

## Recycling of waste porcelain for ceramic ware

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Recycling of waste porcelain body is important and useful from an environmental and economic point of views. In this study, recycled ceramic raw material was obtained by crushing and milling from waste porcelain bodies. Using the recycled powder with a particle size of 0.5–2.0  $\mu\text{m}$ , a porcelain ceramic batch composition was prepared by mixing 100–50 wt% of normal ceramic raw materials and 0–50 wt% of the recycled powder. Sintering properties of the porcelain ceramics at sintering temperatures of 1150–1350 °C were investigated. The porcelain body with 10 wt% of the recycled powder sintered at 1200 °C showed the highest sintered density of 2.5 g/cm<sup>3</sup>. When sintered above 1300 °C, many cracks and pores were observed in the porcelain body due to over sintering and preferential shrinkage of the glassy phase during cooling.

**Key words:** Porcelain, Recycling, Ceramic, Sintering.

### Introduction

A quantity of waste porcelain is generated from industries during the production of ceramic ware such as porcelain and bone china. However, most of the waste porcelain bodies are dumped in landfills and only small quantities have been recycled as a raw material of concrete [1]. The wastes reclaimed in landfills may induce soil contamination and an environmental crisis. Thus, it is important and useful to recycle the waste porcelain in ways to save production costs and protect the environment.

The waste porcelain is composed of kaolin, feldspar and silica, which are the raw materials of ceramic ware [2]. Specifically, a glassy phase mainly originating from the feldspar can decrease the sintering temperature of traditional porcelain [3–5]. Thus, this study aimed to recycle the waste porcelain as a raw material for application in porcelain with a better sintering behavior. The effects of the recycled raw material and sintering temperature on the microstructure and densification of the porcelains were also investigated.

### Experimental

Waste porcelain as a raw material was obtained from INSININE (Gwangju, Korea). The waste porcelain bodies were crushed using a jaw and a roll crusher. After screening large particles, the porcelain powder was ball milled for 1–5 days and was used as a recycled powder. To prepare recycled ceramic ware, the recycled powder was added to

normal ceramic raw powder with 30% of water and 0.2% of CF44 as a dispersant. The batch compositions of normal : recycled powders are shown in Table 1. The batch powders were uniaxially compacted and cold isostatically pressed (CIP) at 220 MPa for 15 minutes, and then sintered from 1150 to 1350 °C for 1 h in air at temperature intervals of 100 °C. The sintered bodies with the recycled porcelain were polished to smoothness using 1  $\mu\text{m}$  diamond paste for further microstructural analysis. Sintered densities were measured by the Archimedes' technique. The crystalline phases of the waste porcelain bodies and the sintered samples were determined by X-ray diffraction (XRD). The microstructures of the recycled powders and the sintered samples were analyzed by a field emission scanning electron microscope (FE-SEM). Element analysis of the recycled porcelain was carried out using energy dispersive spectrometry (EDS).

