



# Produce large-sized porous ZnO ceramics at a low temperature down to 573 K



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## ABSTRACT

Large-sized porous ZnO ceramics were successfully produced at a low temperature down to 573 K for the first time. The ceramics were composed of pores with a diameter of hundreds of nanometers and intersected ZnO nanosheets with a thickness of tens of nanometers, and their bending strength was up to 41.4 MPa when its porosity was about 43%, which meant that their strength and the bonds between their building blocks were exactly the same as those in the ceramics produced by sintering its preforms at a high temperature.

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## 1. Introduction

Porous ceramics can be used as electrodes, chemical sensors, solar radiation conversion, supports for batteries and solid oxide fuel cells, scaffolds for bone replacement and tissue engineering and filters to deal with water, molten metal, diesel engine exhaust gases and hot corrosive gases in various industrial processes [1–4]. There are many approaches to fabricate porous ceramics, for example, sintering the initially porous powder compacts at a high temperature [5,6], replica [7–11], sacrificial templating [12–15], direct foaming [16–18], selective leaching [19]. In all of the approaches, in order to shape the final porous ceramic samples and make the final porous ceramic samples get a desired mechanical strength, it is necessary to sinter the porous ceramic preforms at a high temperatures ranging from 1400 K to 2000 K depending on the materials [3]. Sintering the ceramic preforms at a temperature so high will consume a great quantity of energy. So exploring a way to effectively produce large-sized porous ceramics at a low temperature will be a challenge and important work.

In this paper, through oxidizing the samples resulted from the Al–Zn alloy etched by Na(OH) aqueous solution, porous ZnO ceramics were successfully fabricated at a low temperature down to 573 K. The bending strength of porous ceramics was up to 41.4 MPa when their porosity was about 43%, which meant that the bending strength of the ceramics reached the compression strength of ceramics with the same porosity produced through sintering their preforms at a high temperature [3].

## 2. Experimental section

An Al ingot with a purity of 99.9(wt)% and an Zn ingot with a purity of 99.95(wt)% were melted together in an electrical resistance furnace to get an Al–Zn alloy melt with Zn percentage between 30(wt)% and 80%. The liquid alloy was directly rolled to be strips with a thickness not more than 1 mm through a bar rolling mill with a linear velocity of 4 m/s. The strips were then cut into chips with a desired shape, and then the chips were polished gently with 800# waterproof abrasive papers as well as water flowing through them. Then the chips with a desired weight were immersed into 1 M NaOH aqueous solution with a proper volume to remove the Al atoms out of them. For example, for the 50% (wt) Al–Zn alloy chips with a weight of 4 g, the proper volume of 1 M NaOH aqueous solution was about 120 ml. When there were no conspicuous bubbles generated from the chips, the chips were taken out of the solution and dried firstly by absorbent papers and then dried at 373 K for 1 h. At last, the chips were directly heated to 573 K in the atmosphere and kept at the temperature for 6 h, and then the final samples were obtained. In order to verify the samples to be a porous ZnO chips, XRD, SEM and Three-point bending test were carried out. XRD patterns of samples were carried out on a Rigaku Dmx X-ray diffractometer with a CuK $\alpha_1$  radiation with a scanning speed of 10 per min, SEM images were recorded on a JSM-7000F field emission microscope, and three-point bending tests were fulfilled on an electronic universal material testing machine.

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### 3. Results and discussion

Fig. 1 was the XRD patterns for the final sample. All the peaks in the XRD patterns were in keeping with those of wurtzite ZnO (PDF card No. 36-1451, space group  $P6_3mc$ ), thus the final sample was wurtzite ZnO.

