



Measuring the Hardness of Three Different Types of Commercially Available Zirconia Blanks Applied to Dentistry

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Abstract:

Problem Statement: The use of polycrystalline yttria-stabilized tetragonal zirconia (3Y-TZP) in dental restorations has increased due to its exceptional properties. Among these characteristics is hardness, which provides durability to zirconia dental restorations under special conditions within the oral cavity. **Aim:** To investigate the hardness and density of pre-sintered and sintered different types of commercially available zirconia blanks applied to dentistry. **Materials and Methods:** Three different types of commercial zirconia blanks (HT4, 89HT, and A214) were designed and manufactured, followed by sintering at 1530 °C to achieve the final shape. The apparent density of the samples was determined after collecting pre-sintered and sintered samples. The shore D hardness test was conducted according to ASTM D2240. The mechanical properties are typically measured through indentation. For each group, three specimens were examined. **Results:** The results indicated that sintering temperature contributed to the densification of zirconia samples, with relative density values reaching up to 97.5%, 94.8%, and 93% of the theoretical density (6.1 g/cm³) for HT4, 89HT, and A214, respectively. An increase in the density of zirconia samples after the sintering process led to a significant rise in elastic modulus and hardness. The hardness values for HT4, 98HT, and A214 were 83 SHN, 83 SHN, and 80,17 SHN, respectively, while the elastic modulus values for the same samples were 12 MPa, 12 MPa, and 11.23 MPa, respectively. **Conclusion:** The density, elastic modulus, and hardness values of the tested commercial zirconia blanks exhibited no significant differences and successfully fulfilled the required criteria for dental applications.

Keywords: Dental Zirconia; Sintering; Hardness; Density; Elastic Modulus

Introduction

Dental crowns and bridges are made from various materials, each offering specific advantages. Metal alloys, such as gold and base-metal alloys, are known for their durability and biocompatibility, but they lack natural aesthetics (Kelly, 1997). Porcelain-fused-to-metal (PFM) restorations combine metal strength with porcelain aesthetics; however, their translucency can be reduced by the underlying metal (Anusavice, 2012). All-ceramic systems, such as lithium disilicate, offer excellent translucency and esthetics, especially for anterior restorations, although they are less fracture-resistant than metals (Denry & Kelly, 2008). Recently, dental zirconia has become more popular due to its superior mechanical strength, fracture resistance, biocompatibility, and improved esthetic results (Piconi & Maccauro, 1999; Zhang & Lawn, 2018). The use of polycrystalline yttria-stabilized tetragonal zirconia (3Y-TZP) in dental restorations has increased due to its exceptional properties. 3Y-TZP is a high-strength ceramic widely employed in dentistry and orthopedics because of its excellent mechanical and biological features. Yttria stabilization at about 3 mol% keeps the zirconia in the tetragonal phase at room temperature, enabling transformation toughening and improving fracture resistance (Chevalier & Gremillard, 2009; Aboras et al., 2016a). Among its mechanical properties, hardness is especially important because it directly affects wear resistance, surface durability, and the ability to endure masticatory and functional loads in clinical settings (Denry & Kelly, 2008). High hardness helps ensure the long-term performance of 3Y-TZP by reducing wear and preserving surface smoothness, which are vital for functionality and aesthetics (Zhang & Lawn, 2018). In this study, the density and hardness of various types of commercially available sintered dental zirconia blanks were examined.

Material and Methods

The used materials were provided by Jaghbus Dental Lab (Benghazi) and Alfaieq Dental Center (Misurata). They were purchased from the local market. The details of the collected products are presented in Table 1.

Table 1: Description of experimental materials

Specification	Materials		
Product name	Dental Zirconia Blank	Balaam Zirconia	Everest Zirconia
Product Number	D98-12	HT-W	-
Product Code	HT4	98HT	A214
Structure	Monolayer	Multilayer	Multilayer
Block Dimension	98*14	98*14	98*14
Place of Production	China	China	S. Korea

Specimen Preparation

The preparation of nine zirconia discs was performed using three yttrium oxide-stabilized zirconia blocks, which are commonly used for dental restorations. The specimens were made using CAD software from Exocad GmbH in Darmstadt, Germany, which generated 12.0 x 5.0% circular specimens per disc. To cut the discs, a Roland DWX 52D Computer-Aided Milling (CAM) machine was used. For 13 hours, the furnace (Tabeo-1/m/zircon-100) was used to sinter all zirconia blocks at 1530°C. (Figures 1 and 2).



