

Crystalline phases and physical properties of modified stoneware body with glaze sludge

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Abstract

Ceramic stoneware body has been modified with ceramic and glass industrial wastes by replacing 25–100% as flux in the formula. The effects of solid wastes added to the bodies were studied after firing in the temperature range 950–1280 °C. The physical properties of linear shrinkage, bulk density, apparent porosity, water absorption and 3-point bending strength were determined. A composition which related to the general stoneware properties was found when using soda-lime cullet and glaze sludge. It had a firing range lowered to 1050–1100 °C. SEM results demonstrated the sintered microstructure increased in density with increase in solid waste in the modified body. XRD results after firing showed the crystalline phases comprised of mullite, albite calcian and quartz. Thermal expansion was measured in the range $6.53\text{--}6.67 \times 10^{-6} \text{ K}^{-1}$ at 30–500 °C. The modified bodies were capable of forming prototype products by slip casting and jigging.

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1. Introduction

Ceramic manufacturing requires the reduction of production costs, especially the energy costs by developing the firing process and equipment. Many publications have reported that firing temperature can be lowered by addition of fluxes into the formula. Tulyaganov et al. [1] studied the influence of lithium oxide as an auxiliary flux on the properties of triaxial porcelain bodies. The desirable properties for tableware porcelains could be obtained if the Li_2O -content did not exceed 1.5 wt%. Salem et al. [2] reported a dilatometric study of shrinkage during the sintering process for porcelain stoneware bodies in the presence of nepheline syenite, with the maximum densification rate found with 10.0 wt% of nepheline syenite addition. Whereas the main approach of reducing firing temperature is to improve the formulation of the body and glaze, it became difficult to maintain the raw materials costs when the chemical additions were made. Additionally, raw materials preparation is an important variable, having an effect on the firing temperature, Kivitz et al. [3]. They studied the effect of preparation of the raw materials on the lowering of the porcelain firing temperature, and found that the

sintering temperature had been decreased by approximately 180 °C after 720 min grinding of the raw materials.

Recycling of industrial wastes aids environmentally friendly production and has the advantage of lowering costs further. Since many wastes contain an abundance of alkali and alkaline earth oxides, the production cost decreased according to the lower the firing temperature used in ceramic manufacturing. Solid wastes such as glass cullet, stone residue and fly ash have been used in stoneware and porcelain stoneware tile bodies. Tucci and et al. [4] reported that 10% sodium feldspar replacement with soda-lime scrap-glass could lower the firing temperature and gave better mechanical characteristics, attributed to enhanced microstructural homogeneity. Montero et al. [5] used calcium carbonate residue from the marble industry in manufacturing ceramic tile bodies. They showed that the residue reacted easily with phyllosilicates and quartz, providing better sintering of the original powder. This resulted in a decrease in the bending strength when the addition of marble sludge increased. Yuruyen et al. [6] studied the sintering kinetics of porcelain bodies made from waste glass and fly ash. They reported that the sintering activation energy decreased with increasing waste glass addition. Hojamberdiev et al. [7] used muscovite granite waste in the manufacture of ceramic tiles which satisfied the requirements of the state standard. The commercial stoneware body is fired to ~1200–1280 °C. It has water absorption

