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Study on characteristics of microwave melting of copper powder

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ABSTRACT

Microwave heating has been widely used because of its advantages of higher heating rate, energy efficiency and clean utilization. This paper describes the study carried out on the characteristics of microwave melting of metallic copper powders, and a quantitative description of the heating curve of the copper powders in microwave field is given. The changes in microscopic structure and densification during the process of heating to melting of copper powder with microwave is assessed. The result demonstrated that copper powders could be quickly heated to melting. Heating rate for powdered copper of particle size 25 μm is 25.6 °C/min. Microwave heating efficiency and the heating rate were found to be higher with the decrease in the particle size and increase in microwave power. And also the heating rate had a linear relationship with the reciprocal of the particle size. Microstructure and density indicates that the densification process accelerates when the temperature is above 900 °C, and all the copper particles are heated to melting and shrinkage. At lower temperature the migration of the matter for copper particles is mainly internal diffusion. While the temperature above 1083 °C, among copper particles will be form metallurgical bonding, and the melting process complete quickly.

1. Introduction

Microwave is a part of electromagnetic wave with a frequency range from 300 MHz to 300 GHz, and the corresponding wavelength varies from 1 mm to 1 m. At present, microwave has been widely used in different fields [1–4], such as communication equipment, information engineering, food and medical treatment, material preparation, chemical reaction and etc. Among them, the microwave heating technology is a main form of microwave energy application. Heating matter through microwave has gained eminence because the microwave energy converts into heat within the matter. Therefore, microwave heating has the characteristics of non-contact uniform heating, selective heating and overall penetrating heating, and also possess various advantages of being clean, highly efficient, energy saving and environmentally safe [5–8]. In the field of material preparation, microwave sintering technology has been developed as an important technical means to prepare high-quality novel materials rapidly, especially having a broad application in the preparation of powder metallurgy materials [9–12].

Microwave heating has more advantages than traditional sintering in the preparation of materials where high uniformity in phase structure, higher density and microstructure with better properties can be obtained [11,12]. Roy et al. [13], studied the microwave sintering of different powdered metals and their alloys, such as iron, aluminum, nickel, molybdenum, cobalt, and so on. They obtained fully dense metal products with better mechanical properties than the conventionally sintered metal, which paved way to increased research on microwave sintering powdered metals. Annamalai et al. [14], studied on microwave sintering of Fe, Fe-2Cu and Fe-2Cu-0.8C alloys. Their results showed that despite the composition of alloys being different, all samples showed nearly similar sintered densities and the carbonyl powder compacts had better mechanical properties. Another study reported sintering of Ti powder compacts by microwave with the assistance of

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susceptors, where a faster heating rate of 34 °C/min was observed using microwave than the conventional heating of 4 °C/min [15]. The microwave sintering of ultrafine WC-Co at a frequency of 2.45 GHz was studied by Agrawal et al., [16]. They have reported the lower porosity of WC matrix as compared to the traditional sintering, and the growth of WC grains was restrained, thus the microstructure was more uniform. Mondal et al. [17–19], have studied the effect of heating methods and sintering temperatures on 90W-7Ni-3Fe alloy. The results suggested that the microwave sintering of W-Ni-Fe alloy could reduce the process time by 80%, and the alloys exhibited relatively higher hardness and flexural strength. Prabhu et al. [20], Zhou et al. [21], and Bao et al. [22,23], have carried out extensive research on microwave sintering of tungsten and its alloys, and have achieved superior results. In addition, Ghosh et al. [24], reported that Al-α-Al_2O_3 core-shell composite could be prepared by the microwave radiation of aluminum powders for 45 min. Demirskyi et al. [25,26], have studied the densification kinetics of powdered copper under single-mode and multimode microwave sintering and have concluded that densification kinetics in single-mode applicator were faster comparing to multimode microwave sintering.

In our previous work, an investigation on the preparation of copper-tungsten alloy using microwave vacuum infiltration sintering was done, and the results were encouraging [27]. The present work focuses on the characteristics of melting and heating of powdered copper in the microwave field. The changes in the microscopic structure and density of powdered copper sintered by microwave is assessed and analyzed.

2. Experimental

2.1. Materials and methods

Commercial copper powders (purity higher than 99.7%) of different particle sizes were purchased from Shanghai Longxin Chemical Industry Co. Ltd., China, and used in the experiments. The copper particle size was measured by laser particle size analyzer (Mastersizer 2000), and the particle sizes used in this study were around 25 μm, 38 μm and 74 μm.

