation heat. These materials need- ed permanence, weathering resistance and low density. Because, in many cases, it is difficult to change constructed materials [1]. Ceramic tiles as building materials have the advantages of permanence, weather resistance and decoration. However, dense ceramics such as conventional tiles are heavy and low machinability. Porous ceramics have a lot of advantages as construction materials compare with dense ceramics. It is because of not only lightweight and high machinability but also heat insulation, sound absorption, and others. In addition, water is absorbed and retained into the pore [1].

Porous ceramic have attracted many researcher to tailor the propeties for construction industries. Porous ceramics finds it a lot of new applications in industrial areas, however, because the porosity of ceramic material can be arranged in a well-defined and homogeneous manner or heterogeneously on the other hand and offers the ceramic material many special characteristics ranging from an increased surface area, to permeability, to the control of heat transport within the structure, to the maximization of the strength and density ratio. Materials containing tailored porosity exhibit special properties and features that usually cannot be achieved by their conventional dense counterparts [2]. Water absorption and retention of porous ceramics as building materials are characterized by their permanence, heat insulation and water retention. Whilst the water retention properties of the samples depend on their pore size, larger sizes giving both higher water absorption and water release rates [4,5,6].

Recently, many researchers have reported the technique of fabricating porous ceramics made from industrial wastes such as low grade silica, glass, and waste alumina. In this technique, molding does not depend on the plasticity of the raw material. Therefore, the flow process and the solidification process can be separated and the control of the porosity is easy. Furthermore various characteristics based on the pores can be changed [1]. The development of new technologies to recycle and convert waste materials into reusable materials is important for environmental protection and sustainable improvement of our society [5].

2. Porous geopolymer

Geopolymer is an inorganic polymer composite which has a potential sustainable construction material because of its lower energy and carbon footprint as compared to Portland cement-based materials [7]. The microstructure and mechanical properties are known to depend strongly on the chemical compositions of the starting materials [2,5,6]. Geopolymers exhibit a wide variety of properties and characteristics, including high compressive strength, low shrinkage, high temperature resistance [8] and acid and fire resistance [9, 10], and seem to be a desirable alternative to ordinary Portland cement and environmentally sustainable characteristics [10,11]. Besides, the CO2 emission due to production of fly ash-based geopolymer is at least 80% less compared to manufacture of ordinary Portland cement [11,12].

Previously, many works [13-17] have been conducted on fly ash based geopolymers and have gained some achievements. However, almost all of these literatures focused on the effects of some parameters on the compressive strength of geopolymers and few researches have emphasized on adding foaming agent into the polymer pastes to produce porous geopolymer materials and taken the thermal conductivity of them into consideration. In this study, H_2O_2 was added to the polymer pastes to make porous geopolymer materials through the decomposition of H_2O_2 at alkaline environment before the pastes were concreted. Considering the fact that the organic thermal insulation materials widely used today are flammable and the inorganic thermal insulation materials need complex processing conditions and high sintering temperature, which is a big component in manufacturing cost, the porous fly ash-based geopolymer material synthesized in this study has good application potential as thermal insulation material in some situations.

2.1. Pore morphology of porous geopolymer

Based on research done by Junjie Feng, figure 1 represents the photographs of fracture surfaces of samples cured at various temperatures with different amounts of sodium water glass and H_2O_2 added [18].

It can be figured out clearly that the increase of sodium water glass amount enlarges the pore size of the samples. In addition, when adding superfluous water glass, the 5 decomposition of H_2O_2 is violent and some macropores are left inside the sample, which is unfavorable.

Comparing photographs of (d), (e) and (f), it is easy to reach a decision that increasing the dosage of H_2O_2 can also magnify the pore size because of the continuous decomposition of H_2O_2.

