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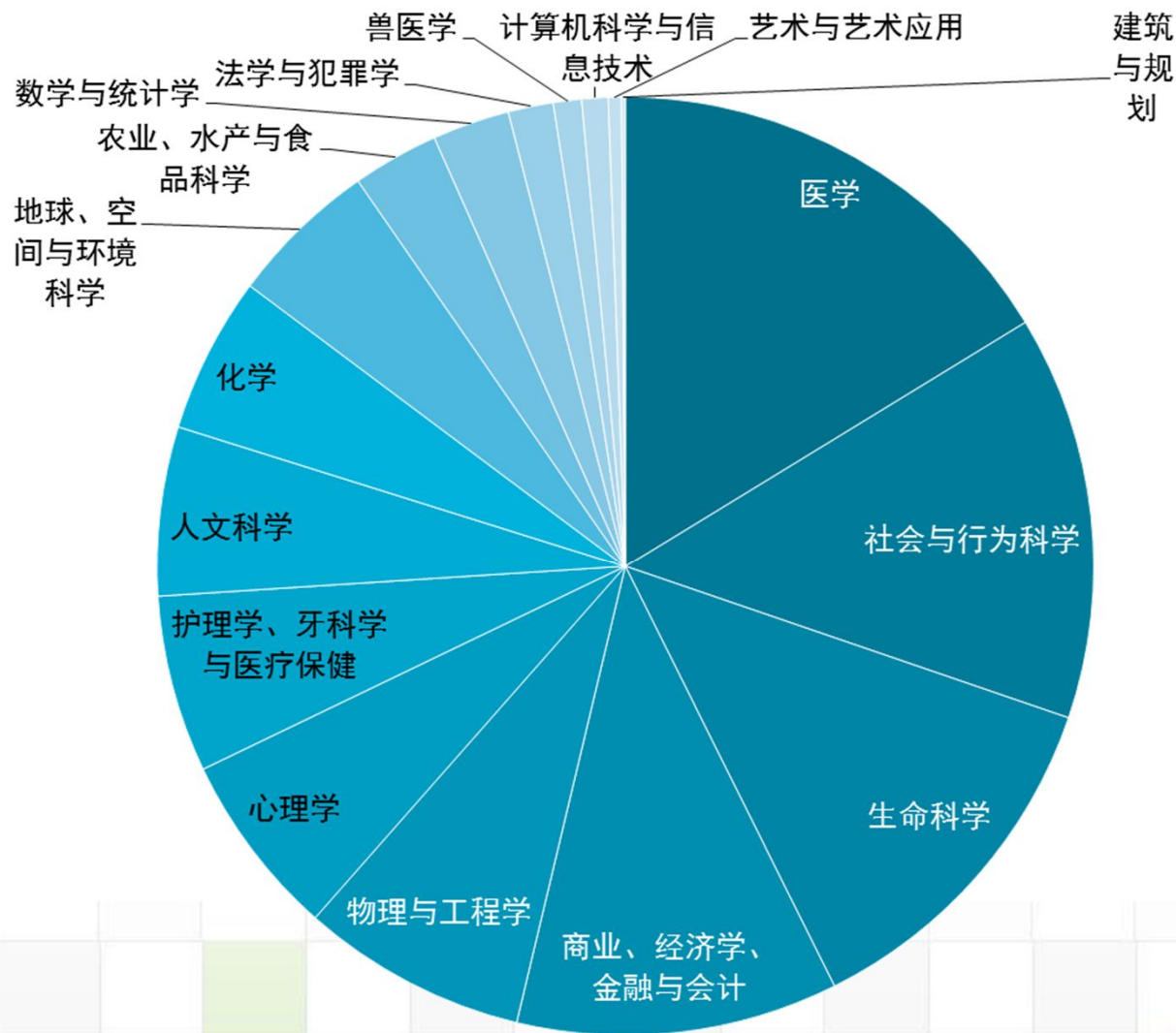
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Decoding the Fingerprint of Ferroelectric Loops: Comprehension of the Material Properties and Structures (pages 1-27)