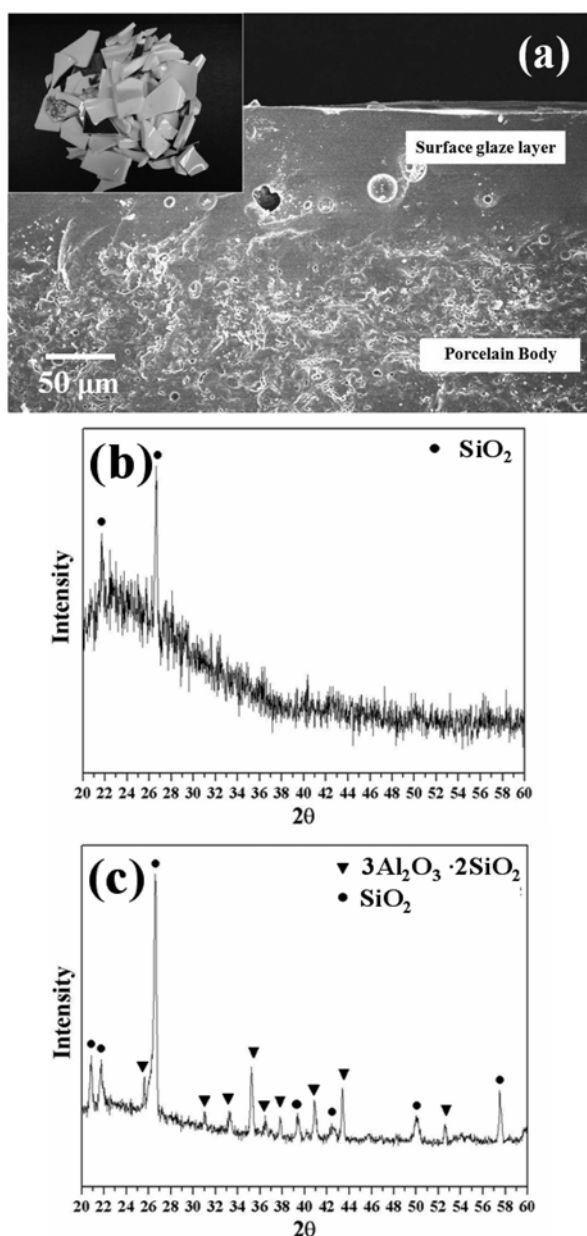
### Results and Discussion

Fig. 1 shows FE-SEM micrograph and XRD patterns of the waste porcelain. The fracture surface showed that the surface of the porcelain was covered by a glazed dense layer approximately 100  $\mu\text{m}$  in thickness, but there were many pores in the interior region of the porcelain body

**Table 1.** Ceramic batch composition with recycled porcelain powder

batch composition	recycled powder(%)	normal powder(%)
0R	0	100
10R	10	90
20R	20	80
30R	30	70
40R	40	60
50R	50	50

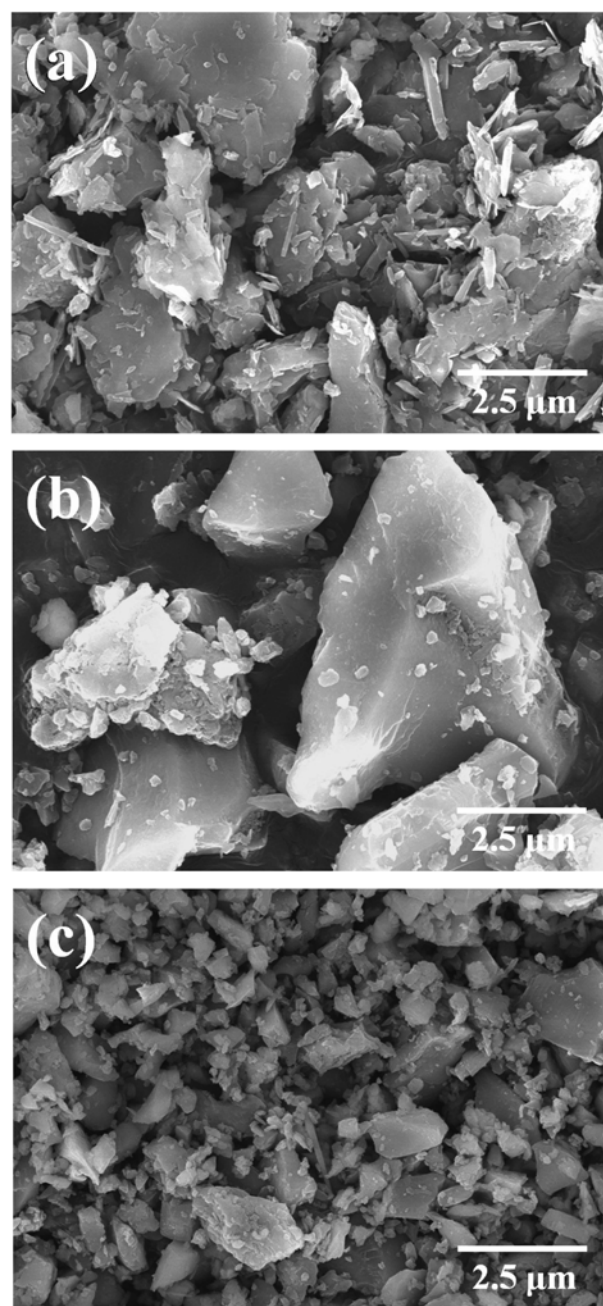
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**Fig. 1.** (a) SEM micrograph of the waste porcelain, and XRD patterns of (b) the glazed surface and (c) the body of the waste porcelain.

compared with the glazed surface layer. During sintering, a few pores with a round shape were formed in the glazed layer resulting from the presence of a captured gas and lens type pores, however existed throughout the porcelain body due to less densification. The different crystal structures between the glazed surface and porcelain body were also observed from the XRD patterns. The crystalline phase identified in the glazed surface is quartz ( $\text{SiO}_2$ ) and other peaks were not observed indicating the presence of glassy phases. The body part consisted of quartz and mullite ( $2\text{SiO}_2 \cdot 3\text{Al}_2\text{O}_3$ ). Quartz is a residual mineral from the original raw materials and mullite was formed during sintering.

