Sintering-free fly ash ceramsite prepared with ammonium carbonate as foaming agent and its properties

Shuyan Gao¹, Rongjun Pan¹,², Huiqin Wu¹, Hongmei Zhou¹, Ying Tang¹, Qingyu Zhong¹, Zhizhou Zhou¹ and Huansheng Huang¹

¹College of Civil Engineering, Guangxi University of Science & Technology, Liuzhou, Guangxi, 545006, China
²Engineering Research Center of Advanced Design and Manufacturing for Heavy Vehicle Components, Ministry of Education, Guangxi University of Science & Technology, Liuzhou, Guangxi, 545006, China

*Corresponding author’s e-mail: rongjune@163.com (Rongjun Pan), whq6329@163.com (Huiqin Wu)

Keywords: Sintering-free ceramsite, Ammonium carbonate, Pore structure, Thermal insulation

Abstract. Ceramsite possesses a low thermal conductivity due to its porous structure. Sintering-free ceramsite was prepared by using ammonium carbonate as foaming agent with the assistance of microwave irradiation. It was found that when the total porosity of ceramsite was up to 51%, its thermal conductivity was as low as 0.182W/(m*K). However, with the increase of porosity, the increase of bulk density and the loss of cylinder compressive strength were detected.

Introduction

The global carbon emissions had reached 37.1 billion tons in 2017, meanwhile there also was slightly increase compared with 2016 [1]. Therefore, the implementation of energy saving and emission reduction is necessary and urgent. There was about one fifth energy consumption mainly from construction industry in China [2]. It could be found that there was 45% of the energy consumption of buildings were contributed by the heating in northern part of China, meanwhile the main reason was the poor thermal insulation performance of building envelopes [3]. Therefore, many researchers considered to improve these situations through enhancing the thermal insulation performance of buildings. At the same time, J.M. Lu [4] stated that the energy consumption of exterior walls made of ceramsite concrete was 30% lower than that of ordinary concrete, which was attributed to ceramsite.

When using fly ash as raw materials to prepare sintering-free ceramsite [5-7], cement and calcium hydroxide contributed to hydration and pozzolanic reaction, which could increase the compressive strength of the ceramsite and reduce water absorption. M. Gesoğlu [6] also identified that it could effectively improve its strength immersing the sintering-free ceramsite prepared high calcium fly ash in water glass for 30 minutes. Further, R. Manikandan [7] found that the porosities of ceramsite cured by autoclaving or steam curing were higher than those cured by normal water curing, meanwhile it also contributed to the higher water absorption and 10% fines value of ceramsites. It was demonstrated that adjusting the pore structure could tune the properties of porous materials [8-16]. A.A. Hilal [8] found that powder additives could refine macropores and improve the strength of foamed concrete. Z.M. Huang [9] made ultra-lightweight foam concretes using hydrogen peroxide as foaming agent, and found that the decrease of porosity could lead to an increase of thermal conductivity. It was found that larger pore diameter affected strength, while smaller ones affected heat insulation [10-16]. The higher D90, the lower strength, and the higher D50, the lower thermal conductivity, which means that inhomogeneity in pore diameter might influence the strength of the material, but it can improve the thermal insulation performance of the material.

The aim of this work is to improve the thermal insulation performance of ceramsite. In order to achieve it, the mixture of fly ash, cement, quicklime and gypsum dihydrate as raw materials, and ammonium carbonate as foaming agent were used to prepare sintering-free ceramsite with the assistance of microwave irradiation.
Experiment

Raw materials and instruments. The raw material was a mixture of fly ash, cement, quicklime and gypsum powder according to the mass ratio of 25:5:2:1 [17]. Chemical foaming agent was analytical pure ammonium carbonate produced by Xilong Chemical Co., Ltd..

The ZL-500 disc pelletizer (Zhengzhou Shijin Machinery Equipment Co., Ltd.) was used for pelleting, and its rotational speed was set at 35r/min and inclination angle was set at 45 degrees [19]. Microwave irradiation was realized by G80F20CN2L-B8 (R0) microwave oven (Guangdong Granz Group Co., Ltd.).

Experimental procedure. The mass ratio of water to raw material in ceramsite preparation was controlled 0.2±0.02 [21]. Two groups of ceramsite were prepared without using foaming agent (denoted as NF) and with ammonium carbonate as foaming agent (denoted as AC), in which the amount of ammonium carbonate to that of the mixture was maintained 3%. The pellet ceramsite were irradiated with various microwave power and times according to Table 1 and Table 2, respectively. The obtained ceramsite was then used for subsequent test to evaluate the effect of microwave irradiation on the properties of the ceramsite.

Table 1. The effect of microwave power on ceramsite with irradiation time of 5 minutes.