Li Jin, Fei Li and Shujun Zhang

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Three-dimensional Ceramic/Camphene-based Coextrusion for Unidirectionally Macrochanneled Alumina Ceramics with Controlled Porous Walls

Young-Wook Moon¹, Kwan-Ha Shin¹, Young-Hag Koh^{1,2,*}, Hyun-Do Jung³ and Hyoun-Ee Kim³

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We report the utility of three-dimensional ceramic/camphene-based coextrusion, newly developed in this study, for the production of unidirectionally macrochanneled alumina ceramics with three-dimensionally interconnected porous alumina walls. In this technique, a continuous ceramic/camphene filament with a diameter of 1 mm, comprised of a pure camphene core and a frozen alumina/camphene shell, was produced by the coextrusion process and then deposited in a layer-by-layer sequence using a computer-controlled 3-axis moving table. Unidirectionally aligned macrochannels (~400 μm in diameter) and three-dimensionally interconnected pores (several tens of micrometers in size) in the alumina walls were created by removing the camphene core and the camphene dendrites formed in the alumina/camphene region, respectively. The sample showed much higher compressive strength in the macrochannel direction than in the perpendicular direction. In addition, the compressive strength of the sample could increase with an increase in initial alumina content owing to a decrease in the total porosity.

I. Introduction

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The creation of highly oriented pores in ceramics is one of the most active research areas in bone tissue engineering [1] as it can resemble the anisotropic porous structure of natural cancellous bone and provide outstanding mechanical properties (i.e., high specific strength). [2] Extrusion using flammable fibers [3] and coextrusion [4, 5] traditionally have been used to produce porous ceramics with unidirectional pores. However, these techniques generally result in poor interconnection between the unidirectional pores, which limits their applications for bone tissue regeneration, where three-dimensionally interconnected pores are necessary.

More recently, unidirectional freeze casting has demonstrated its usefulness for creating highly aligned pores with excellent three-dimensional interconnectivity. [6-10] In





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Three-dimensional Ceramic/Camphene-based Coextrusion for Unidirectionally Macrochanneled Alumina Ceramics with Controlled Porous Walls

Young-Hag Koh, Kwan-Ha Shin, Hyoun-Ee Kim, Young-Wook Moon, Hyun-Do Jung

Do Jung, Hyoun-Ee Kim

Published: 29 November 2013 Full

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We report the utility of three-dimensional ceramic/camphene-based coextrusion, newly developed in this study, for the production of unidirectionally macrochanneled alumina ceramics with three-dimensionally interconnected porous walls. In this technique, a continuous ceramic/camphene filament with a diameter of 1 mm, comprised of a pure camphene core and a frozen alumina/camphene shell, was produced by the coextrusion process and then deposited in a layer-by-layer sequence using a computer-controlled 3-axis moving table. Unidirectionally macrochannels (~400 μm in diameter) and three-dimensionally interconnected pores (several tens of micrometers in size) in the alumina walls were created by removing the camphene core and the camphene dendrites formed in the alumina/camphene shell, respectively. The samples showed much higher compressive strength in the



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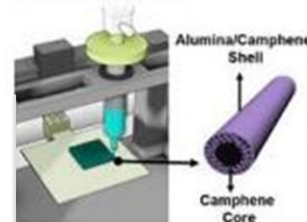
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II. Experimental Procedure

Commercial alumina powder (Kojundo Chemical Co., Ltd, Saitama, Japan) with a mean particle size of 0.3 μm was used as the ceramic component, and camphene (C₁₀H₁₆; Sigma Aldrich, St Louis, MO) with a purity of 95% was used as the freezing vehicle and binder.

(a) 3-D Co-extrusion



(b) Unidirectionally Macrochanneled Ceramic



Schematic diagrams of three-dimensional ceramic/camphene-based coextrusion (3D-CoEx) for the production of unidirectionally macrochanneled alumina ceramics with three-dimensionally interconnected porous walls: (a) The 3-D co-extrusion process and (b) unidirectionally macrochanneled alumina ceramics with three-dimensionally interconnected porous walls after freeze drying.

