The effect of environmental factors on selected mechanical properties of zirconium dioxide

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Abstract. In many centers around the world, research studies are carried out on the mechanical strength of dental materials and glued joints. A literature review shows the variety of testing techniques related to analyzing the strength and durability of the material itself and the glued joints. In dental ceramics, zirconium dioxide is most often used as a base material, and chemically it consists of 97% ZrO2 and 3% Y2O3. This study was to determine the mechanical properties of zirconium dioxide under different environmental conditions. The material is used for the production of dental crowns and tooth bridges in the CAD/CAM technology. This medium is currently one of the most advanced-generation materials used for prosthetic and implant restorations. They were then subjected to a three-point bending test on the Instron ElektroPlus E3000 durability machine. Storage conditions and time have a positive influence on reducing variation in zirconium resistance for active forces and destructive stresses.

1. Introduction

In many centers around the world, research studies are carried out on the mechanical strength of dental materials and glued joints. A literature review shows the variety of testing techniques related to analyzing the strength and durability of the material itself and the glued joints. The most extensive research development was observed for dental adhesives and materials used for the production of dental crowns. Research results related to the analysis of mechanical properties are used in dental practice to improve the quality of service. In dental ceramics, zirconium dioxide is most often used as a base material, and chemically it consists of 97% ZrO2 and 3% Y2O3. Another issue with modern prosthetics is the aging of dental materials in the oral cavity. Teeth are mechanically exploited on a daily basis under changing physical and chemical conditions (including temperature and pH changes). Under such conditions, the teeth can lose their natural colour, damage the enamel, and weaken their structure and age. In order to minimize these destructive factors, the authors of the paper [2] present the processes of regeneration of the natural tooth. A review of the scientific literature allows to list four basic research methods for zirconium dioxide with other dental materials or natural teeth. These research methods are durability testing for: bending, stretching, shearing, compression. The bending tests are carried out on all dental materials in order to find out and analyze their basic mechanical properties [1].

This study was to determine the mechanical properties of zirconium dioxide under different environmental conditions.
2. Methodology
Zirconium dioxide called 3M ESPE was used for static testing. The material is used for the production of dental crowns and tooth bridges in the CAD/CAM technology. This medium is currently one of the most advanced-generation materials used for prosthetic and implant restorations. All samples were subjected to an the authors’ own machining technique, which consisted of trimming with a Buehler ISOMET 5000 saw blade and grinding with a 1200 grit sandpaper. The final machining was performed using the Mazak Vertical Center Smart 430A milling machine. Ceramic materials used in dentistry are characterized by shrinkage during the process of curing and sintering. According to the manufacturer of the Cyrkon Lava material, technological shrinkage is at 20%. Prior to static testing, samples were measured with a Mitutoyo caliper. Two samples with dimensions of 1.5 mm x 1.5 mm (A and A’) and large samples with dimensions of 2 mm x 2.5 mm (B and B’) were used for the analysis. Results of the geometry analysis are presented in Table 1.

| Dimensions        | Mean values of width and height in mm | Standard deviation in mm | Relative standard deviation in% |
|-------------------|--------------------------------------|--------------------------|---------------------------------|
| 1.5 mm x 1.5 mm   |                                       |                          |                                 |
|                   | 1.46                                 | 0.039                    | 2.68                            |
|                   | 1.44                                 | 0.036                    | 2.51                            |
| 2 mm x 2.5 mm     |                                       |                          |                                 |
|                   | 2.03                                 | 0.09                     | 4.42                            |
|                   | 2.43                                 | 0.07                     | 3.01                            |

The samples were divided into four groups (A, A’, B, B’) of 30 samples per group. The samples of 1.5 mm x 1.5 mm (A’) and 2 mm x 2.5 mm (B’) in the number of 30 were immersed in a NaCl 0.9% saline solution. The samples were kept in that solution for 3 years. They were then subjected to a three-point bending test on the Instron ElektroPlus E3000 durability machine. The upper arm movement was at 0.5mm/min. A strain gauge of ± 5 kN was used to measure the force. The static three-point bending test was performed in accordance with the PN-EN 843-1 standard.