The copper powder melting experiments were conducted by using a 3 kW microwave high temperature furnace, with the frequency of 2.45 GHz. The microstructure of sintered copper powder samples was observed after surface polishing by metallographic microscopy (Axio Vert.A1, provided by Carl Zeiss Microscopy GmbH, GERMANY), and the neck growth of copper powder sintering was observed by scanning electron microscopy (JSM-5610LV, JEOL, Ltd., Tokyo, Japan). The density of sintered samples was measured using Archimedes principle.

2.2. Experimental procedure

Prior to carrying out the experiments, a known amount of copper powders were weighted. Copper powder was transferred to a 100 ml alumina crucible and was placed in the microwave high temperature furnace. The polycrystalline mullite fiber was used as insulation material because of its high thermal insulation and microwave penetration performance. Argon which acts as protective gas was filled into the furnace cavity after vacuum processing. Then a power of 1.3 kW–1.8 kW of microwave was applied for the heating of powdered copper. In the present experiments, heating and melting of copper powder by microwave was done without using any microwave absorbing matters as auxiliary. In order to ensure the accuracy of measurement, an infrared detector was used for measuring temperature. The samples of copper powder were collected after sintering at different temperatures of 900 °C,1060 °C, 1083 °C and 1090 °C. The change in the microstructure and density of powdered copper during heating under microwave irradiation was analyzed. A schematic illustration of microwave assisted melting of copper powder is shown in Fig. 1.

3. Results and discussion

3.1. Characteristics of microwave heating metallic copper powder

In order to assess the melting characteristics of powdered copper in microwave field, the temperature rise curve of copper powder with the particle size of 74 μm was measured. Fig. 2 shows the temperature rise curve of different amounts of copper powder (50 g, 100 g and 150 g) under 1.3 kW microwave irradiation.

From Fig. 2, it can be noticed that microwave heating is effective in melting the copper powder without using any auxiliary microwave absorbing materials. The temperature rise curve shows an obvious melting temperature area (marked with circle) which indicates that the copper powder begins to absorb heat and melt. A drop in the heating rate clearly indicates the energy utilized for phase change. An observation of all the three curves indicate a near exponential heating rate before melting and a slow heating zone after the melting point. However, our experiment demonstrated that 100 g of copper powders showed better temperature rise performance by microwave heating, with a significant rising temperature trend up to 1200 °C. These indicated that the molten copper can still absorb microwave energy and convert it into thermal energy, which makes the temperature to rise. However, in the case of smaller amount of copper powders (50 g), the absorption of microwave energy is lesser and hence the heating rate is lower. Noticeable, by increasing the copper powders to 150 g, thermal energy released from the melting of copper is consistent with absorbed microwave energy, thus the temperature remains almost steady after melting.

In addition, the effect of microwave power on the melting characteristics has been investigated. The temperature rise of powdered copper of particle size 74 μm under 1.3 kW and 1.8 kW microwave radiation power was measured and the corresponding

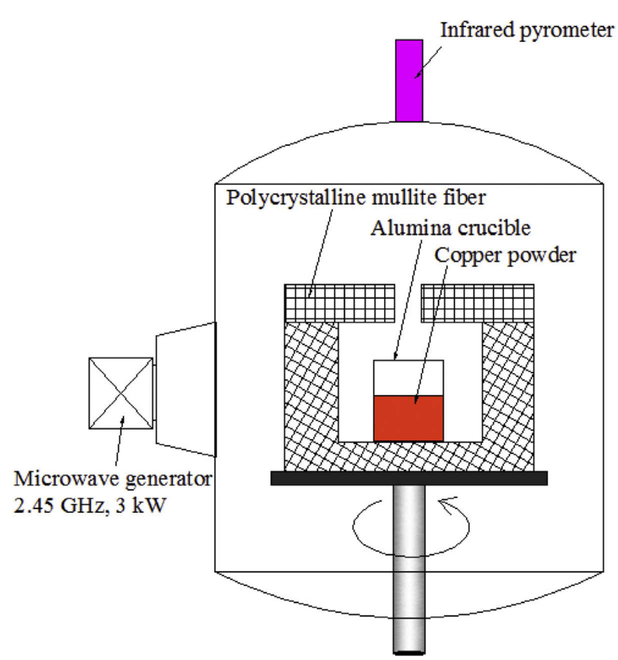

Fig. 1. Schematic illustration of microwave melting of copper powder.