Fig. 2 shows SEM micrographs of the normal ceramic raw powder and the recycled powders. The normal ceramic



**Fig. 2.** SEM micrographs of (a) the normal ceramic raw powder, and the recycled powders; (b) before ball milling and (c) ball milled for 5 days.

powder consisted of rod-like small particles with  $0.5\text{ }\mu\text{m}$  and large particles of  $> 3\text{ }\mu\text{m}$  with irregular shape (Fig. 2(a)). The waste porcelain powder crushed by a jaw and a roll crusher had particles of  $0.5\text{--}6.0\text{ }\mu\text{m}$  in size with a wide size distribution and irregular particle shape (Fig. 2(b)). The recycled powders ball milled for 5 days showed the smallest particle size of  $0.5\text{--}2.5\text{ }\mu\text{m}$  with a relatively narrow size distribution and the particles had an angular shape. The powders milled for 5 days were used for the preparation of recycled porcelain bodies.

Fig. 3 shows sintered densities of the recycled porcelains

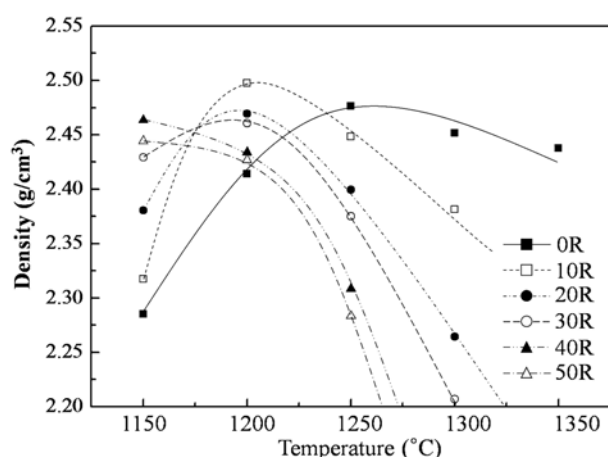


Fig. 3. Sintered densities of the porcelains as functions of batch composition and sintering temperature.

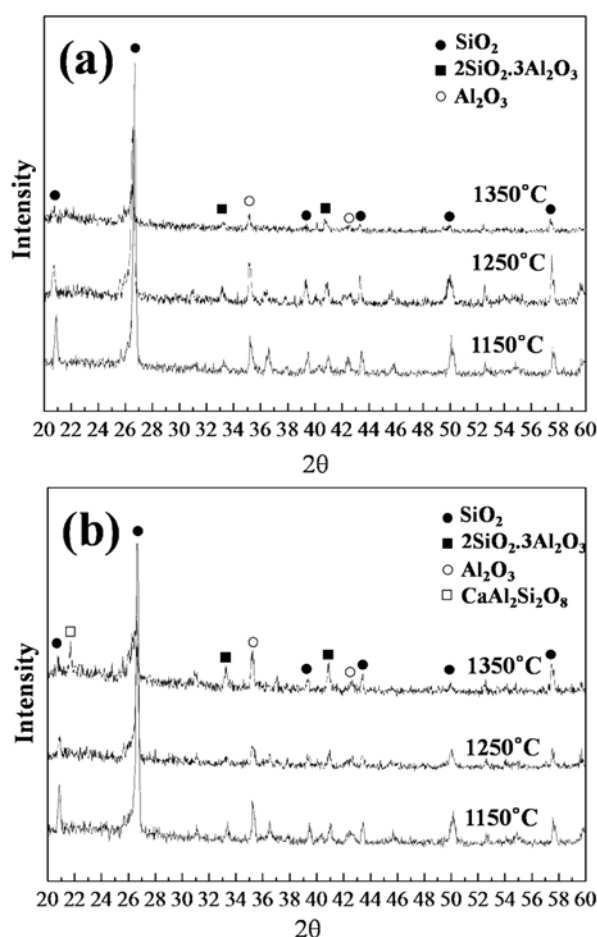


Fig. 4. XRD patterns of (a) 0R and (b) 10R porcelains as a function of the sintering temperature.

as functions of batch composition and sintering temperature. The densities increased up to 1200 °C. However, a distinct decrease of the densities in all compositions appeared at temperatures above 1200 °C. With an increase in the amount of recycled powders, the densities decreased drastically above 1200 °C meaning that an excessive amount of the

recycled powders affects adversely on densification of the porcelains. The highest density of 2.50 g/cm<sup>3</sup> was obtained in the 10R porcelain (10 wt% recycled powder addition) sintered at 1200 °C. By contrast, the porcelain without the recycled powder, i.e., 0R, showed the highest density of 2.47 g/cm<sup>3</sup> at 1250 °C. This result indicates that a higher density of a traditional porcelain can be obtained at a lower sintering temperature by using an appropriate amount of the recycled powders.

