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Research Paper

Effect of sandblasting and residual stress on strength of zirconia for restorative dentistry applications

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ABSTRACT

Sandblasting is a commonly used surface treatment technique for dental crowns to improve the adhesion of the mating parts of a restoration. The goal of this work is to study the effect of different sandblasting conditions on the mechanical properties of 3 mol % yttria stabilized tetragonal zirconia (3Y-TZP), such as biaxial strength, surface elastic modulus, contact hardness and residual stresses induced by sandblasting. The specimens were sandblasted considering two different particle sizes (110, 250 μm), two pressures (2 and 4 bar) and two impact angles (30° and 90°). Biaxial strength of 3Y-TZP increases when sandblasted with 110 μm particles while its decreases with 250 μm particles for impact angle of 90°. Strength increases slightly when sandblasting with 30° impact angle regardless of the size of the particle. Elastic modulus and contact hardness were not affected by sandblasting with 110 μm particles, and compressive residual stresses are produced down to a depth of ~10 μm.

1. Introduction

In recent years, zirconia ceramics are increasingly employed in restorative dentistry for the treatment and repair of damaged teeth and for improving the aesthetic appearance of irregular teeth (Denry and Kelly, 2008; Kelly and Denry 2008; Wolfhart et al., 2008). These ceramics are mainly employed for implants, abutments, orthodontic brackets, cores for crowns, endodontic posts and fixed partial denture prosthesis frameworks (Devigus and Lombardi, 2004; Raigrodski, 2004; Conrad et al., 2007). Zirconia-based ceramics are superior candidates for restorative dentistry due to their excellent strength, fracture toughness and biocompatibility (Denry and Kelly, 2008). Dental crowns made out of zirconia are typically subjected to surface treatments in order to improve their wettability and the bond strength between the ceramic core and the luting cement at the intaglio surface, and between the outer surface and the veneering porcelain at the outer surface (Kern and Wegner, 1998; Gahlert et al., 2007; Fischer et al., 2008).

Sandblasting, dental grinding and chemical etching are commonly used surface treatments (Kern and Wegner, 1998;

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Ban, 2008; Patchanee and Kelly, 2012). Sandblasting involves impacting the required surface with hard particles at high velocities thereby eroding the material and leaving a roughened surface with expected higher wettability. Sandblasting also generates residual stress in the surface due to local irreversible deformation at the high velocity impacts. Sandblasting of a polished tetragonal polycrystalline zirconia (TZP) surface increases roughness and induces tetragonal–monoclinic (*t*–*m*) phase transformation, compressive residual stresses, cracks and damage to the near surface zone (Kosmac et al., 1999; Zhang et al., 2004; Sato et al., 2008).

Zirconia-based dental restorations are subjected to cyclic contact loads during chewing and mastication. Therefore, the mechanical properties such as strength, hardness, fracture toughness, subcritical crack growth threshold and presence of residual stresses are critical parameters that influence the long-term performance of the restorations. More importantly, proper process parameters of the sandblasting treatment must be selected to achieve the desired result (higher wettability) with minimal adverse effects.

It is well known that sandblasting increases surface roughness of polished dental zirconia (Ban, 2008; Fischer et al., 2008). The influence of sandblasting conditions such as particle size and pressure on the roughness has been studied by several authors (Albakry et al., 2004; Fischer et al., 2008; Cattani-Lorente et al., 2010; Scherrer et al., 2011), but very often by examining the effect of only one sandblasting parameter. Ban (2008) and Sato et al. (2008) employed different particle sizes and reported that the roughness achieved in 3Y-TZP and a zirconia composite (Nanozr) sandblasted with 125 μm SiC particles was approximately twice as compared to sandblasting with 70 μm alumina particles. However, it is not clear whether the increase was associated to the particle size, since both types of particles were also of different materials. On the other hand, Curtis et al. (2006) found no significant changes in roughness of dental zirconia (LAVA 3Y-TZP) after sandblasting with alumina particles of sizes 25, 50 and 110 μm at 4.8 bar pressure. Ozcan et al. (2013) reported no change in roughness in dental zirconia (3Y-TZP VITA InCeram) sandblasted with 30 and 110 um alumina particles coated with silica at 2.8 bar pressure, however they observed higher roughness with 50 μm alumina particles without the silica coating at the same pressure.

