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Influence of magnesia on sinter-crystallization, phase composition and flexural strength of sintered glass-ceramics from waste materials

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HIGHLIGHTS

- The addition of magnesia decreased the bulk density of glass-ceramics.
- The addition of magnesia increased the crystallinity of glass-ceramics.
- The porosity and crystallinity determined the flexural strength of glass-ceramics.
- Fast sintering achieved the densification and strengthening of glass-ceramics.

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ABSTRACT

Sintered glass-ceramics have been prepared from the powder mixtures of waste glass and fly ash with the addition of magnesia. The sinter-crystallization behavior of glass-ceramics was investigated in terms of densification and differential thermal analysis. The bulk density of sintered glass-ceramics decreased with increasing the magnesia content, suggesting the hindrance effect of magnesia on the sintering process. With the increase in the sintering temperature, the bulk density firstly increased and then decreased, showing a maximum value of 1.94 g/cm^3 at 1000 °C. The crystalline structure of glass-ceramics consisted of pyroxene and forsterite, and the crystallinity increased with increasing the magnesia content. The enhancement in the flexural strength of glass-ceramics was substantially influenced by three factors including porosity, crystallinity and crystal shape anisotropy. Fast sintering improved the densification, and thus increased the flexural strength of glass-ceramics. The simple sintering process and the relatively high strength of glass-ceramics shed light on the potential application of waste materials in the construction tiles.

1. Introduction

Disposal of solid wastes, including mining tailings, industrial slags, incineration ash and waste glass, has been an increasingly serious issue of the environmental protection and resource sustainability. The annual production of solid wastes is so huge that most of these wastes were scarcely disposed other than being embedded in the landfills. The recycling of solid wastes can not only solve the environmental pollution, but also achieve additional values. The silicate-based wastes are suitable to the production of profitable products, e.g. glass-ceramics, building tiles and sewage disposal agents [1–3].

Waste glass from liquid crystal display was employed to produce ceramic tiles, insulating glass-ceramics as well as a raw material for commercial sodium lime silicate glasses [4–6]. These applications help reduce the mineral usage, energy consumption and environmental pollution. Furlani et al. [7] prepared ceramic tiles by fast firing of steel slag and glass cullet, with the best result from the composition of 60 wt.% steel slag and 40 wt.% glass cullet. Similarly, Ponsot et al. [8] prepared sintered glass-ceramics from pre-stabilized fly ash mixed with clay and recycled soda-lime glass. The resultant cellular glass-ceramics showed mechanical properties comparable to the conventional porcelain. The porous glass-ceramics useful in the fire-proof, adiabatic and structural applications could also be sintered from metallurgical slag and waste glass either by the addition of foaming agents [9] or by the self-bloating mechanism [10].

As a modifying component of silicate glasses, magnesia plays an essential role in weakening the glass network, and thus promotes

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Table 1
Chemical composition of waste glass and fly ash (mass%).

Composition	SiO_2	CaO	Al_2O_3	MgO	Na_2O	K_2O	Fe_2O_3	SO_3
Waste glass	71.1	9.9	2.1	2.2	12.9	1.0	0.8	–
Fly ash	55.9	2.0	32.7	1.3	0.1	0.2	4.2	3.0

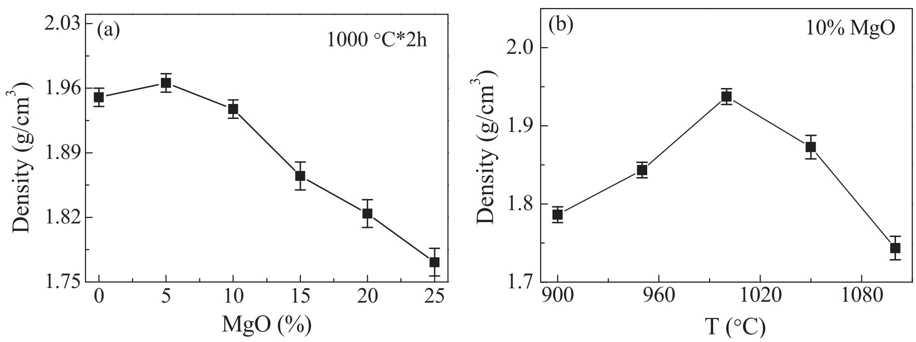

Fig. 1. Bulk density of sintered glass-ceramics. (a) different MgO contents; (b) different sintering temperatures.

