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Fabrication and morphology control of highly porous mullite thermal insulators prepared by gelation freezing route

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ABSTRACT

Mullite thermal insulators with high porosities of up to 91 vol% were fabricated using a gelation freezing method, resulting in a honeycomb-like morphology with micrometer-sized cells. Mullite particles dispersed gelatin based gels with and without an ice binding protein additives were frozen, dried under vacuum and sintered at 1500 °C. Ice binding proteins could inhibit the formation of large ice crystals and reduce cell size in insulators obtained. The thermal conductivity of the obtained thermal insulators ranged from 0.23 to 0.38 W/mK at room temperature. The compressive strength was measured to be 1.4–21.7 MPa. These properties could be varied by adjusting the process parameters of the gelation freezing. The method proposed here is a promising method of preparing ceramic insulators with very high porosity and improved strength.

1. Introduction

Pores are generally treated as fracture origins for structural applications of brittle ceramic materials. However, there have been many industrial applications, in which porosity can be positively taken into account, due to wide range of applications such as refractories, filtrations, biomaterials, catalyst supports, thermal insulators and lightweight structural components. Among these applications, ceramic thermal insulators have recently gained in the importance. By employing thermal insulators with very low conductivity, heat leakage can be decreased in high temperature furnaces and chemical plants, leading to improved energy efficiency and energy savings.

Traditional insulating firebricks and ceramic fibrous insulators have been most frequently utilized in various industrial applications mentioned above. The thermal conductivity of the firebrick is relatively high, due to its low porosity, but the applications are mainly structural components such as the lining of high temperature furnace [1,2]. This firebrick is generally fabricated by partial sintering, together mixing with sacrificial organic additives to be burned out. Whereas the thermal conductivities of the refractory fibrous insulators are much lower than those of the firebricks, less than or around approximately 0.1 W/mK, they provide insufficient mechanical reliability due to their very high porosity. Furthermore, ceramic fibers are categorized as Group 2B (a possible human carcinogen) as stipulated by the WHO (World Health Organization). Thus, the fibrous insulators have to be carefully reviewed, but the substitutes must be considered. Recent demands on ceramic insulators present two challenges: one is an improved mechanical strength comparable to those of the firebricks, and the other one is lowered thermal conductivity, similar to those of the fibrous insulators. Although a reduction in porosity can result in increased strength, it can also increase the thermal conductivity. Thus, there is a trade-off between mechanical strength and thermal conductivity.

It may be possible to overcome the above problems by using a freeze casting method to fabricate thermal insulators, because the porous ceramics prepared by this route have exhibited improved mechanical strength and structural rigidity, despite their very high porosity [3–5]. Typical approaches involve the freeze-drying of aqueous slurry, in which porosity can be created by the formation and sublimation of ice crystals grown in the slurry, followed by sintering. Fukasawa and Ohji reported pioneering works in this field [6–8]. Deville et al. [9–11] studied the anisotropic interface kinetics of the solid/liquid, along with the morphological features of the