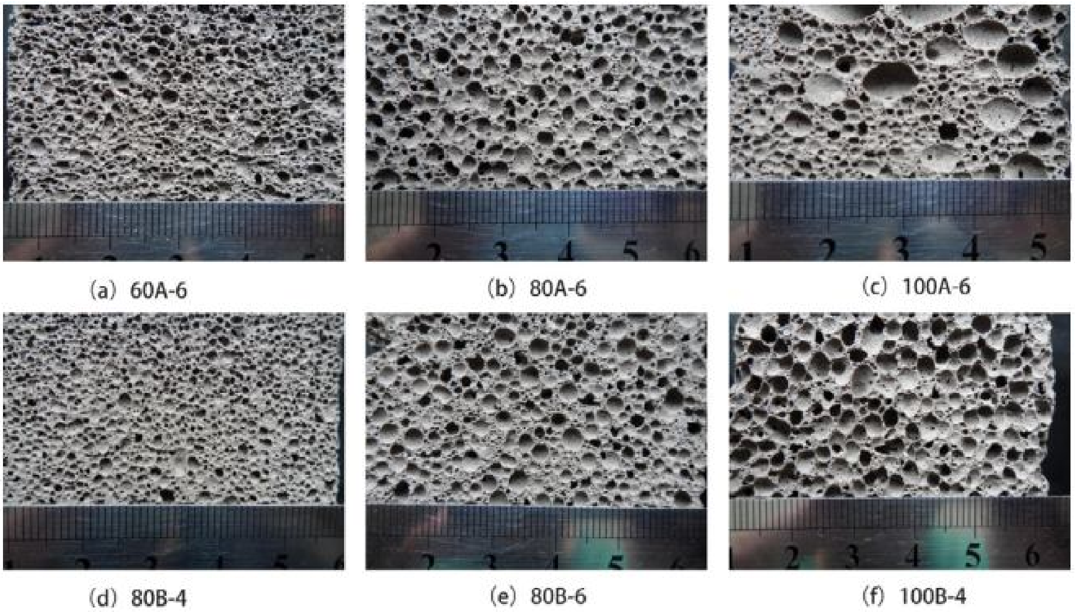

Figure 1. Photographs of fracture surfaces of samples (a) 60A-6 (b) 80A-6 (c) 100A-6 (d) 80B-4 (e) 80B-6 (f) 80B-8 [18].

Moreover, by the contrast of images (b) and (e), conclusion can be made that curing temperature has little influence on the pore morphology.

2.2. Water absorption properties porous geopolymer

The features and properties of the porous geopolymer, for example, porosity, pore size distribution, pore morphology, and pore connectivity (commonly identified as the relationship between open and closed porosity), depend strongly on the composition and processing method. Research study shows that the chemical compositions of the geopolymers (in terms of their H_2O/Al_2O_3 and Na_2O/Al_2O_3 ratios) were systematically varied, allowing the porosity and water retention properties to be adjusted [6]. Figure 2 shows that geopolymers synthesized with higher H_2O/Al_2O_3 ratios are more porous, their larger pore size and higher pore volume giving them good water absorption and water retention properties but decreasing their mechanical strength.

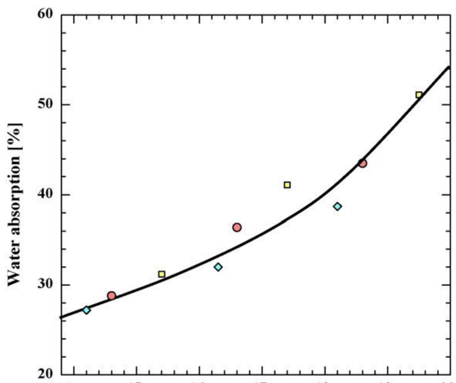

Figure 2. Water absorption of the samples as a function of their H O/Al O ratio [6].

The limited mechanical strength of this type of geopolymers may have restriction on some applications. By contrast, the geopolymers synthesized with lower H_2O/Al_2O_3 ratios are denser, with smaller pore sizes and lower pore volumes, resulting in better water retention and mechanical properties than materials with higher H_2O/Al_2O_3 ratios. Thus, these two types of geopolymers are suitable for different water retention applications [6].

3. Processing of porous waste ceramic

This study examines potential waste diatomite and coal fly ash reuse to prepare water absorption and retain porous ceramics. The coal fly ash can be converted into porous ceramics by using this method. The ability to use diatomite and coal fly ash produced as water absorption and retention of porous ceramic is also examined by studying their water retention and thermal conductivity properties. The compressive strength is the crucial index of the engineering quality of porous ceramic material. The sintering temperatures were varied to obtain the optimum temperature for fabricating the porous ceramic [2].