<table>
<thead>
<tr>
<th>Microwave power [W]</th>
<th>0</th>
<th>160</th>
<th>320</th>
<th>480</th>
<th>640</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF</td>
<td>NF</td>
<td>NF</td>
<td>NF</td>
<td>NF</td>
<td>NF</td>
</tr>
<tr>
<td>AC</td>
<td>AC</td>
<td>AC</td>
<td>AC</td>
<td>AC</td>
<td>AC</td>
</tr>
</tbody>
</table>

Table 2. The effect of irradiation time on ceramsite with microwave power of 480W.

<table>
<thead>
<tr>
<th>Irradiation time [min]</th>
<th>0</th>
<th>1</th>
<th>3</th>
<th>5</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF</td>
<td>NF</td>
<td>NF</td>
<td>NF</td>
<td>NF</td>
<td>NF</td>
</tr>
<tr>
<td>AC</td>
<td>AC</td>
<td>AC</td>
<td>AC</td>
<td>AC</td>
<td>AC</td>
</tr>
</tbody>
</table>

Test methods for properties of ceramsite. The bulk density and cylinder compressive strength of ceramsite were measured by Lightweight Aggregates and Its Test Methods-Part 2: Test Methods for Lightweight Aggregates (GB/T 17431.1-2010). The thermal conductivity of the ceramsite was measured by TPS 1500 thermal constant thermal conductivity analyser (Hot Disk Co., Ltd., Sweden).

Results and discussions

Bulk density. As illustrated in Fig. 1a and b, with the increase of microwave power or irradiation time, the total porosity of ceramsite in both groups increased modestly, while the bulk density decreased, which was consistent with the conclusion in [19,21]. However, the total porosity of ceramsite in AC group was slightly higher than NF group, but the bulk density of ceramsite in AC group was not lower than that in NF group. This was caused by CO$_3^{2-}$ in ammonium carbonate solution reacted rapidly with Ca$^{2+}$ in the mixture to produce much denser CaCO$_3$ [25].
Figure 1. Effect of (a) microwave power and (b) irradiation time on the bulk density and the total porosity of the ceramsite, respectively.

Cylinder compressive strength. According to Fig. 2a and 2b, it could be found that the porosity of ceramsite in AC group was slightly higher than that in NF group, while the cylinder compressive strength of ceramsite in AC group was lower than that in NF group. Similarly, with the increase of microwave power or irradiation time, the total porosity of ceramsite in both groups increased, while the cylinder compressive strength decreased. The strength of ceramsite is mainly contributed by the amount of binder and the porosity of ceramsite, but in this experiment, the former is a fixed value [19,21]. It means that the strength of ceramsite in this experiment is determined by the porosity. The key point of preparing porous ceramsite by chemical foaming is to adjust the hydration rate and the decomposition rate of foaming agent. Although microwave irradiation can promote hydration reaction, it also accelerates the decomposition of foaming agent and evaporation of water [18]. Combined with the results of the experiment, the acceleration of the latter by microwave irradiation significantly outweighed that of the former.

Figure 2. Effect of (a) microwave power and (b) irradiation time on the cylinder compressive strength and the total porosity of the ceramsite, respectively.

Thermal conductivity. In Fig. 3a and b, when microwave power or irradiation time was 0, the addition of ammonium carbonate promoted the porosity and decreased the thermal conductivity obviously, respectively. At present, the curve difference between the two groups was the largest. Afterwards, with the increase of microwave power or irradiation time, we could see that the gap was shrinking. The thermal conductivity of ceramsite in NF group decreased during this process, and the total porosity increased roughly. The thermal conductivity of ceramsite in FA group increased firstly and then decreased, and the total porosity decreased firstly and then increased. It could be found that the thermal conductivity decreased with the increase of total porosity, which was the same as the conclusion in references [9,20,22-24].
Figure 3. Effect of (a) microwave power and (b) irradiation time on the thermal conductivity and the total porosity of the ceramsite, respectively.

Conclusions
In this experiment, ammonium carbonate was used as foaming agent to improve the thermal insulation of ceramsite, and microwave irradiation was used to promote the decomposition of ammonium carbonate. Meanwhile, the effects of microwave power and irradiation time on the properties of ceramsite were also studied. These results revealed that the addition of ammonium carbonate could improve the porosity of ceramsite and reduce the thermal conductivity of ceramsite. Surprisingly, the bulk density of ceramsite increased instead. With the increase of microwave power or irradiation time, the porosity of ceramsite increased, while bulk density and cylinder compressive strength of ceramsite decreased, meanwhile it is worth to notice that the decrease of thermal conductivity was not at a significant level.

Acknowledgements
This work was supported by the Natural Science Foundation of Guangxi (Grant No. 2013GXNSFAA019316, 2018JJA160170), and the Science Foundation of Education Department of Guangxi (Grant No. 2013YB173).

References