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Three-dimensional Ceramic/Camphene-based Coextrusion for Unidirectionally Macrochanneled Alumina Ceramics with Controlled Porous Walls

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We report the utility of three-dimensional ceramic/camphene-based coextrusion, newly developed in this study, for the production of unidirectionally macrochanneled alumina ceramics with three-dimensionally interconnected porous alumina walls. In this technique, a continuous ceramic/camphene filament with a diameter of 1 mm, comprised of a pure camphene core and a frozen alumina/camphene shell, was produced by the coextrusion process and then deposited in a layer-by-layer sequence using a computer-controlled 3-axis moving table. Unidirectionally aligned macrochannels (~400 μm in diameter) and three-dimensionally interconnected pores (several tens of micrometers in size) in the alumina walls were created by removing the camphene core and the camphene dendrites formed in the alumina/camphene region, respectively. The sample showed much higher compressive strength in the macrochanneled direction than in the perpendicular direction. In addition, the compressive strength of the sample could increase with an increase in initial alumina content owing to a decrease in the total porosity.

1. Introduction

The creation of highly oriented pores in ceramics is one of the most active research areas in bone tissue engineering,¹ as it can resemble the anisotropic porous structure of natural cancellous bone and provide outstanding mechanical properties (i.e., high specific strength).² Extrusion using fusible fibers³ and coextrusion^{4,5} traditionally have been used to produce porous ceramics with unidirectional pores. However, these techniques generally result in poor interconnection between the unidirectional pores, which limits their applications for bone tissue regeneration, where three-dimensionally interconnected pores are necessary.

More recently, unidirectional freeze casting has demonstrated its usefulness for creating highly aligned pores with excellent three-dimensional interconnectivity.^{6–10} In this technique, a highly aligned porous structure can be achieved by removing a frozen vehicle network grown preferentially along the freezing direction.¹¹ However, it is difficult in practice to maintain the continuous preferential growth of dendrites during the entire process, limiting the degree of pore alignment throughout the sample.

We herein propose a novel manufacturing method for creating unidirectionally aligned macrochannels with

three-dimensionally interconnected pores using three-dimensional ceramic/camphene-based coextrusion, denoted as “3D-CoEx”. This 3D-CoEx technique can directly deposit a continuous ceramic/camphene filament consisting of a pure camphene core and a frozen alumina/camphene shell, which can be produced by ceramic/camphene-based coextrusion,⁴ in a layer-by-layer sequence using a computer-controlled moving machine [Fig. 1(a)]. Subsequently, unidirectional macrochannels and three-dimensionally interconnected pores can be created after removing the camphene core and the camphene dendrites formed in the alumina/camphene region, respectively [Fig. 1(b)]. The porous structure and compressive strength of the samples produced using various alumina contents (15, 20, and 25 vol%) after sintering at 1600°C for 3 h were examined.

II. Experimental Procedure

Commercial alumina powder (Kojundo Chemicals, Saitama, Japan) with a mean particle size of 0.3 μm as the ceramic component, and camphene (C₁₀H₁₆, Aldrich, St. Louis, MO) with a purity of 95% was the freezing vehicle and binder.

Alumina/camphene slurries with various alumina contents (15, 20, and 25 vol%) were prepared by mixing the powder and molten camphene by ball-milling for 24 h with the assistance of 3 wt% of an oligomeric dispersant (Hypermer KD-4, UniQema, Ewburg, Germany). Subsequently, initial feedrods for coextrusion were prepared by casting the prepared alumina/camphene slurries with a diameter of 20 mm containing a camphene core with a diameter of 10 mm and kept at room temperature for 30 min to allow for complete solidification.

The prepared feedrods were coextruded through a die with a diameter of 1 mm at a constant rotation speed of 1 mm/min and then three-dimensionally deposited in a layer-by-layer sequence using a computer-controlled moving machine (Jenster Co., Seoul, Korea). The green body was gently pressed into a rigid mold to improve bonding between the deposited filaments and then heat-treated at 470°C in an oven to induce continual growth of the camphene dendrites formed in the alumina/camphene region. Subsequently, the samples were freeze dried to remove the camphene and camphene dendrites in the alumina/camphene region, followed by sintering at 1600°C for 3 h to densify the alumina walls.