3. Results and Discussion
Statistical analysis was performed using the Statistica 13 software. All descriptive data are shown in tables as mean, standard deviations and variation coefficient. The Schapiro-Wilk test was used to determine compliance with the normal distribution. The statistical comparison between the sample types was made for the mean using Student’s t-test, and the Levene’s test for the standard deviation. Specimens marked with A were non-normalized samples. Samples marked letter B is a normalized sample. Absence of apostrophe meant testing the samples after complete processing and synthesis. Samples marked with apostrophe in addition to complex. The treatments were stored in an environment that imitates the oral environment. The results of the descriptive statistics on the durability of the samples are presented in Table 2.

The statistical analysis does not indicate significant differences in the force required to destroy the samples due to storage conditions for both small samples (A) and large samples (B). It can only be noted that the destructive force has increased by approximately 18.37 N for large samples (B) stored under conditions that mimic the oral cavity environment.
Table 2. Results of descriptive durability statistics for three-point bending of different types of samples and comparison to normal distribution

| Sample type | Mean  | SD    | Relative SD | Min   | Max    | Shapiro-Wilk test critical value | Shapiro-Wilk test p value |
|-------------|-------|-------|-------------|-------|--------|----------------------------------|--------------------------|
| Fmax [N]    |       |       |             |       |        |                                  |                          |
| A           | 185.07| 33.69 | 18%         | 97.00 | 248.00 | 0.958                            | 0.278                    |
| A'          | 189.17| 9.64  | 5%          | 166.69| 211.55 | 0.975                            | 0.672                    |
| B           | 367.90| 42.80 | 12%         | 283.00| 461.00 | 0.973                            | 0.628                    |
| B'          | 386.27| 28.55 | 7%          | 315.71| 418.96 | 0.919                            | 0.090                    |
| Σmax        |       |       |             |       |        |                                  |                          |
| A           | 947.56| 182.35| 19%         | 494.63| 1299.40| 0.951                            | 0.175                    |
| A'          | 933.53| 51.60 | 6%          | 827.90| 1047.42| 0.976                            | 0.706                    |
| B           | 1151.46| 115.88| 10%         | 879.58| 1380.80| 0.981                            | 0.840                    |
| B'          | 1109.54| 75.92 | 7%          | 924.98| 1259.60| 0.988                            | 0.980                    |

An additional analysis of the results relying on Levene’s test, in both cases, indicates the presence of statistically significant differences in standard deviation. In both cases, the spread of results in standard deviation was reduced. In the case of small samples (A), the deviation decreased by 24.05[N] and for large samples - by 14.24 [N]. The results obtained in this way point to zirconium stabilization that occurs in the aquatic environment.

An analogical analysis for the σmax results also fails to indicate any significant difference between the mean values. Damage stress results slightly decrease in the oral cavity imaging medium, namely by 14.04 MPa for the small samples (A) and 41.91MPa for the large samples (B), respectively. There was a statistically significant decrease in the result variability for the small samples (A) and the tendency to reduce the variability of the large samples (B). Also, these parameters can indicate the beneficial effects of oral conditions on zirconium stabilization.

Table 3. Statistical analysis of the results of comparison of sample results with respect to storage conditions by sample size

| Sample | Mean | Mean difference | t Student test critical value | t Student test p Value | SD | SD difference | Levene's test critical value | Levene’s test p value |
|--------|------|----------------|------------------------------|------------------------|----|---------------|------------------------------|----------------------|
| Fmax [N] |       |               |                              |                        |    |               |                              |                      |
| A vs A' | 185.07| 189.17        | 4.10                         | -0.64                  | 0.526| 33.69         | 9.64                         | -24.05               | 16.73               | <0.001               |
| B vs B' | 367.90| 386.27        | 18.37                        | -1.96                  | 0.056| 42.80         | 28.55                        | -14.24               | 3.99                | 0.042                |
| σmax    |       |               |                              |                        |    |               |                              |                      |
| A vs A' | 947.56| 933.53        | -14.04                       | 0.41                   | 0.688| 182.35        | 51.60                        | -130.75              | 16.68               | <0.001               |
| B vs B' | 1151.46| 1109.54      | -41.91                       | 1.66                   | 0.104| 115.88        | 75.92                        | -39.96               | 3.35                | 0.072                |
Figure 1. Breakdown of the results in terms of the force needed to destroy the sample by sample size and storage conditions

Figure 2. Breakdown of the results in terms of the force needed to destroy the sample by sample size and storage conditions
4. Conclusions
The following conclusions were drawn based on the conducted research: The study did not show any significant change in zirconium stored in oral-like conditions within the range of occurring forces and destructive stresses. Storage conditions and time have a positive influence on reducing variation in zirconium resistance for active forces and destructive stresses.

References
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