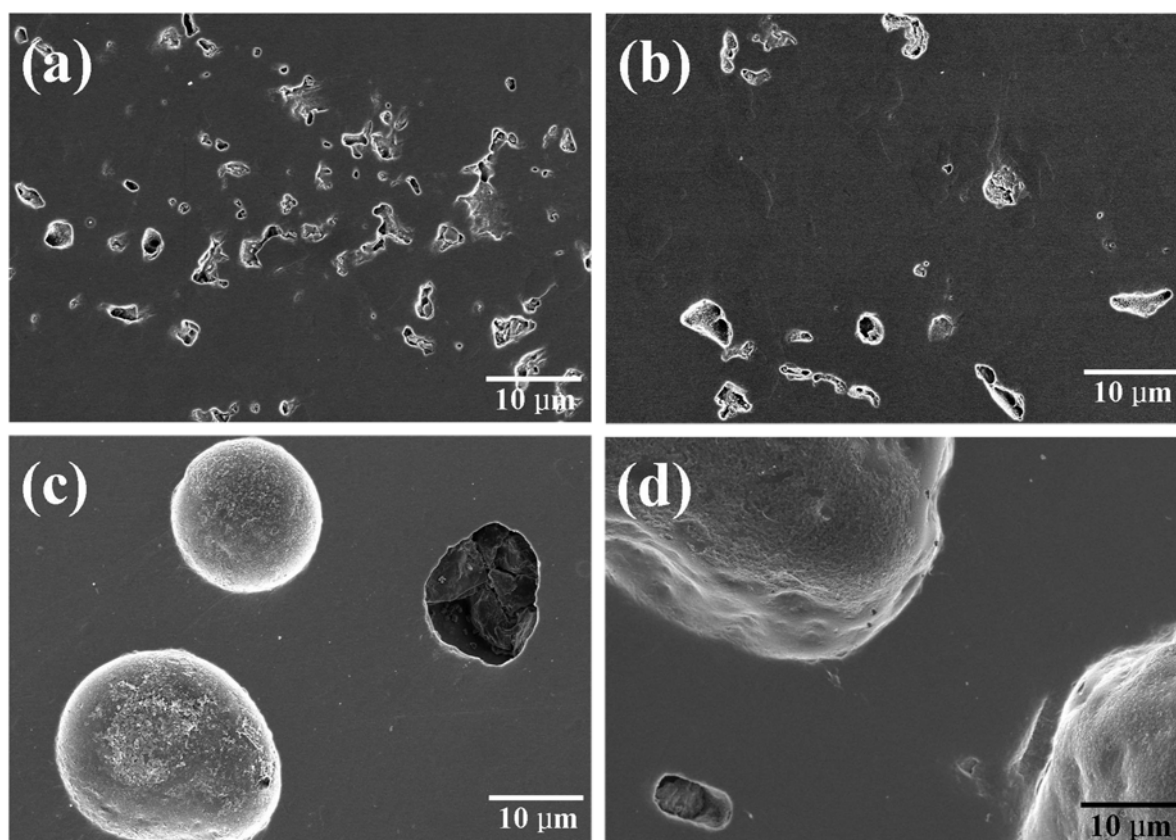
Fig. 4 shows XRD patterns of 0R and 10R porcelains with as a function of the sintering temperature. The main crystal phases in both compositions were mullite, quartz and alumina. The difference between 0R and 10R porcelains was the presence of the anorthite (CaAl<sub>2</sub>Si<sub>2</sub>O<sub>8</sub>) phase in the 10R porcelain sintered at 1350 °C. The drastic decrease in sintered density may be attributed to the formation of the anorthite phase.

Microstructural observations for the 10R porcelains in Fig. 5 revealed that densification was improved up to 1200 °C. However, large pores were formed at higher sintering temperatures, and the size of the pores increased up to 30 μm at 1350 °C. The presence of the large pores may be responsible for the decrease in sintered density with an increase in the temperature.