The photograph and the SEM images of the final ZnO sample with different magnifications were shown in Fig. 2. From the Fig. 2a, it can be seen that the length and the width of the final ZnO sample were all up to centimeter, thus the final ZnO sample was large sized. Except some scratches on its surfaces (which may come from the process of polishing the alloy chips with waterproof abrasive papers), there were no other breaks in the sample, thus the ZnO sample was an integrated body. Moreover, as shown in Fig. 2c, the sample consisted of pores and intersected nanosheets with a thickness of tens of nanometers, thus the ZnO sample was a large-sized porous ZnO ceramics with a fine nanostructure.

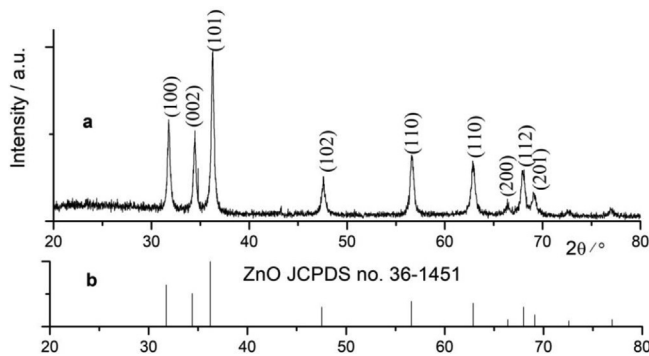


Fig. 1. XRD patterns of sample (a) and standard ZnO (JCPDS no. 36-1451) (b).

In order to further verify that the final ZnO ceramic sample was an integrated body, instead of a compacted accumulation of building blocks, a sample, which was resulted from the 40%(wt) Al-Zn alloy chip with a length of 30 mm, a width of 3.67 mm and a thickness of 0.73 mm, was used to carry out three-point bending tests. According to the percentage of Al in the alloy chip and the volume change for Zn oxidized into ZnO, the porosity of the ZnO sample was evaluated to be about 43% (in the calculation, it was supposed that when the alloy chip was etched in Na(OH) solution, the shape and the sizes of chip were unchanged, the volume of the Al-Zn alloy chip was the sum of the Al volume and the Zn volume and the porosity of the final ZnO sample was equal to the difference between 1 and the volume percentage of ZnO in the sample. Thus the porosity of the sample can be calculated by the formula:

$1 - \frac{Zn\%(wt) \times M}{m \times \rho_{ZnO}} / \left( \frac{Al\%(wt)}{\rho_{Al}} + \frac{Zn\%(wt)}{\rho_{Zn}} \right)$ , where M was the molar mass of ZnO, m was the molar mass of Zn,  $\rho$  was the density of materials, and Zn%(wt) and Al%(wt) were the weight percentage of Al and Zn in the alloy respectively. The Fig. 3 exhibited the bending displacement curve of the sample. The curve indicated that when the sample was broken, the force on the sample was 2.7 N. Then according to the following formula, its bending strength can be calculated.

$$\sigma = 3F \cdot L / (2b \cdot h^2)$$

where  $\sigma$  was the bending strength, F was the force (when the sample was broken, the force was equal to 2.7 N), L was the distance between the two supporting points on the mould (the distance was 20 mm in the experiment), b was the width of the sample (b was 3.67 mm as mentioned above), and h was the thickness of the sample and equal to 0.73 mm. The bending strength for the sample was 41.4 MPa, which was close to the compression strength theoretically expected for open-cell porous ceramics according to the model from Gibson and Ashby [3,20], so the bending strength

