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Sintering-free preparation of porous ceramsite using low-temperature decomposing pore former and its sound-absorbing performance

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HIGHLIGHTS

- Ceramsite is a good sound absorbing material.
- Heating rate, foaming agent addition amount, curing time to achieve control.
- Ceramic micro-hole structure determines its sound absorption properties.

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ABSTRACT

Porous ceramsite features excellent sound-absorption performance which is governed by the pore characteristics, such as pore size, apparent porosity, and interconnected pore network. In this work, porous sound-absorption ceramsite with different apparent porosities was prepared by using ammonium hydrogen carbonate as pore former.

The effects of pore former dosage, heating rate, and curing time on the microstructure of the obtained ceramsite were investigated. The results revealed that the pore size and apparent porosity increase as a function of the pore former dosage and heating rate, respectively; whereas decrease as a function of curing time. For the ceramsite without curing, a maximum apparent porosity of 32.67% could be reached under a pore former dosage of 2.0% and a heating rate of 20.0 °C/min; however, for those cured for 72 h, the maximum apparent porosity was estimated to be only 27.43%. The sound-absorption performance correlated positively with the apparent porosity, whereas the growth and decline of pore size resulted in fluctuation of sound-absorption coefficient within the frequency rang of 200–2000 Hz because the linear flow resistance and the air friction increase with the decrease of the pore diameter.

1. Introduction

Noise pollution is becoming one of the three most severe issues worldwide. It has been reported that 70% of the urban environmental noise comes from traffic to which the expressway, railway, and traffic contribute [1–6]. Not only can noise pollution damage hearing, it can also result in kinds of diseases, especially for the vulnerable groups. Therefore, it is imperative to abate the traffic noise. Besides controlling the noise source, the measures by which noise pollution can be handled include applying sound-absorption materials, such as resonance absorption materials and porous absorption ones. The sound-absorption of porous materials is a physical energy conversion process and the intrinsic damping and the viscous loss of pore surface are considered as the main absorption mechanisms [7–10]. When a sound wave transmits through porous sound-absorption materials, the wave is converted into thermal energy which then disperses into the air by viscosity resistance, compression-expansion, and/or vibration-transmission [11]. The key that governs the performance of porous sound-absorption materials will be the pore structure, such as the apparent porosity and the fine, uniform, and connected pores [12].

Traditionally, porous sound-absorption materials can be divided into three types based on the substrate: organic polymer porous

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materials, porous metallic materials, and inorganic porous materials. As organic porous materials can not withstand high temperature and porous metallic materials are usually costly, much effort has been expended to investigate the acoustic properties and optimize the pore structure of inorganic porous materials during the past decades. In resent years, the rigid skeleton model and JAC model based on the circular pipe theory have been extensively used, which provides a theoretical foundation for the porous sound-absorption materials [13,14]. According to the circular pipe theory, the acoustic absorption regularity of the porous materials could be established and verified experimentally. The results revealed that: (i) a higher apparent porosity leads to a stronger absorption and the maximum absorption coefficient shifts towards high frequency as a function of porosity; (ii) the pores with size below 1.0 mm possess a strong absorption in a wide frequency range of 400–2000 Hz although the absorption coefficient in low frequency is higher than that in high frequency; (iii) the absorption coefficient increases and then decreases when the pore size ranges from 0.4 to 2.0 mm; and (iv) those pores with size above 1 mm show a strong and narrow absorption within 700–900 Hz. Hence, it is very meaningful to tailor the pore structure of the sound-absorption materials.

To date, some researches has focused on the sintering preparation of porous sound-absorbing material using various industrial solid wastes, such as fly ash, coal gangue, blast furnace slag, and steel slag [15–17]. The obtained products possess high porosity, which resultantly leads to excellent sound-absorption performance in the range of high frequency. As demonstrated in the studies, when the porous material is prepared by foaming process, the pore structure can be tuned by controlling the foaming agent dosage, the heating temperature, and the heating rate, which essentially manages the pressure difference inside and outside the generated pores [18–20].

As a traditional porous material, ceramsite can be divided into different types according to the raw materials, such as clay, shale and fly ash [21–23]. Due to the excellent properties of heat preservation, durability, anti-corrosion, and light weight, it has been widely used in the fields of prefabricated parts and cast-in-place concrete for industrial and civil buildings [24]. Moreover, because of its porous structure, it has been explored to served as sound-absorbing materials in recent years [25].

