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Research Paper

Effect of fiber addition on slow crack growth of a dental porcelain

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ABSTRACT

Aims: To evaluate the effect of the processing method (conventional sintering, S, and heat-pressing, HP) and addition of potassium titanate fibers, PTF, on the microstructure, mechanical properties (flexural strength, σ_f, and Weibull parameters, m and $\sigma_{5\%}$), slow crack growth parameters n (stress corrosion susceptibility coefficient), and optical properties (translucency parameter, TP, and opalescence index, OI) of a feldsphatic dental porcelain.

Methods: Disks (n=240, Ø12 × 1 mm) of porcelain (Vintage-Halo, Shofu) were produced using S and HP methods with and without addition of 10 wt% (conventional sintering) or 5 wt% (heat-pressing) of PTF. For the S method, porcelain was sintered in a conventional furnace. In the HP technique, refractory molds were produced by lost wax technique. The porcelain slurry was dry-pressed (3 t/30 s) to form a cylinder with 12 mm (diameter) and 20 mm (height), which was heat-pressed for 5 min/3.5 bar into the mold. Specimens were tested for biaxial flexural strength in artificial saliva at 37 °C. Weibull analysis was used to determine m and $\sigma_{5\%}$. Slow crack growth (SCG) parameters were determined by the dynamic fatigue test, and specimens were tested in biaxial flexure at five stress rates: 10^{-2}, 10^{-1}, 10^{0}, 10^{1} and 10^{2} MPa/s (n=10), immersed in artificial saliva at 37 °C. Parameter n was calculated and statistically analyzed according to ASTM F394-78. Optical properties were determined in a spectrophotometer in the diffuse reflectance mode.

Results: The highest n value was obtained by the combination of heat-pressing with fiber addition (37.1) and this value was significantly higher than those obtained by both sintered groups (26.2 for control group and 27.7 for sintered with fiber). Although heat-pressing alone also resulted in higher n values compared to the sintered groups, there were no significant differences among them. Fiber addition had no effect on mechanical strength, but it resulted in decreased TP values and increased OI values for both processing methods. Heat-pressing alone was able to reduce the porosity level of the porcelain.

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Conclusions: Addition of PTF combined with heat-pressing can reduce strength degradation of a dental porcelain compared to sintered materials with or without fibers. Heat-pressing (HP) alone should be considered as a good alternative for clinical cases where high translucency is required.

1. Introduction

Ceramic restorations are widely used in dentistry due to their high biocompatibility, chemical stability, and excellent aesthetics. However, their brittle behavior and high abrasive potential limit their use in critical clinical situations (Albakry et al., 2004a, 2004b; Kelly et al., 1996). The main causes of failure of all-ceramic restorations are fracture, microleakage and debonding (Ergin and Gemalmaz, 2002). The fracture of porcelain restorations is related to the low fracture toughness of these materials, around 1.0 MPa $m^{1/2}$ (Cesar et al., 2005, 2006; Drummond et al., 2005; Morena et al., 1986a, 1986b; Rizkalla and Jones, 2004; Yoshimura et al., 2005a). One way of increasing the clinical lifetime of all-ceramic restorations is through tailoring of the material microstructure.

Dental porcelains are usually composed of leucite crystals dispersed in a glassy matrix. The presence of leucite increases the porcelain coefficient of thermal expansion (CTE), making the material suitable to be used over metallic frameworks. However, the mismatch between leucite and glass CTEs can also generate microcraks around the leucite particles during cooling (Mackert and Williams, 1996). These defects can act as crack initiators and lead to catastrophic failure when subjected to functional loads (Albakry et al., 2004b). On the other hand, the generation of microcracks during loading has been associated with the microcrack toughening mechanism (Gorman et al., 2000).

Porcelain restorations are produced by the condensation method, in which a slurry is prepared by mixing a porcelain powder with distilled water, shaping the green restoration under vibration, and taking the resulting formed body into a sintering furnace to prepare the sintered body (Fredericci et al., 2011). This processing method is not able to completely eliminate the porosity of the material and the remaining pores may end up acting as stress concentrators and also decreasing the total area over which the masticatory forces are distributed, leading to a significant decrease in the mechanical strength (Bernard et al., 2005; Jones and Wilson, 1975). The high porosity level also negatively affects the optical properties of the porcelain restoration, as pores cause scattering of the transmitted light and therefore decrease the material's transmittance (Cheung and Darvell, 2002).

An alternative to the traditional method of porcelain preparation is the heat-pressing technique, which was developed in the dental field to produce glass–ceramic restorations. This method uses the lost wax method to produce an investment mold with subsequent injection of glass–ceramic ingots (IPS Empress, Ivoclar Vivadent) at 1150 °C for 20 min and pressure varying from 0.3 to 0.4 MPa (Dong et al., 1992). The glass–ceramic used in this technique also contains leucite crystals dispersed in a glassy matrix. The reported fracture toughness for this material is similar to that of conventional porcelain (around 1.5 MPa $m^{1/2}$) (Albakry et al., 2003; Della Bona et al., 2004; Drummond et al., 2005; Fischer and Marx, 2002; Holand et al., 2000; Wagner and Chu, 1996; Wen et al., 1999).

The mechanical properties of ceramic materials can be significantly improved by fiber reinforcement. It has been shown that the development of a ceramic composite by the addition of fibers to a porcelain can result in the creation of several toughening mechanisms, like microcrack toughening, crack bridging, energy absorption by plastic deformation, and fiber fracture, debonding and-or pullout. The fibers to be added to the porcelain must have some important requisites, like high flexural strength and a coefficient of thermal expansion (CTE) similar to that of the porcelain in order to avoid undesirable residual stresses or cracking during the cooling procedure after sintering (Dutton et al., 2000).

Few studies can be found in the literature regarding porcelains reinforced with fibers. The work of Tanimoto and Nemoto (2004) reported significant increase in the values of flexural strength of a ceramic composite reinforced by continuous and long fibers of alumina with a diameter of 10 μm. Medeiros et al. showed that the addition of continuous or milled Al_2O_3/$GdAlO_3$ fibers resulted in significant increases in the flexural strength values (Medeiros et al., 2009; Sgura et al., 2012). Another type of fiber commonly reported in the literature is the so-called whisker, which can be composed of carbon, silicon carbide, and potassium titanate. Potassium titanate whiskers ($K_2O \cdot nTiO_2$) are frequently used in the engineering field to produce thermal insulators, filters and to reinforce polymers, metals and ceramic materials that benefit from its high thermal resistance, chemical stability, and good optical properties (Watanabe et al., 1985). These fibers are known to have crystalline structure and high strength, which provide better reinforcement than conventional carbon or glass fibers. Silicon carbide (SiC) whiskers can be very expensive and cost 10 to 20 times more than potassium titanate ($K_2O \cdot nTiO_2$) (Suganuma et al., 1989). Usually, its diameter varies between 0.1 and 1 μm, which can be considered an advantage in relation to glass and carbon fibers, that have a diameter that is approximately 10 times higher (Xie et al., 2010). These fibers can be incorporated to porcelain restorations at a relatively low cost (Suganuma et al., 1989), and if processing is successfully carried out by heat-pressing, it is possible to optimize the fiber distribution to achieve better mechanical and optical properties.

The slow crack growth (SCG) is a mechanical degradation that can occur during the lifetime of a restoration, caused mainly by a stress corrosion mechanism resulting in crack extension by water molecule attack at the crack tip (Pinto et al., 2008). Silicate glasses, like porcelains, are particularly susceptive to this phenomenon (Yoshimura et al., 2008a). It is expected that the increase of mechanical properties by fiber reinforcement can