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Mono or polycrystalline alumina-modified hybrid ceramics



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ABSTRACT

Objectives. This study evaluated the effect of addition of alumina particles (polycrystalline or monocrystalline), with or without silica coating, on the optical and mechanical properties of a porcelain.

Methods. Groups tested were: control (C), polycrystalline alumina (PA), polycrystalline alumina-silica (PAS), monocrystalline alumina (MA), monocrystalline alumina-silica (MAS). Polycrystalline alumina powder was synthesized using a polymeric precursor method; a commercially available monocrystalline alumina powder (sapphire) was acquired. Silica coating was obtained by immersing alumina powders in a tetraethylorthosilicate solution, followed by heat-treatment. Electrostatic stable suspension method was used to ensure homogenous dispersion of the alumina particles within the porcelain powder. The ceramic specimens were obtained by heat-pressing. Microstructure, translucency parameter, contrast ratio, opalescence index, porosity, biaxial flexural strength, roughness, and elastic constants were characterized.

Results. A better interaction between glass matrix and silica coated crystalline particles is suggested in some analyses, yet further investigation is needed to confirm it. The materials did not present significant differences in biaxial flexural strength, due to the presence of higher porosity in the groups with alumina addition. Elastic modulus was higher for MA and MAS groups. Also, these were the groups with optical qualities and roughness closer to control. The PA and PAS groups were considerably more opaque as well as rougher.

Significance. Porcelains with addition of monocrystalline particles presented superior esthetic qualities compared to those with polycrystalline particles. In order to eliminate the porosity in the ceramic materials investigated herein, processing parameters need to be optimized as well as different glass frits should be tested.

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1. Introduction

Advanced ceramics used in some highly specialized applications require both optical and mechanical properties for an excellent performance. Amongst these applications is the use of ceramics as dental biomaterials, which need to be constructed into complex and stable-during-sintering shapes, and are subjected to long-term sliding fatigue under mastication in a corrosive/moist environment [1–6]. Furthermore, dental ceramics are expected to survive for decades in the oral environment, without breaking or loosing the esthetical natural-tooth-looking appearance [7,8]. The ceramic materials used in dentistry that try to fulfill these expectations usually have a glass matrix with varying crystalline content [1,9]. Final properties of such materials are affected by the amount of crystalline phase, size and type of crystals, and their dispersion within the glass matrix [10–13].

In general terms, increase in the crystalline content leads to mechanical reinforcement [11,14,15]. In addition to that, an effective interfacial interaction between matrix and reinforcing crystalline particles is required for improved properties [16,17]. The presence of a gap between phases would prevent dissipation of stresses from the matrix to the tougher particles [16,17]. Such gaps would also act as pores and therefore further compromise the material mechanical properties, as well as increase its opacity due to light scattering [10,18–22]. When crystalline particles are nucleated and crystalized from the glass matrix, the phases are chemically alike and prone to a chemically stable interfacial interaction [14,23]. On the other hand, the development of hybrid-ceramic materials by means of addition of second-phase crystalline particles into the glass powder before sintering [24] allows the use of non-silicate tough crystalline oxides, like zirconia or alumina, as reinforcement phase. Because these oxides have such a distinct chemical composition compared to that of the glass, the final mechanical reinforcement can only be achieved if these particles are functionalized to produce an effective interaction with the glass matrix.

To date, only two hybrid-ceramic materials with addition of second-phase crystalline particles are commercially available for dental applications, both having zirconia particles added as crystalline phase into a lithium silicate glass-ceramic system: Vita Suprinity (VITA Zahnfabrik, Bad Säckingen, Germany) and Celtra DeguDent (DeguDent, Hanau, Germany). Despite the current appeal of zirconia, alumina is a technologically important material widely used in numerous applications [25,26], yet it is not being used in the tailoring of hybrid-ceramics for dental applications. Alumina is believed to exist in more than 15 different crystallographic phases [27,28], which can determine distinct microstructures and properties if applied in hybrid-ceramics. Crystalline alumina has also been given a lot of attention in its transparent monocrystalline state, known as artificial sapphire [29–31]. The refractive index mismatch between phases is usually the most important aspect to be considered to estimate translucency for hybrid-materials [22]. However, no evidence was found on whether the inherent microstructure, thus inherent translucency of these alumina particles would affect final properties of hybrid-ceramic materials.

To the best of the authors' knowledge, neither monocrystalline alumina powder nor functionalization of the surface of non-silicate particles with a silicon-rich film have been described in the scientific literature for the development of hybrid-ceramic materials. Therefore, this study was designed to apply nanostructured polycrystalline or translucent monocrystalline alumina particles in the modeling of optical and mechanical properties of a dental ceramic. A silica coating (core-shell) method was used aiming at an effective interfacial interaction between the alumina particles and the glass matrix in the tailoring of hybrid-ceramic materials as dental biomaterials.

2. Materials and methods

2.1. Materials

The dental ceramic used as matrix for the hybrid-ceramic materials in this study is commercially available under the brand name Cerabien (Noritake Dental, Aichi, Japan). The manufacturer classifies this material as porcelain, yet they do not disclose information about its composition. This porcelain was chosen because it has a coefficient of thermal expansion that matches that of alumina, and therefore less residual stresses concentrate near the interface between the two phases. Two types of alumina particles were used in the modeling of the properties of the porcelain: polycrystalline alumina sintered by means of a polymeric precursor method, and monocrystalline alumina commercially available under the brand name Sapphire Powder (GoodFellow, Huntingdon, England). The alumina particles were either silica coated or kept without any coating before being added to the porcelain powder. Coating was carried out using tetraethylorthosilicate (TEOS) as silica precursor (Sigma-Aldrich, St. Louis, MO, USA). In total, five experimental groups were tested: porcelain only (control, C), porcelain + polycrystalline alumina (PA), porcelain + polycrystalline alumina coated with silica (PAS), porcelain + monocrystalline alumina (MA), and porcelain + monocrystalline alumina coated with silica (MAS).

2.2. Synthesis of polycrystalline alumina by a polymeric precursor method

The nanostructured alumina powder was produced by using a variation of a previously described method [27]. Briefly, 1 M aluminum nitrate ($\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$) P.A. (Synth, São Paulo, SP, Brazil) and 3 M anhydrous citric acid ($\text{C}_6\text{H}_8\text{O}_7$) P.A. (Synth) were dissolved in water at 50 °C for 1 h for the formation of aluminum citrate. Ethylene glycol ($\text{C}_2\text{H}_6\text{O}_2$) P.A. (Synth) was added at a 60:40 mass ratio of the citric acid/ethylene glycol. This mixture was then stirred at 80 °C for 1 h, and the temperature was then increased to 130 °C to promote polymerization and remove excess solvents. The resin was then heat-treated in an atmospheric air furnace, with 10 °C/min heating rate up to 300 °C dwell temperature for 2 h in order to burn the organic components, resulting in a black solid mass. This material was finely hand-ground by using mortar and pestle. The powder obtained is referred as the “precursor”. In the furnace, the precursor was heat-treated at 10 °C/min heating rate up to

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