Figure 1: Zirconia discs



Figure 2: Zirconia Sintering Furnace

Density Determination

After collecting the pre-sintered and sintered samples, a digital caliper was used to measure the exact dimensions (thickness and diameter). The specimens were then weighed using a digital balance (ME204E, Mettler Toledo, USA). The apparent density of the samples was determined by the sample's weight divided by the sample's volume. The theoretical density is 6.51 g/cm³, which is employed for computing the relative density (Alwade et al., 2019).

Evaluation of Surface Hardness

Vickers' hardness test was used because of its exceptional capability to differentiate among solid substances having high rigidity and abrasion resistance (Aljubori et al., 2020; Elshereksi et al., 2022). The hardness test was performed according to ASTM D2240 using the Shore D scale hardness tester (Shahe, China). Shore D hardness is a quick and easy way to measure a material's hardness or resistance to indentation damage.

Shore hardness is measured using a durometer, an instrument consisting of an indenter tip with a 0.1 mm radius and a 30° angle, attached to a calibrated force spring and read-out display. The indenter tip protrudes 2.54 mm below the durometer's flat presser foot when the testing load of 45 N is applied. Once the entire presser foot is in contact with a specimen's surface, the indenter tip is pushed up into the durometer. The displacement of the indenter tip pushed into the durometer reflects the material's hardness, with greater displacement indicating higher hardness.

To determine the microhardness, each specimen was placed under the indenter of the durometer, and a load was manually applied to generate indentations. The Shore D hardness values were then recorded (Czajkowska et al., 2020). Measurements were made within the specified distances from the edge of the sample's surface and from each other. Three specimens were examined for each group.

Modulus of Elasticity (E)

Hardness values were used to estimate the elastic modulus of zirconia samples via the following equation:

$$E = \text{EXP}((H_s + 50) * 0.0235 - 0.6403)$$

where: H_s represents the shore hardness values

Results and Discussion

Density Determination

Figure 3 shows the alternations in the apparent density of pre-sintered and sintered zirconia. It can be observed that the density of pre-sintered samples is much lower than that of the sintered ones. Alternatively, there is no notable variance among the pre-sintered specimens. The reduction in density of pre-sintered zirconia can be attributed to the particles retaining their original shape due to the low sintering temperature, leading to low densification. At this point, the surface diffusion mechanism dominates the sintering process. These results are in good agreement with those of previous work (Wahi et al., 2016), where low sintering temperatures yielded poor density. As depicted in a separate study, morphological examination revealed that samples pre-sintered at 900 °C and 1000 °C exhibit a coarse surface with noticeable pores (Amat et al., 2020).

