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Environmentally-harmless polylactic acid-polyethylene glycol binder for deformable ceramic green body

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ABSTRACT

We report a polylactic acid (PLA)-polyethylene glycol (PEG) mixture as a thermoplastic binder to prepare shape-machinable ceramic green bodies. During the mixing process, the high viscosity of the PLA binder impedes effective mixing with ceramic powders. To address this issue, PEG was introduced as a plasticizer into ceramic/PLA composites to diminish the overall viscosity of the feedstock, which resulted in effective mixing with ceramic powders. After sintering green bodies composed of PLA-PEG binders and ceramic compounds, the mechanical properties (flexural strength and porosity) of the sintered specimens were investigated and compared with those of sintered specimens made from wax-based green bodies. The sintered specimens made from ceramic/PLA-PEG composites showed comparable mechanical properties and porosities with the sintered specimens made from ceramic/wax composites. In addition, the shape-machinable characteristic of the green bodies made from ceramic/PLA-PEG composites was demonstrated by deforming the entire structure of the green bodies via simple heat treatment.

1. Introduction

Advanced structural ceramics with complex shapes are widely utilized in diesel engines and gas turbines, among many other applications [1–6]. Structural ceramics have excellent properties such as high mechanical and thermal stability, thermal shock resistance, and chemical inertness, making them ideal for use as ceramic core bodies for turbine blades [3,7,8]. To meet the specifications for these types of applications, patterned shapes are required. However, the fabrication of well-patterned ceramics is highly dependent upon processing techniques because of the high melting point and mechanical brittleness of ceramics [3,7]. Manufacturing complex-shaped ceramic components by machining sintered ceramics is critically limited because of flaking and sub-surface cracks, which result in ceramic products with poor mechanical properties [4,9]. For this reason, structural ceramics are generally prepared via investment casting (lost wax casting), which involves the following processes: a) mixing of ceramic powders with organic binder to prepare a feedstock; b) introduction of the as-prepared feedstock into the patterned SUS mold to form green body; and c) sintering of the ceramic green body [3,4]. However, modification of the entire structure of the green body is challenging using this method. Once the ceramic green body is fabricated, it is difficult to modify its specific pattern and structure due to the limited processing ability of pre-patterned molds and the low melting temperature of wax [4–6].

To address the manufacturing-associated challenges associated with structural ceramics, we developed deformable green bodies using polylactic acid (PLA)-polyethylene glycol (PEG) as the binder. PLA is a common, biodegradable, thermoplastic material derived from sustainable sources [10–12]. It does not release any toxic products during calcination because the polymer chain does not contain chlorine groups or heavy metals. In addition, PLA has excellent thermal properties and high tensile strengths; these properties have been exploited to create 3D filament materials [10,13]. Paraffin wax as a typical binder for injection molding has a low melting temperature of ~ 70 °C and weak mechanical strength, resulting in poor processability of the green bodies [3,4,14,15]. In contrast, PLA binder has a low glass transition temperature of 65 °C, high melting point of 220 °C, and mechanical sturdiness, enabling shape deformation of the mold under heat treatment [16]. PEG has been reported to strengthen the mechanical properties of PLA and lower the glass transition temperature of PLA [17,18]. In this study, we investigated the binder properties of PLA-PEG for silica-based ceramic materials and the physical properties of the ceramics obtained