Table I shows the compressive strength test results for porous ceramics made from diatomite and coal fly ash mixtures. The compressive strength of the porous ceramics increased when the sintering temperature increased from 1000°C to 1270°C. The results showed that the optimal sintering temperature that maximized the compressive strength was 1270°C. The compressive strength of the mixed porous ceramic samples of diatomite that contained the coal fly ash decreased slightly when the sintering temperature increased above 1200°C. The porous diatomite ceramic strength decreased when up to 20% of the coal fly ash was added to the porous ceramics that were heated to 1200°C [2].

Table 1. Mechanical characteristic of porous ceramics [2].

TABLE II: MECHANICAL CHARACTERISTICS OF POROUS CERAMICS

Mechanic Characteristic	Heating Temperature (℃)	Coal Fly Ash Replacement Level (%)				
		0	5	10	15	20
Porosity (%)	1000	64.02	62.14	61.86	61.63	60.23
	1100	63.41	61.29	60.49	59.69	58.95
	1200	62.59	59.97	57.51	56.01	54.61
	1270	61.27	57.23	55.07	53.83	51.71
Water absorption (%)	1000	93.39	88.08	84.72	81.65	75.91
	1100	91.13	83.83	80.59	77.79	74.12
	1200	87.85	80.60	75.04	71.36	67.34
	1270	85.23	75.83	70.92	67.43	63.44
Compressive strength (MPa)	1000	2.48	3.29	3.89	4.39	4.89
	1100	4.36	5.55	6.48	7.20	8.17
	1200	5.92	8.10	11.25	13.65	16.31
	1270	6.10	9.67	12.77	15.38	17.04

Consequently, the coal fly ash can be blended with diatomite to produce porous ceramics. The porous ceramic samples containing the coal fly ash exhibited excellent slow water-releasing properties, which may be attributed to the smaller pores, compared to those in the foamed glass. The large amounts of coal fly ash in the porous ceramic samples also facilitated a slow water release, which yielded acceptable water-retention properties. These properties make the porous ceramic samples containing coal fly ash samples promising for use as water-retaining materials to combat this rising temperatures effects [2]. Li L et al also reported about the use of vermiculite as a cementitious material in agricultural field which also known as 'planting concrete'. It was found that vermiculite has a high water absorption and water retention capacity.

The water absorption increases according to open porosity. The water absorption is calculated from sample weight. Because the density of the high porosity sample is low, the water absorption is estimated high. In fact, it turned out that the amount of the water contained in the sample decreased. Porous ceramics fabricated from waste material shows better water absorption and retention. Porous ceramics can also being fabricated from waste glass and fly ash using the milling method and annealing procedures. This technique is effective in changing waste materials into valuable porous ceramics by mechanically applying a milling method and low sintering process [5].

The mechanical properties such as hardness or bending strength for porous ceramics are related to the pore size or generation of pores of porous ceramics. In other words, when a number of variables such as sintering temperature or soaking time, it will caused the pore size to grow bigger or the pores to grow in number. Hence the mechanical properties of porous ceramics become such that ceramics having a small pore sizes or small pore volumes yield a better result than ceramics having large pore sizes or greater pore volumes [5]. The bending strength of the porous ceramics prepared indicated that with an increase in the heat treatment temperature from 600^{o}C to 700^{o}C, the bending strength improved from 9.25 to 26.81 MPa. The porous ceramic specimens exhibited a decreasing tendency of strength with increasing pore size and pore volume, which may be attributed to defect formation [5].

The porous ceramic specimens at all sintering temperature range used are strong enough for practical usage. The water absorption and retention were depending on the pore structures. These properties were deteriorated with the large pore size, or the too high porosity. As a result, in the design of water retentive build- ing materials, the control of pore structure is important to control of water absorption and retention. Ideally, the small contact area of each pore is effective to improve in a water retention property at high porosity [6].

4. Conclusion

The water absorption and capillary lift properties of geopolymers synthesized with higher H_2O/Al_2O_3 ratios could be enhanced by the introduction of pores generated by thermal and/or chemical treatment of organic pore-forming fibers. The porous ceramics fabricated from waste material exhibited enhanced water absorption and retention capabilities. Moreover, the results of this study also indicated that water absorption and retention are dependent on the pore structures. In summary, porous ceramic samples containing the coal fly ash have excellent mechanical properties, making them feasible for use in water absorption and retention of porous ceramic applications. The formation of porous ceramic can be tailored from the raw material's properties and processing method for it's absorption properties but the mechanical strength must be major consideration as to make it acceptable in construction industry.

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