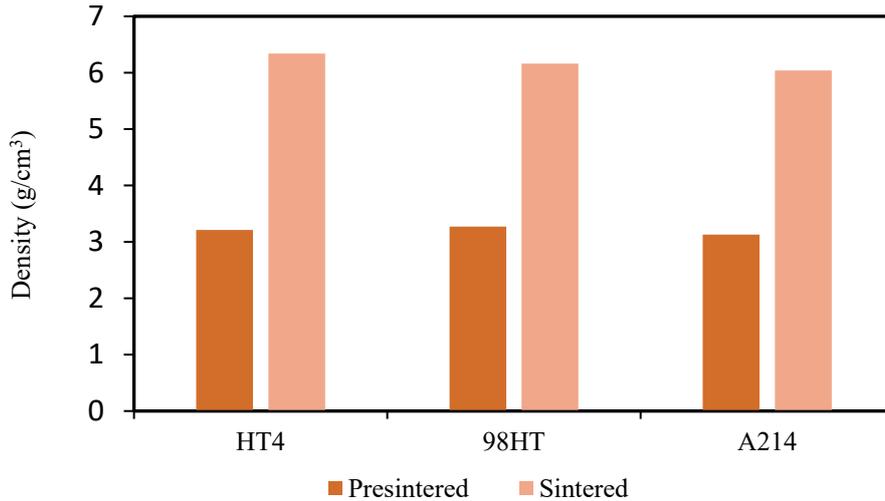


Figure 3: Average apparent densities of the experimented zirconia

After sintering, no significant difference was observed in the density of the sintered blocks among the various experimental groups. As the sintering temperature increased, the densification of the zirconia samples increased (Abbas et al., 2023); therefore, at 1530°C, the HT4, 89HT, and A214 zirconia exhibited similar trends, i.e., the relative density values reached up to 97.5%, 94.8%, and 93%, respectively, as shown in Figure 4. It can be assumed that this is due to the use of the same sintering conditions for all of the samples (Oh et al., 2010). At a higher sintering temperature of 1530 °C, the zirconia powder bonding occurs rapidly and becomes networked. Diffusion mechanisms become active at high temperatures, leading to a reduction of porosity. The energy supplied to the powder particles helps the powder to bond massively (Wahi et al., 2016). Similar findings were reported by others who inferred that increasing the sintering temperature significantly increased the density and translucency (Hao et al., 2016; Vafaei et al., 2022). Although fully dense blanks have better mechanical properties, they lack the popularity of partially sintered blanks owing to their long milling times and the hardness of the dense blanks, especially in the fabrication of fixed partial denture frameworks (Amat et al., 2020; Rao et al., 2023).

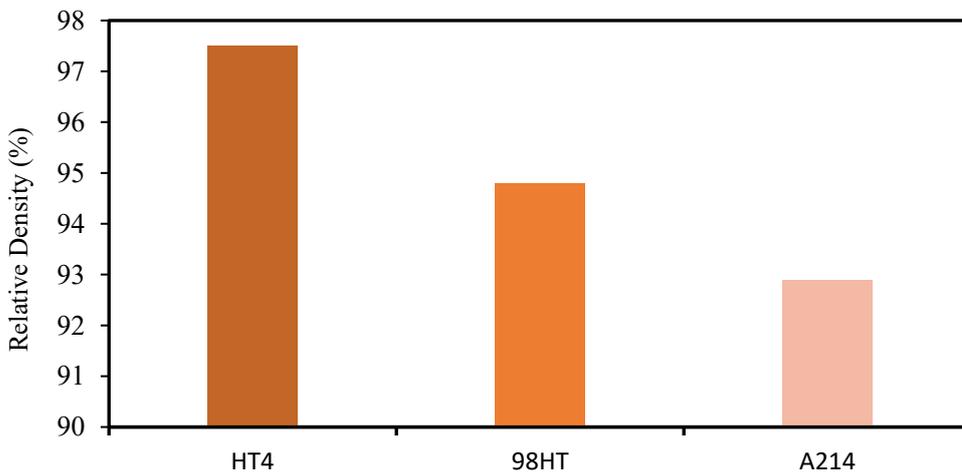


Figure 4: Relative densities of the sintered zirconia

Surface Hardness

Hardness is a crucial mechanical property in dental ceramics, as it is linked to the ability to resist wear and deformation under functional loading conditions (Denry & Kelly, 2008). According to the findings, the sintering temperature played a role in the densification of zirconia samples. An increase in the density of zirconia samples after the sintering process led to a significant increase in hardness. HT4, 98HT, and A214 had a hardness value of 83 SHN, 83 SHN, and 80.17 SHN, respectively, as shown in Figure 5.

The hardness of three commercially available dental zirconia blanks, HT4, 98HT, and A214, after sintering at 1530 °C, is evaluated to reveal how sintering-induced densification affects mechanical performance. As per the results, HT4 and 98HT had hardness values of 83 SHN, while A214 had a slightly lower hardness value of 80.17 SHN. These differences indicate that the material's specific characteristics, such as initial powder composition, particle size, stabilizer content, and green body density, affect the final hardness outcome, even though the sintering conditions were kept constant.

Minor variations in microstructure, particularly grain size and residual porosity, can significantly influence hardness, even when identical sintering parameters are applied (Chevalier et al., 2009; Aboras et al., 2016b; Chin et al., 2018). Sintering at elevated temperatures (such as 1530 °C) promotes densification and grain coalescence, reducing porosity and enhancing the contact between grains. This structural refinement increases resistance to plastic deformation, which directly contributes to higher hardness values (Zhang & Lawn, 2018). According to Guazzato et al. (2004), well-sintered zirconia exhibits fewer flaws and defects, leading to improved hardness and overall mechanical integrity. The similar hardness values of HT4 and 98HT may indicate comparable microstructural characteristics post-sintering, such as uniform tetragonal phase distribution and high relative density.

This consistency is clinically relevant because materials with higher and more uniform hardness are better suited for load-bearing applications, such as posterior crowns and bridges, where resistance to wear and chipping is essential (Piconi & Maccauro, 1999). In contrast, the slightly lower hardness of A214 could reflect differences in yttria content or phase composition. For instance, a higher cubic phase content, which is sometimes introduced to improve translucency, can reduce hardness due to lower transformation toughening capability compared to the tetragonal phase (Zhang et al., 2012). Such variations emphasize the importance of selecting zirconia materials not solely based on esthetics but also on their mechanical performance for specific clinical situations.

