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The study of thermal interaction and microstructure of sodium silicate/bentonite composite under microwave radiation

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HIGHLIGHTS

- Amorphous phase transforms to liquid phase by microwave radiation.
- Pure sodium silicate and pure bentonite cannot show temperature overshoot.
- Silicate-bentonite composite shows a high temperature overshoot above 700 °C.
- A rapid heating crucible for the annealing application is fabricated.

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ABSTRACT

The commercial heating oven usually consumes the power around 2500–3000 Watt and the temperature inside the oven is still below 350 °C. If we need to increase a temperature above 500 °C, a special heating setup with a higher power furnace is required. However, in this work, we propose a composite material that interacts with 2.45 GHz 500 Watt microwave and rapidly redeems the thermal energy with the temperature around 600–900 °C. The composite amorphous material easily forms liquid ceramics phase with a high temperature output and responds to the microwave radiation better than that of the solid phase. During the heating process, phase transformation occurs. This method is very effective and can be used to drastically reduce the power consumption of any heating process.

1. Introduction

Microwave radiation is an electromagnetic wave transmission with a broad range of radio frequency. Instead of transmitting a wave with a lowest heat loss, microwave technology tries to generate a highest heat loss to a material. The short wave radio frequency in microwave technology can generate heat by dielectric-heating concept [1]. With an improvement of radio transmission during World War II, a cavity magnetron was invented and extensively used in the war, not so long before it was combined into a microwave oven by Percy Spencer, an American engineer [2]. Seventy years later, microwave oven had become a common houseware around the world. Current microwave oven uses a frequency around 2.45 GHz which is suitable to heat water or the other water-contained food [3–5]. Lately microwave technology has attracted researcher attention again due to the ability to heat and sinter metal and ceramics powder [6,7]. There are many tricks to modify the microwave system to sinter materials, for example, placing an insulated refractory surrounding the sample to reduce the thermal runaway, using a high power microwave, or adjusting the frequency [8–11]. Some microwave system such as spark plasma sintering (SPS) combines the vacuum technology and plasma concept to increase the heating rate and sintering efficiency [12–14]. A simpler method to harvest energy from microwave radiation is to choose a material with a very high dielectric loss (high complex permittivity ε_r"). Materials in this group are SiC, graphite, and carbon black which have complex permittivity ε_r" from 0.1 to 100 [15–17]. Graphite accumulates the microwave power and transfer the thermal energy to the surrounding materials. Hence the material that gains energy from graphite becomes very hot and the temperature rises up. It's well known that the carbon-based materials can be used as a wave collector via the electronic

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motion which is different from non-carbon based materials where dipole vibration is the main heating mechanism [18,19]. In this research, sodium silicate and bentonite were mixed and used as a wave collector and a heater in a microwave, and the microstructure of composite material had been observed. Although bentonite is a clay material which is usually used for other purpose, it is proved to be useful in microwave application in this work [20].

2. Results and discussions

The dried bentonite and sodium silicate mixtures were prepared in an alumina container and placed inside a microwave system (LG MS2022D 20 L). The rotating glass plate inside the machine was removed because it could not tolerate the thermal shock [21,22]. Only a small insulated ceramic fiber was placed under the container to prevent the damage to the metallic frame of microwave oven. There was no additional modification inside and outside the microwave oven. The microwave power was set at 500 Watt, a bit higher than defrost mode. This commercial microwave worked by emitting the microwave radiation with the power of 750 Watt for a shot time and the power was on and off continuously. The temperature fluctuation occurred due to the on and off cycle of microwave radiation. The final average power consumption was finally 500 Watt. The temperature of each composition was recorded by infrared thermometer as shown in Fig. 1A. For a pure sodium silicate, microwave radiation created a white foam structure as shown in schematic Fig. 1B. The volume of the pure sodium silicate was expanded more than 100%. However, the temperature was not increased beyond 230 °C. The sodium silicate foam was a good thermal insulator and heat could not accumulate and finally dissipated [23]. After the microwave radiation, a big hollow structure was observed inside the foam. It is possible that there could be a burning process inside the foam for a short time. With the mixture of 10% bentonite 90% sodium silicate by weight, foam formation hardly occurs and the heat transfer inside the composite was increased. Furthermore bentonite has a high complex