Most previous reports on TZP after sandblasting have found an increase in the biaxial flexural strength of the sandblasted surface. Ban (2008) and Sato et al. (2008) reported that strength increased by sandblasting with 70 and 110 μm particles at 4 bar. Similarly, Kosmac et al. (1999, 2000, 2007a) also concluded that the strength increased after sandblasting with 110 μm particles at 4 bar, though the sandblasted material had lower Weibull modulus as compared to control group. Souza et al. (2013) also reported increase in strength after sandblasting with alumina (50 and 100 μm) and silica (30 and 110 μm) particles at 2.5 and 3.5 bar pressure compared to control specimens. However, Curtis et al. (2006) and Karakoca and Yilmaz (2009) did not report significant change in the mean biaxial flexural strength of zirconia-based Lava and Cercon dental ceramics after sandblasting with 25, 50 and 110 μm particles at 4.8 bar as compared to untreated group. In CAD/CAM zirconia frameworks sandblasted at 3.5 bar, Wang et al. (2008) noticed that the strength increased with 50 μm particle size and decreased with 120 μm particle size. The dissimilar results on the strength that exist in the literature are often associated to different type and size of particle, working pressure, nozzle size, angle of projection, and other parameters such as the microstructure of the material studied. However, sandblasting conditions and their effect on strength is not clearly understood.

In other dental ceramics such as pressable-reinforced glass ceramics (IPS Empress), Albakry et al. (2004) observed no significant difference in the mean strength between the sandblasted (50 μm particle, 3 bar) and the control groups. On the other hand, Guazzato et al. (2004) reported a significant decrease in the strength after sandblasting (110 μm particles, 5 bar) in glass-infiltrated alumina-reinforced dental ceramics.

The near surface microstructure and mechanical properties play a crucial role in maintaining the structural integrity and performance of the dental crowns and implants under contact loads. Microcracks are generated during sandblasting (Kosmac et al., 2000, 2008), which according to Zhang et al. (2004) are responsible for the reductions in near surface elastic modulus of sandblasted zirconia measured by nanoindentation, At the same time, the increase in strength after sandblasting of Y-TZP is often attributed to the *t*–*m* phase transformation associated with the generation of residual compressive stresses (Kosmac et al., 1999; Ban, 2008; Sato et al., 2008). The final strength of the sandblasted material must be the result of a trade-off between damage and compressive residual stress generated by the impact of particles.

Though much work has been done on sandblasting of dental TZP, it is difficult from the data found in literature to correlate sandblasting parameters with the final roughness and strength. Moreover, the influence on the strength of the near surface properties and residual compressive stresses induced in sandblasting has not been studied in detail, and this is critical for long-term clinical performance of dental restorations. In a previous work (Chintapalli et al., 2013), we have shown in detail the gradient in the amount of transformation that is formed at the surface down to a depth of about 12 μm after sandblasting. With this regard, now the attention is addressed to study the influence of sandblasting particle size, pressure, and impact angle on the flexural biaxial strength by considering the presence of this surface phase transformation gradient and the associated gradient residual stress.

2. Materials and methods

2.1. *Specimen preparation*

3Y-TZP powder (TZ-3YSB-E) procured from Tosoh Co. Japan was cold isostatically pressed at a 200 MPa in a cylindrical mould and sintered in an alumina tube furnace at 1450 °C for 2 h (3 °C/min heating and cooling rates). The sintered rods were cut into discs of 2 mm thickness and 10 mm diameter. The discs were polished until mirror-like surface finish. These will be referred as the "control" specimens. The bulk density was more than 99% of the theoretical value as