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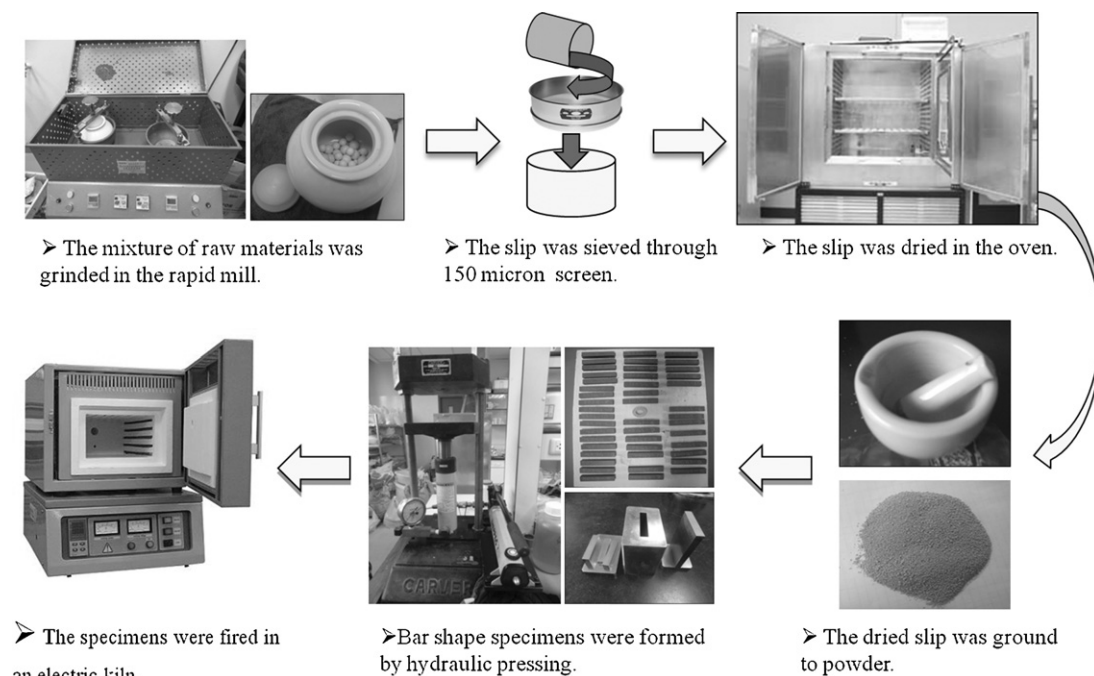


Fig. 1. Preparation of the trial specimens.

Table 1
Chemical compositions of raw materials and selected industrial wastes.

Oxides	Raw materials (wt%)					
	Ball clay	Kaolin	Silica sand	Potassium feldspar	Glaze sludge	Soda lime waste glass
SiO ₂	55.50	46.59	99.36	68.33	58.09	71.16
Al ₂ O ₃	26.78	36.06	0.20	16.75	10.23	1.12
Na ₂ O	0.20	–	–	2.39	5.49	13.46
K ₂ O	2.39	1.60	0.04	11.08	1.36	0.23
MgO	0.29	0.75	0.04	0.28	0.71	4.18
CaO	0.45	1.05	0.01	0.32	6.05	8.94
BaO	0.02	–	–	–	0.89	0.19
TiO ₂	0.32	–	0.06	–	0.12	0.20
Fe ₂ O ₃	1.73	1.59	0.09	–	0.14	0.48
ZrO ₂	–	–	0.02	–	9.82	0.02
ZnO	0.01	–	–	–	3.23	–
Others	0.12	–	0.04	–	1.98	0.02
LOI	12.19	12.36	0.13	0.85	1.91	0.00

<8%, linear shrinkage at <14% and a bending strength up to 88 MPa. The use of solid wastes such as, glass cullet and glaze sludge to modify the firing temperature of stoneware body is in the interests of ceramics industry. The sintering behavior and crystalline phases developed can be investigated to describe the affect of solid waste addition to the properties of product.

2. Materials and methods

Raw materials used in this research composed of clays (ball clay:kaolin = 4:1 by weight), potassium feldspar and silica sand which were varied in the composition. The trial compositions were ground and mixed in a rapid mill for 10 min as shown in Fig. 1. The slip was sieved through 150 μ m and dried in the oven. The dried slip was ground to powder before hydraulic pressing at 2000 psi to 10 mm $\times$ 10 mm $\times$ 50 mm bars. The sample bars were fired at 1280 $^{\circ}$ C for 60 min and each body formula was

tested for the stoneware properties including linear shrinkage (ASTM C326-03), water absorption (ASTM C373-88), apparent porosity (ASTM C373-88), bulk density (ASTM C373-88) and 3-point bending strength (ASTM C674-88). The most suitable formula was used as the reference stoneware body.

Several industrial wastes were selected as additions for the fusion test and were analyzed for chemical composition before calculating the formula of the starting powders. The chemical composition of raw materials and selected industrial wastes are shown in Table 1. The trial bodies were prepared by replacement of potassium feldspar in the reference stoneware body with 25, 50, 75 and 100% of glaze sludge. Raw material composition of the trial formulas 25GS–100GS is shown in Table 2. After the properties were investigated, the suitable formula was selected and modified again by adding 5, 10, 15 and 20% of soda-lime cullet in order to improve properties and achieve lower firing body.

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