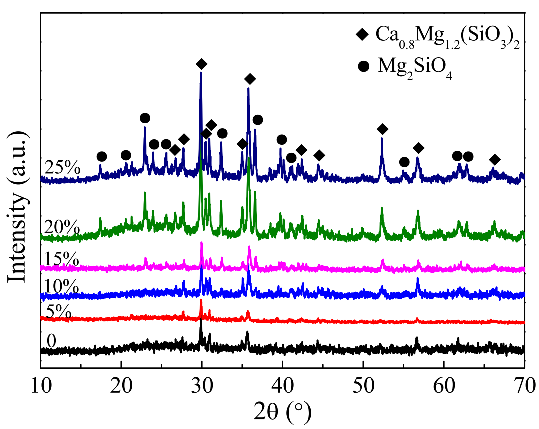

Fig. 2. XRD patterns of sintered glass-ceramics with different MgO contents.

Table 2
Phase composition (vol%) of glass-ceramics with different MgO contents.

MgO/%	0	5	10	15	20	25
Pyroxene	35	42	45	47	48	48
Forsterite	0	0	7	20	25	28
Glassy phase	65	58	48	33	27	24

the precipitation of crystalline phases in the glass matrix at relatively lower temperatures [11,12]. In the preparation of sintered glass-ceramics, the addition of magnesia remarkably increased the degree of crystallinity, but hindered the sintering process by the crystal precipitation [13]. In this paper, sintered glass-ceramics were prepared from the powder mixtures of waste glass and fly ash with the addition of different MgO contents. The sinterability, crystallization behavior and mechanical property of glass-ceramics were systematically investigated in terms of their densification, phase composition and microstructure. The heating rate of sintering process was also examined to clarify its effect on the densification, crystallization and flexural strength.

2. Materials and methods

The raw materials included waste glass from soda-lime silicate glass (float glass) and fly ash from thermal power plant. The chemical composition of raw materials is listed in Table 1. Analytically pure magnesia powder was purchased from Sinopharm Chemical Reagent Co., Ltd. The glass cullet was ground using alumina balls in a planetary mill to obtain glass powders. Fly ash powder was calcined at 800 °C for 2 h to remove any volatiles. Both glass and fly ash powders were separately passed through 120-mesh sieves.

2.1. Preparation of glass-ceramics

The starting materials of glass-ceramics consisted of 70% glass (mass%) and 30% fly ash with the addition of different magnesia contents, i.e. 5–25% MgO. The powder mixtures were firstly blended in a mortar with pestle for 30 min, and thoroughly passed through 120-mesh sieves. Then, the powder mixtures were uniformly mixed with a polyvinyl alcohol (PVA) aqueous solution (5%), and uniaxially pressed at 100 MPa to obtain rectangular bars. The green compacts were dried at 120 °C overnight, embedded in the alumina powder, and sintered at different temperatures in a temperature-programmed muffle furnace with a heating rate of 10 °C/min. In the heating stage the as-prepared samples were thermally treated at 500 °C for 2 h to eliminate the PVA binder and adsorbed gases. Moreover, various heating rates of 2–30 °C/min were attempted to study the effect of fast sintering on the densification, microstructure and mechanical property of glass-ceramics.

2.2. Characterization

The bulk density of glass-ceramics was measured using the Archimedes' method (ASTM C373-88). The crystalline structure of glass-ceramics was identified by X-ray powder diffraction (XRD, D8 Advance, Bruker-AXS) using Cu Kα radiation, and the phase composition was estimated from the XRD pattern simulation by using the MDI Jade 5.0 software, with the aim to study the variation of different phases. The crystallization behavior of glass-ceramics was investigated by differential thermal analysis (DTA, Pyris Diamond, Perkin Elmer).

The microstructure observation and elemental analysis of glass-