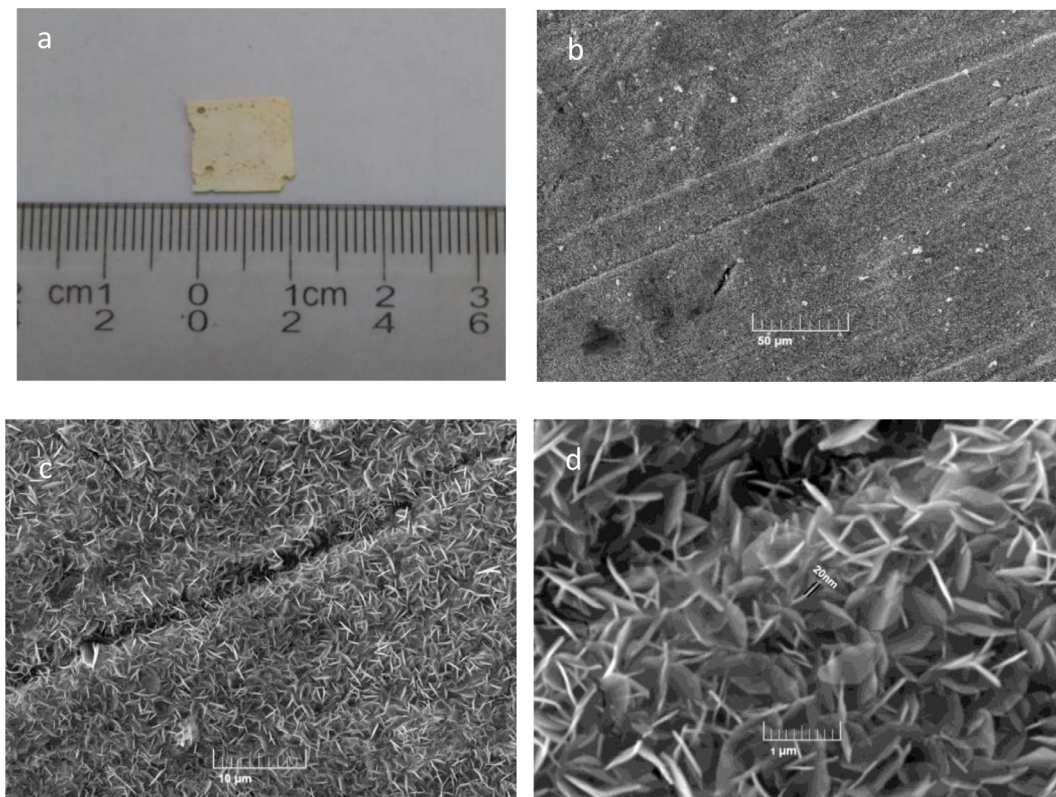


Fig. 2. SEM images of the ZnO sample with different magnifications.

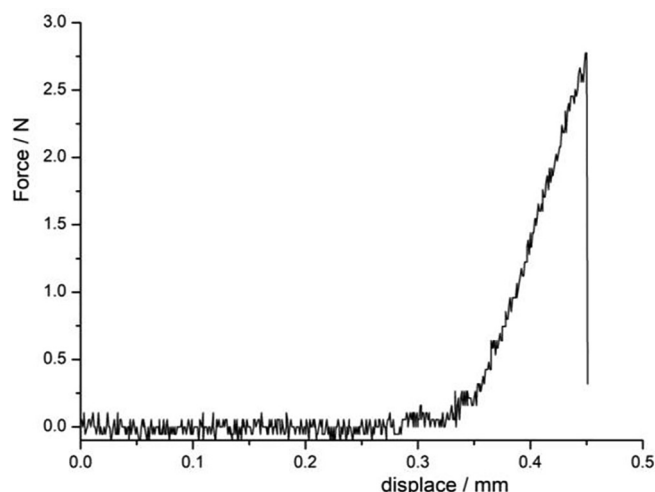


Fig. 3. Bending displacement-Force curve of the sample.

further verified that the porous ZnO sample was a integrated porous ceramics and was as same as the porous ceramics prepared through sintering their preforms at a high temperature. The reason that the process introduced in this paper can be used to prepare porous ceramics at a low temperature was still in investigation.

#### 4. Conclusions

Porous ceramics with a length and a width up to centimeter was prepared successfully at a temperature 573 K. The bending strength of the porous ceramics was 41.4 MPa when its porosity was about 43%. The process presented in this paper may be a new method to manufacture the large-sized porous ceramics at a low temperature.

#### Conflict of interest

None.

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