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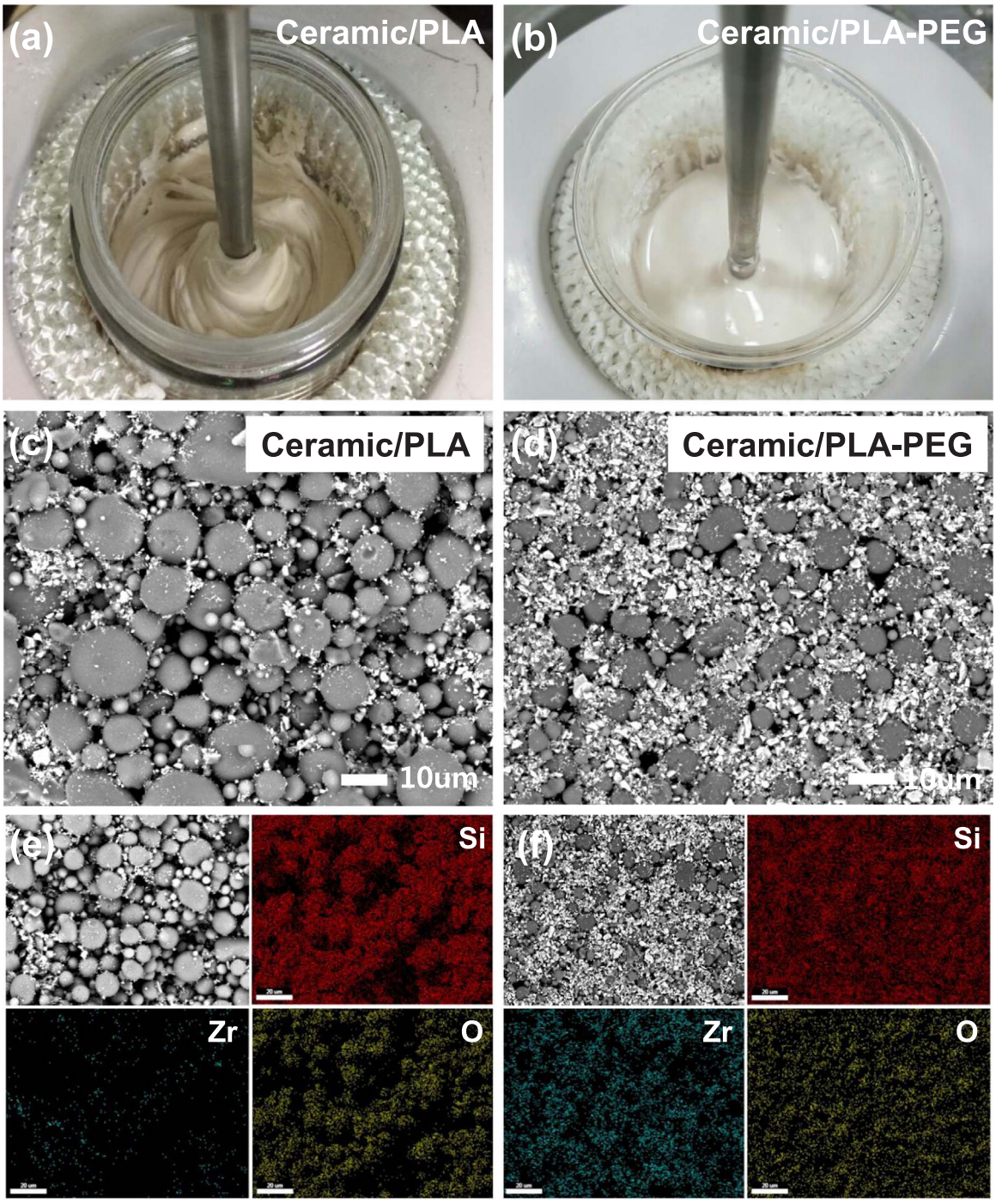

Fig. 1. Photographic images of mixing process for (a) Ceramic/PLA and (b) Ceramic/PLA-PEG. SEM images of (c) Ceramic/PLA and (d) Ceramic/PLA-PEG. EDS mapping images of (e) Ceramic/PLA and (f) Ceramic/PLA-PEG by SEM.

after sintering. The same composition and ratio of ceramic powders was chosen to create specimens using the wax binder system for comparison [3,4]. Moreover, we evaluated the deformation ability of the resulting green bodies.

2. Experimental

2.1. Feedstock preparation

Fused silica (amorphous SiO_2, 325mesh, Imerys, United States) and zircon flour ($ZrSiO_4$, 1 μm, Cenotec, Korea) were mixed using a ball milling machine (Nanointech, Korea) for 6 h. Mixing ratio was 75 wt% fused silica and 25 wt% zircon flour. Feedstock was prepared by blending as-prepared ceramic powders and a PLA pellet (Natureworks, United States)/polyethylene glycol (PEG, Mw ~ 200) mixture at 180 °C for 3 h. The mixing ratio of ceramic powder to PLA was 75:25. Ten percent PEG was mixed with the PLA to control the viscosity of the feedstock.

2.2. Green body preparation and sintering

Green bodies were prepared using a hot press machine. Feedstock was loaded on the stainless-steel frame and pressed at 120 °C to form plates with the desired dimensions (10 cm × 10 cm). As-prepared