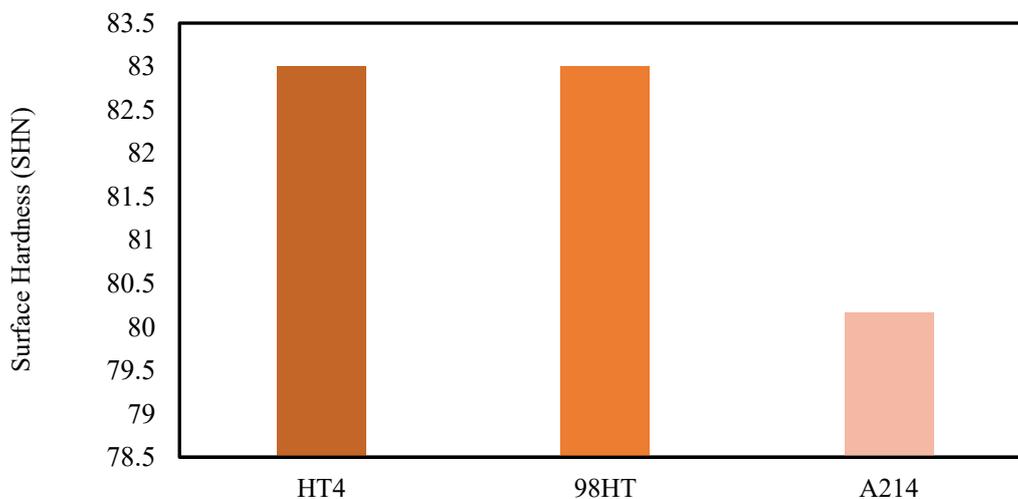


Figure 5: The hardness values of all tested commercial zirconia blanks

Modulus of Elasticity

The elastic modulus is the relative rigidity of a material and the ability to bend under constant forces without deformation. In other words, this property describes the stretchability and relative stiffness of the material without deformation under constant loading caused by the indenter, which is applied to the material (Alqarni et al., 2021). This property is essential in engineering and materials science, as it determines a material's ability to support loads and maintain its shape. Figure 6 represents the elastic modulus of the experimental zirconia. Such an attribute could be influenced by the microstructure of the material and internal porosity.

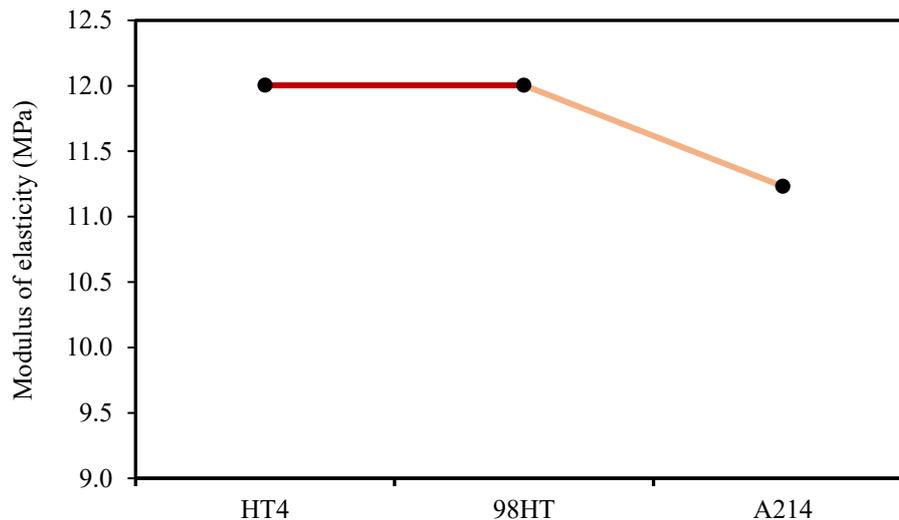


Figure 6: The hardness values of all tested commercial zirconia blanks

Conclusion

In conclusion, the differences in hardness among the three commercial zirconia blanks (HT4, 98HT, and A214) were minimal, indicating that all materials successfully meet the mechanical criteria for dental applications. While these findings support the suitability of all three for clinical use, it is important to consider other factors, such as phase composition, translucency, and aging resistance, when selecting zirconia for specific restorative indications.

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