Sintering-free fly ash ceramsite is environmentally friendly porous sound-absorbing material. It can not only maintain the performances of strength, durability, and anticorrosion, but also feature excellent sound-absorption. In our previous studies, concrete made of porous sound-absorption ceramsite was engaged to abate the subway noise. Its sound-absorption coefficient was evaluated to be 0.85, which is rated as Grade 1 according to *The Graduation of Sound Absorption Property for Absorbent Products of China* (GB/T 16731-1997) [26].

As illustrated previously, the sound-absorption performance of porous materials depends on the pore size and apparent porosity [27–31]. Unfortunately, researches on regulating the open porosity and the pore size are rare for fly ash ceramsite so far. Therefore, in order to develop a sound-absorption ceramsite with desired pore structure, porous ceramsite with varying pore structures was prepared by using fly ash, cement, lime, and gypsum powder as raw materials, in which a low-temperature decomposing agent**,** ammonium hydrogen carbonate, was used as pore former.

2. Experiment

2.1. Raw materials

The mortar mixture was obtained from Ouweimu Machinery Manufacturing Co. Ltd. (Liuzhou, China). The mass ratio of the components is listed in Table 1. Within the mortar mixture, the cement was 42.5 ordinary Portland cement. The dark gray fly ash was from Liuzhou Power Generation Co., Ltd. (Liuzhou, China), with a weight of screen residue of 18.4%. As an activator, pure quick lime powder was selected to improve the activity of the fly ash by activating the glass of the fly ash. The used gesso was obtained from Liuzhou Global Gesso Production Factory, which could serve as both accelerator and stimulant [32,33]. To determine the mineralogical phases of the mortar mixture, XRD characterization was performed and the XRD pattern is presented in Fig. 1. As can be seen, the main components are mullite, calcite, and quartz, originated from fly ash, cement, and gesso, respectively. The pore former, analytically pure ammonium hydrogen carbonate, was purchased from Guangdong Xilong Chemical Co. Ltd.

Table 1
The mass ratio of various components in mortar mixture used for preparing ceramsite.

Composition of mixture	Fly ash	Cement	Gesso	Quick lime
Mass ratio	1.00	0.20	0.08	0.04

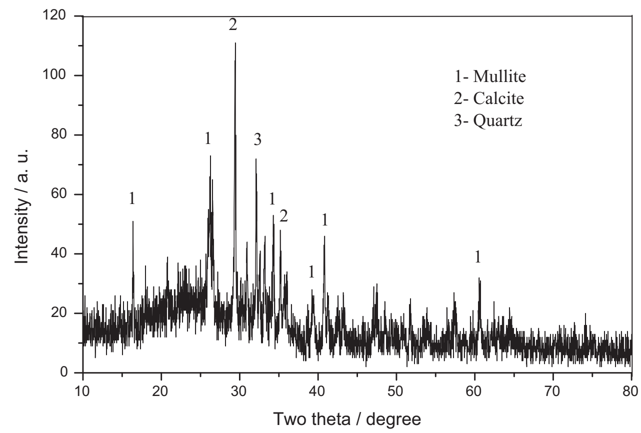

Fig. 1. XRD pattern of the mortar mixture.

2.2. Determination of heat treatment process

To investigate the decomposition process of ammonium hydrogen carbonate, simultaneous thermal analysis was conducted on a thermal analyzer (Netzsch, STA 449 F3) by using the mixture of raw materials and pore former (a mass fraction of 0.5%) at a heating rate of 5.0 °C/min.

As illustrated in Fig. 2, according to the TG curve, the starting and ending temperatures are 38.2 °C and 87.6 °C, respectively. During the temperature range of 38.2 °C–87.6 °C, the mass loss can be estimated to be 2.6%, which is attributed to the evaporation of water and the decomposition of the pore former [34]. When the temperature was raised to 288.4 °C, a slight mass loss could be observed, which is caused by the loss of crystal water existed in the raw materials. Obviously, the DSC curve further confirmed the above inference [11,12]. An endothermic peak appeared at 30 °C to 100 °C, indicating the complete decomposition of ammonium hydrogen carbonate. Another endothermic peak observed at ~125 °C could be attributed to the loss of crystal water.

When the fly ash ceramsite is calcined at a temperature higher than 400 °C, the yield of ceramsite will be only 40%–50% due to the destruction of ceramsite caused by efflorescence [12]. According to thermal analysis, the thermal decomposition temperature of ammonium hydrogen carbonate ranges from 30 °C to 100 °C.