The pore structure of alumina ceramics produced using various initial alumina contents (15, 20, and 25 vol%) was characterized by field-emission scanning electron microscopy (FE-SEM; JSM-6701F, JEOL, Tokyo, Japan). The overall porosity of the samples was calculated from their

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Three-dimensional Macrochannelled Porous Walls

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[‡]Department of Dental Laboratory Science and Engineering, 123
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We report the utility of three-dimensional ceramic/camphene-based coextrusion, newly developed in this study, for the production of unidirectionally macrochannelled alumina ceramics with three-dimensionally interconnected porous alumina walls. In this technique, a continuous ceramic/camphene filament with a diameter of 1 mm, comprised of a pure camphene core and a frozen alumina/camphene shell, was produced by the coextrusion process and then deposited in a layer-by-layer sequence using a computer-controlled 3-axis moving table. Unidirectionally aligned macrochannels (~400 μm in diameter) and three-dimensionally interconnected pores (several tens of micrometers in size) in the alumina walls were created by removing the camphene core and the camphene dendrites formed in the alumina/camphene region, respectively. The sample showed much higher compressive strength in the macrochannel direction than in the perpendicular direction. In addition, the compressive strength of the sample could increase with an increase in initial alumina content owing to a decrease in the total porosity.

I. Introduction

THE creation of highly oriented pores in ceramics is one of the most active research areas in bone tissue engineering,¹ as it can resemble the anisotropic porous structure of natural cancellous bone and provide outstanding mechanical properties (i.e., high specific strength).² Extrusion using flammable fibers³ and coextrusion^{4,5} traditionally have been used to produce porous ceramics with unidirectional pores. However, these techniques generally result in poor interconnection between the unidirectional pores, which limits their applications for bone tissue regeneration, where three-dimensionally

Commercial alumina powder (Kojundo Chemical Co., Ltd, Saitama, Japan) with a mean particle size of 0.3 μm was used as the ceramic component, and camphene (C₁₀H₁₆; Sigma Aldrich, St Louis, MO) with a purity of 95% was used as the freezing vehicle and binder.

Alumina/camphene slurries with various alumina contents (15, 20, and 25 vol%) were prepared by mixing the alumina powder and molten camphene by ball-milling at 60°C for 24 h with the assistance of 3 wt% of an oligomeric polyester dispersant (Hypermer KD-4; UniQema, Everburg, Belgium). Subsequently, initial feedrods for coextrusion were prepared by casting the prepared alumina/camphene slurries in molds with a diameter of 20 mm containing a camphene core with

Gram. Soc., 97 [1] 32–34 (2014)
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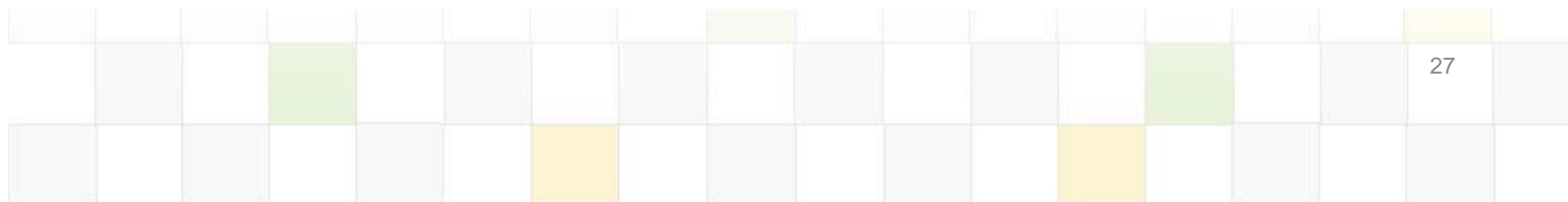
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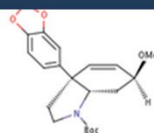
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