JOURNAL OF THE MECHANICAL BEHAVIOR OF BIOMEDICAL MATERIALS 55 (2016) 120–126

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Research Paper

The improved mechanical properties of β-$CaSiO_3$ bioceramics with Si_3N_4 addition

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ARTICLE INFO

Article history:
Received 31 August 2015
Received in revised form
14 October 2015
Accepted 20 October 2015
Available online 30 October 2015

Keywords:
β-$CaSiO_3$
Si_3N_4
Oxidation
Mechanical properties

ABSTRACT

The motivation of this study is to investigate the effect of Si_3N_4 addition on the sinterability of β-$CaSiO_3$ ceramics. β-$CaSiO_3$ ceramics with different content of Si_3N_4 were prepared at the sintering temperature ranging from 1000 °C to 1150 °C. The results showed that Si_3N_4 can be successfully used as sintering additive by being oxidized to form SiO_2. The β-$CaSiO_3$ ceramics with 3 wt% Si_3N_4 sintered at 1100 °C revealed flexural strength, hardness and fracture toughness of 157.2 MPa, 4.4 GPa and 2.3 MPa $m^{1/2}$ respectively, which was much higher than that of pure β-$CaSiO_3$ ceramics (41.1 MPa, 1.0 GPa, 1.1 MPa $m^{1/2}$). XRD analysis and SEM observation indicated that the main phase maintained to be β-phase after sintering.

1. Introduction

Over the past two decades, calcium silicate (Ca–Si) based bioceramics have been introduced as potential bioactive materials for bone tissue regeneration due to their superior bone bioactivity compared to hydroxyapatite (HA) (Deaza et al., 1994; Ni et al., 2007; Oonishi et al., 2000). As one of the most important calcium silicate, β-$CaSiO_3$ is widely used for industrial ceramics. In recent years, β-$CaSiO_3$ has been investigated as bioactive biomaterials, and has drawn growing attention for its promising applications in bone tissue regeneration because of its good bioactivity, biocompatibility and biodegradability (De Aza et al., 1999; Ni et al., 2006, 2007). Nevertheless, the extensive use of β-$CaSiO_3$ is limited by their inadequate strength (Mehrali et al., 2014). Difficulties in preparing dense β-$CaSiO_3$ ceramics with improved mechanical properties make them suitable only for low-bearing applications (Endo et al., 1994; Shirazi et al., 2014b)

In order to improve the mechanical properties of β-$CaSiO_3$ ceramics, one of the effective methods is the incorporation of a second phase with good mechanical properties into β-$CaSiO_3$ (Mehrali et al., 2014; Shirazi et al., 2015). Using glasses as sintering additives has been considered as an effective way to promote the sintering properties of ceramics by liquid-phase sintering (Lin et al., 2009), whereas glassy phase in the ceramic matrix may be disadvantageous to the

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http://dx.doi.org/10.1016/j.jmbbm.2015.10.014
1751-6161/

mechanical strength of ceramics. Some researchers investigated the alumina reinforced β-$CaSiO_3$ and demonstrated that alumina particles could improve its hardness and fracture toughness (Shirazi et al., 2014a). Nevertheless, the sintering temperature of β-$CaSiO_3$ ceramics needed to be higher than 1125 °C, at which the flexural strength of the composites was considerably degraded by the transformation of β-phase into α-phase of $CaSiO_3$. Silicon nitride (Si_3N_4) is a kind of ceramics known for its high performance characterized by fracture toughness, high wear resistance and low coefficient of friction. Several works on biocompatibility and bioactivity of Si_3N_4 outlined that Si_3N_4-based ceramics can be used as materials in the field of hard tissues surgery. Si_3N_4-based ceramics can be used as toxic free materials which has already been testified (Silva et al., 2004). In vivo tests, implanting Si_3N_4 pieces into the femurs of rabbits had demonstrated good bone/implant attachment and no adverse cell reactions (Guedes e Silva et al., 2008). What is more, at low temperature, the surface of Si_3N_4 particles can be oxidized to form SiO_2 with high reaction activity and the

