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Review paper

A review of fabrication strategies and applications of porous ceramics prepared by freeze-casting method

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Abstract

Freeze casting is a promising technique to fabricate porous materials with complex pore shapes and component geometries. Of particular interest are the unique structure and properties exhibited by porous freeze-casted ceramics, which opened new opportunities in various applications. In this review, we aim to elaborate the fundamental principles of the porous microstructure evolution and summarize the latest achievements and strategies for the freeze casting process as well as the applications of porous ceramics prepared by this method. The effects of additives, freezing conditions, suspension solids loading and particle size on pore structure of the porous ceramics and its applications are discussed. We also outlook the existing issues and challenges in the fabrication porous ceramics by freeze a casting method.

Keywords: A. Sintering; B. Microstructure-final; E. Batteries; E. Insulators

Contents

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1. Introduction

Porous ceramic as a technological important material possess a wide range of applications, such as separation materials [1], catalyst supports [2,3], and implantable bioceramics [4–6], etc. Parameters relating to the pore structure, such as pore size, shape, distribution, and connectivity all play into the resulting functionality of the porous ceramics. Various methods for the manufacturing of such materials have been developed in the past years, such as direct foaming method, sacrificial template method and gel-casting method [7–12]. Each of these methods has its own merits and drawbacks. Among them, the freeze casting technique, or freeze drying, as a novel method, is one of the most innovative techniques which provide highly porous ceramics with a well-controlled structure [13–21].

Numerous research works on porous ceramics prepared by freeze drying process have been published during the last decade, and different types of porous materials such as aligned porous materials and hybrid porous materials, have been successfully prepared by freeze drying [22–24]. The technique consists of freezing a liquid suspension (aqueous or not), followed by sublimation of the solidified phase from the solid to the gas state under reduced pressure, and subsequent sintering to consolidate and densify the walls. This method has several advantages, including simple sintering process without materials to be burnt out, a wide range of porosity (30–99%) controllable by the suspension concentration, applicability to various types of materials, and cost-effective production with simple equipment requirement. Furthermore, when removing the solvent, the freeze casting process does not bring impurities into the samples and a further purifying process is therefore not necessary. More importantly, by changing the freezing parameters, it is possible to prepare materials with a wealth of pore morphologies and nanostructures. To date, water [25,26], camphene [27,28], tert-butyl alcohol (TBA) [29], naphthalene–camphor [30] and terpene–acrylate photopolymerizable [31] have been successfully used as freezing vehicles. Unique or complex porous structures can be obtained by adjusting the freezing vehicles, starting materials and processing conditions. The tailorability of the freeze casting technique makes it capable of fabricating materials with dense, cellular, lamellar, unidirectional and complex microstructures. Based on the special pore structure, freeze-cast porous ceramics are also promising for various applications including thermal and acoustic insulators, filters, gas distributors, active substance delivery, piezoelectric elements, catalysts and catalyst supports due to high permeability, high specific strength, large surface area, excellent adsorption ability, and good chemical and thermal resistances [32–41].

The objective of this paper is to provide a review of the results obtained up to date and to offer insights on the perspectives of the technique. The current understanding and control over the processing route and the potential applications are described and discussed. The review is organized as follows. First, the processing principles of freeze-casting are briefly described, and the fabrication strategies and key factors of freeze-casting processed to date are summarized in details. Second, the potential applications of the porous ceramics prepared by the freeze casting method are introduced extensively. Finally, we outline the actual limitations of the technique and perspectives for the future of freeze-casting method.

2. Fabrication strategies

2.1. Principles of the freeze-casting method

As shown in Fig. 1, the freeze casting method consists of preparing a stable colloidal suspension (aqueous or otherwise), pouring the suspension into a mould, freezing a liquid suspension, followed by sublimation of the frozen phase and subsequent sintering, leading to a porous structure with unidirectional channels in the case of unidirectional freezing, in which pores are a replica of the ice crystals. Among them, solidification of a prepared suspension is the most critical stage during freeze casting, since the crystal morphology determines the resulting porous microstructure and the volume change associated with the phase transformation greatly influences the integrity. Different freezing conditions including the freezing temperature, freezing time, freezing rate, solids loading,

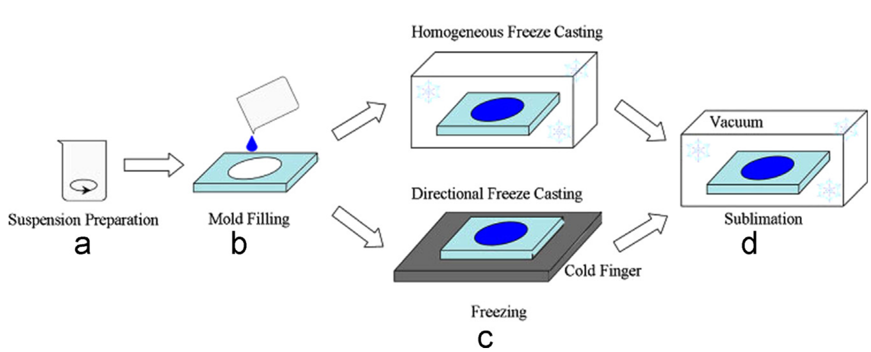

Fig. 1. Schematic of freeze casting method [42] (Reprinted with permission from Ref. [42], Copyright 2012: Maney publisher Ltd.).