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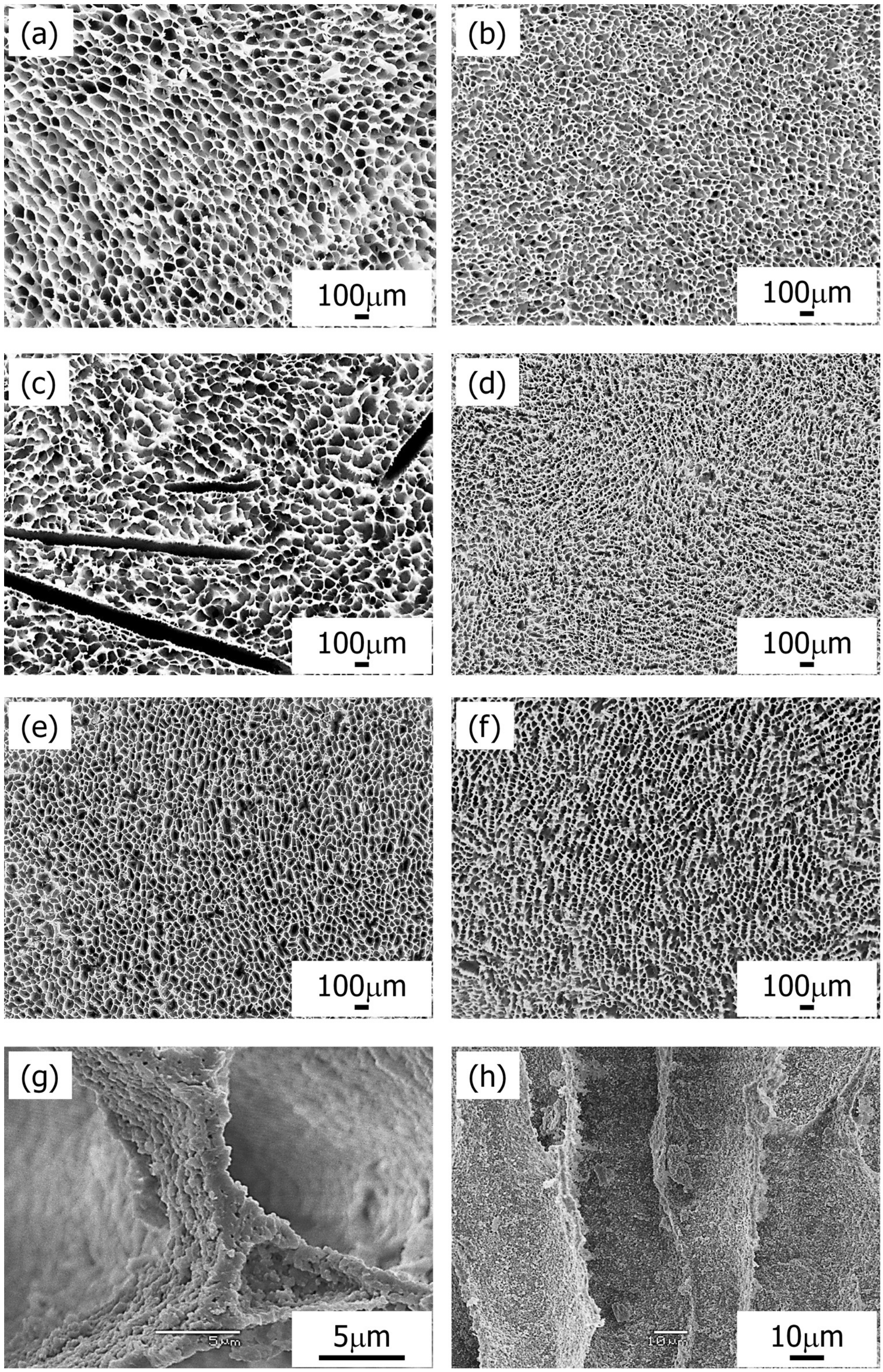

Fig. 1. Digital micrographs of the polished surfaces of (a–f) sample A, B, C, G, I and L, and SEM micrographs of (g–h) K and G. The images (a–g) and (h) were collected in perpendicular and parallel section to the freezing, respectively.

macro-cellular structure. Combining freeze-drying and gel casting technique has been the other frequently employed approach to fabricate cellular materials, which include the use of solutions and gels of polysaccharides, proteins, gelatin and collagen [12–20].

We have focused on gelation freezing to create unique honeycomb-like microstructures, unlike the dendritic, ellipsoidal, and lamellar microstructures obtained via conventional freeze casting, with having highly interconnected porosities from 79 to 98% [4,5,21–23]. Due to this honeycomb structure, the mechanical strength of gelation freezing derived porous ceramics can be substantially improved, even though they have higher porosities [22]. The purpose of this study is to fabricate thermal insulators with very high porosity using a gelation freezing method, producing insulators with both high strength and low thermal conductivity. In this article, we report on the fabrication of mullite insulators, and discuss the thermal and mechanical properties of products obtained.