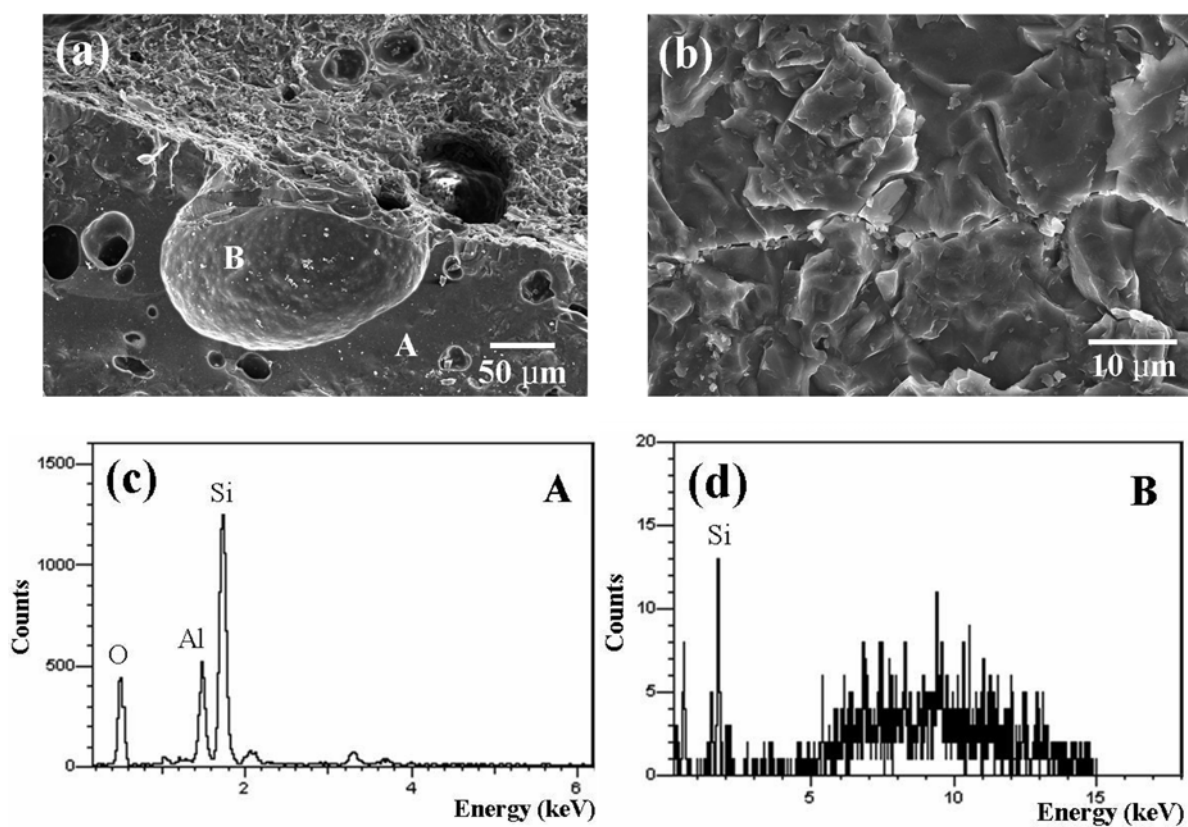
The appearance of the large pores in the recycled porcelains could be explained by the formation of glassy agglomerates, as shown in Fig. 6(a). According to the EDS analysis (Fig. 6(c), (d)), there was only silicon ions in the region B indicating that the spherical agglomerate was a glassy phase. This assumes that the large pores in the porcelain may be formed by a gas trapped in the glassy phase. Furthermore, cracks were observed in the fracture surface due to preferential shrinkage of the glassy phase during cooling. Accordingly, the dramatic decrease in sintered densities with an increase in the sintered temperature, i.e. over sintering, could be explained by the presence of many pores and cracks.

## Conclusions

Waste porcelain was recycled on a laboratory scale and used for the production of traditional porcelain. The amount of the recycled powder and sintering temperature influenced the densification of the porcelain. An excessive amount of the recycled powder and a high sintering temperature induced negative effects on the microstructure and sintering properties of the products due to the formation of a glassy phase. The porcelain made with a mixture of 10 wt% recycled powder and normal ceramic raw material showed the highest sintered density of 2.50 g/cm<sup>3</sup> at 1200 °C, which was a lower sintering temperature compared with the best porcelain prepared without the recycled powder. The enhanced densification at the lower sintering temperature has advantages of improving the reliability of the product and saving production cost. It can be concluded that waste porcelain can be a useful sintering substance for the production of ceramic wares.



**Fig. 5.** SEM micrographs of the porcelains with 10 wt% of the recycled powder added as a function of the sintering temperature; (a) 1150 °C, (b) 1200 °C, (c) 1250 °C and (d) 1350 °C.



**Fig. 6.** Fracture surfaces of the 10R porcelain ((a),(b)), and (c) EDS analysis of the A region and (d) the B region in (a).

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