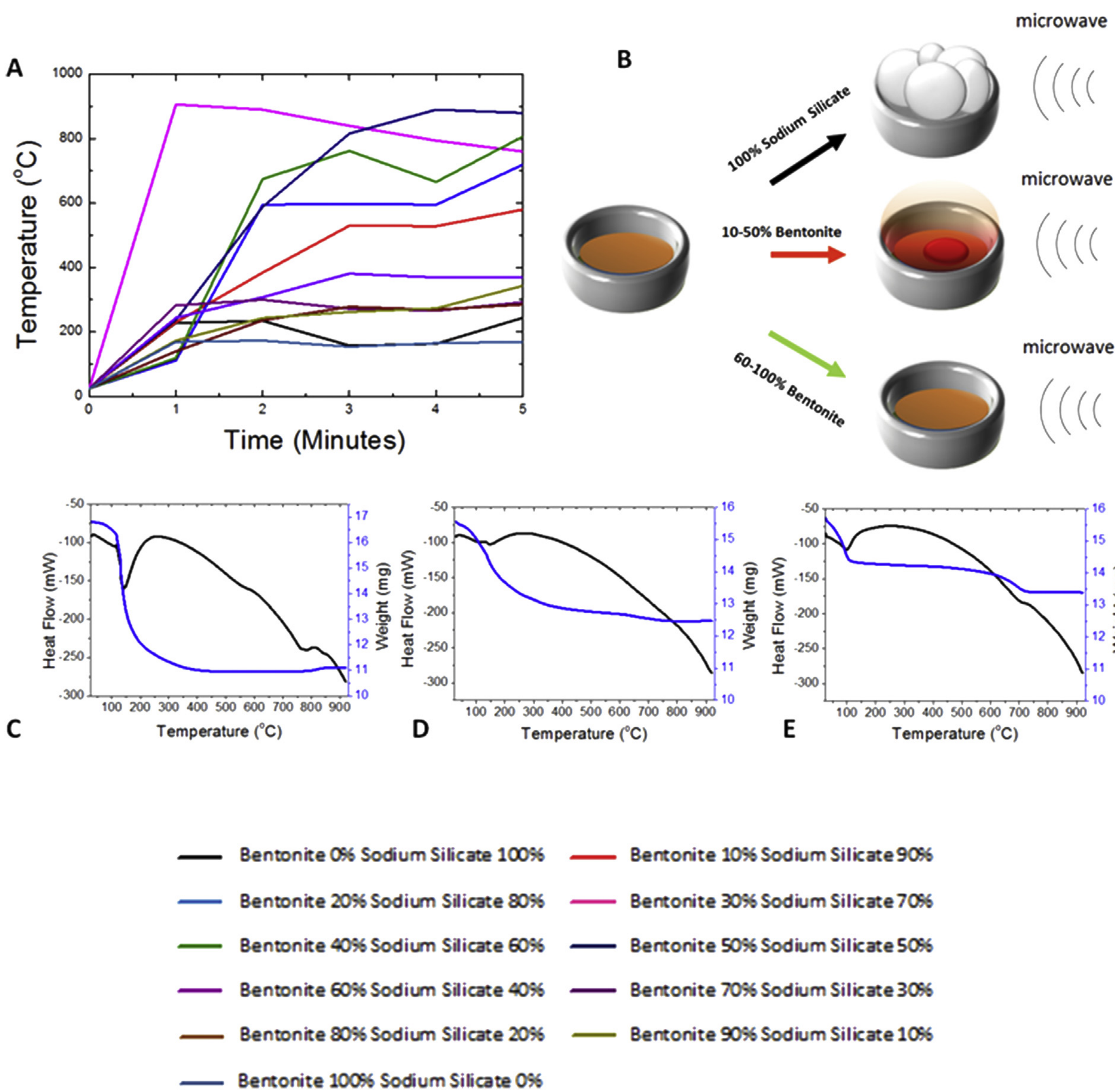

Fig. 1. **A** The temperature profile of the composite under the microwave radiation with the following mixtures. **B** The schematics of structural transformation of composite mixtures after subjecting to the microwave radiation. **C**, **D**, **E**, are DSC and TGA of pure sodium silicate, 40% bentonite 60% sodium silicate mixture, and pure bentonite respectively. (Blue line is TGA, and black line is DSC). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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