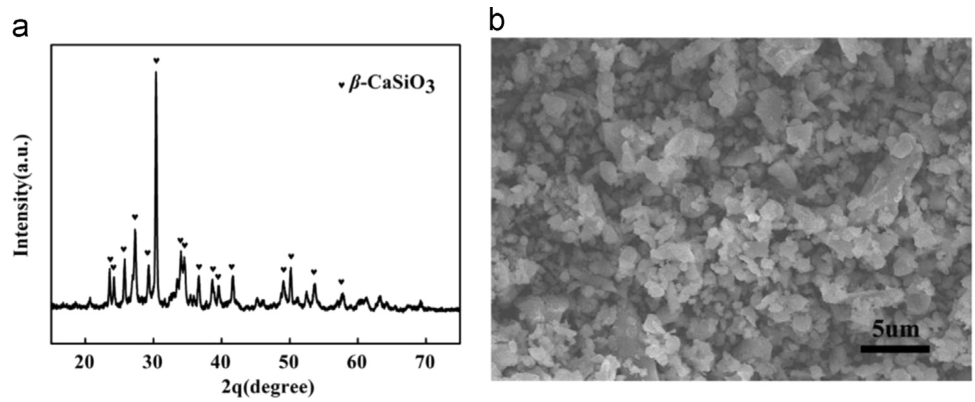

Fig. 1 – (a) X-ray diffraction patterns and (b) SEM micrograph of the as-prepared β-$CaSiO_3$ powder.

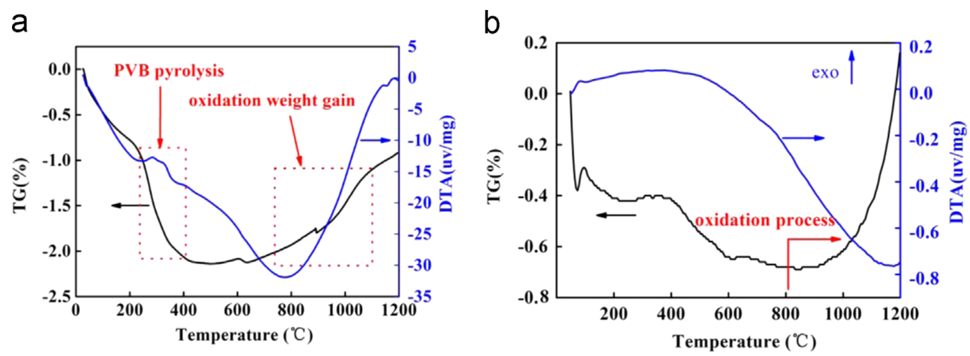

Fig. 2 – TG–DTA curves of (a) pure Si_3N_4 and (b) 3 wt% Si_3N_4 addition of β-$CaSiO_3$ ceramics.

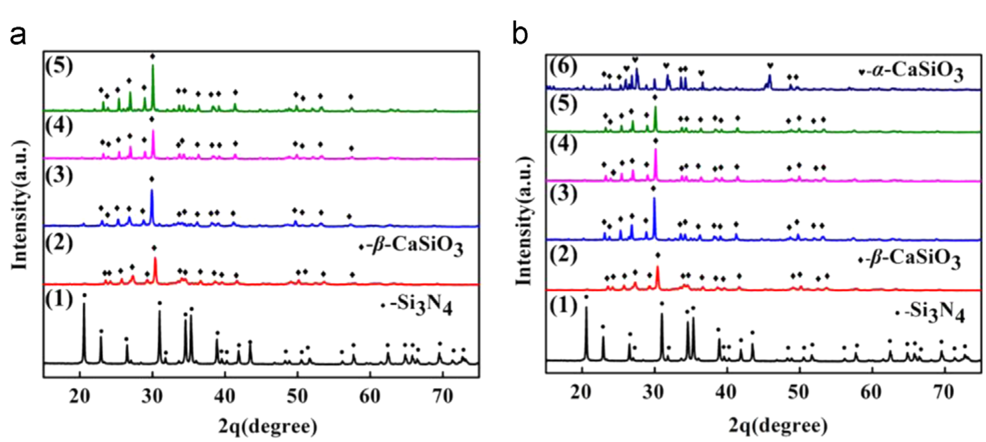

Fig. 3 – (a) X-ray diffraction peaks of β-$CaSiO_3$ ceramics containing different content of Si_3N_4: (1) pure Si_3N_4, (2) pure β-$CaSiO_3$, (3) 1 wt% Si_3N_4, (4) 3 wt% Si_3N_4, (5) 5 wt% Si_3N_4 sintered at 1100 °C. (b) X-ray diffraction peaks of β-$CaSiO_3$ ceramics containing 3 wt% Si_3N_4 sintered at different temperature: (1) pure Si_3N_4, (2) pure β-$CaSiO_3$, (3) 1000 °C, (4) 1050 °C, (5) 1100 °C, (6) 1150 °C.