Journal of POLISH CIMAC
Faculty of Ocean Engineering & Ship Technology
GDAŃSK UNIVERSITY OF TECHNOLOGY

ANALYSIS OF THE WEIBULL DISTRIBUTION FOR STATIC 3-POINT BENDING OF ZIRCONIUM DIOXIDE

Mateusz Wirwicki, Tomasz Topoliński,

University of Technology and Live Sciences in Bydgoszcz
ul. Kaliskiego 7, 85-796 Bydgoszcz, Poland
tel.: +48 52 3408497, fax: +48 52 3408245
e-mail: wirwicki@utp.edu.pl

Abstract

The paper presents the results of studies of the strength of dental material; zirconium dioxide in terms of the needs of dentists. More and more frequently it happens that dentists require not only mean value (or scope) of strength of a given material as well as the analysis of its reliability under load. It seems that it is necessary each day while taking a decision on the material for the fully-ceramic crown or bridge if the element considering the properties assumed by the manufacturer is to meet the patient's expectations. The aim of the paper is to evaluate the risk and to determine the parameters of distribution of the damage probability for zirconium dioxide specimens. The paper has been based on the results of studies of 3-point bending of cuboid beams. There has been presented a method of zirconium dioxide specimen treatment. It has been considered what effect on the scatter of the results is attributed to the cross-section of the specimens. There were determined characteristic stresses σ_o, for which 63% of the specimens will get destroyed.

Keywords*: zirconium dioxide, biomaterial, three point bending, Weibull analysis*

1. Introduction

Contemporary material studies of new biomaterials, including dental ceramics, in many cases cover not only direct material characteristics, such as: compression strength, bending strength, tensile strength, hardness or fragility but also the forecast of maintaining those characteristics under operation conditions. As operation conditions for zirconium dioxide, used for the reconstruction of the tooth crown or 3- and 4-point bridges, one shall understand food chewing or consuming liquids at various temperatures. For each clinical application the dentist must evaluate the risk of damage of the solution proposed. For that reason the mechanical strength studies for ceramics must be extended by the reliability analysis, which often uses the Weibull distribution. The shape parameter, namely the Weibull modulus, is an indicator of variation in the material strength. It has been noted that the higher the value of the Weibull shape parameter m, the higher the clinical reliability [1,2]. The parameter of the Weibull distribution scale σ_0 will determine, in our case, a characteristic value of the material strength for which 63.2% of the elements made from a given material get damaged [3,4]. The value of strength σ_0 can be described referring to e.g. the method of material treatment or syntethisation method. The literature review allows for concluding that the studies reflect the operation conditions of the crown or bridges, the 3- and 4-point ones, made based on bending tests. If you want to investigate the material; zirconium dioxide otherwise referred to as technical advanced ceramics, one shall comply with the PN-EN 843-1:2006 norm. The 3-point bending in its simplest form can be compared, in terms of mechanics, for two construction elements working: teeth for chewing process in the oral cavity. On the dental market there are dental ceramics of various generations. The study of bending strength for ceramics, namely zirconium dioxide, is to help to evaluate the risk and the damage probability considerably. The study of bending strength is also an important criterion of clinical applicability of ceramic materials and it is especially important while facing a very fast development of ceramic materials.

The aim of this paper is to evaluate the risk and the damage probability for zirconium dioxide used in dental surgeries.

2. Material and method

The research involved the use of material under trade name Cyrkon Lava manufactured by 3M used to create crowns and bridges following the CAD/CAM technology. The material supplied by the producer was been cut-in with the circular saw provided by Buehler ISOMET 5000 [POLAND] into smaller blocks 25 mm x 16mm x 1.87mm in size. The elements are exposed to laser-cutting using Alfalas WS [POLAND] with the laser settings not allowing for zirconium dioxide overheating. From the cut made that way one receives 8 specimens 1.87mm x 1.87mm x 15mm in size. Then the specimens are sent to the manufacturer-licensed laboratory in which sinterization takes place. Sinterization in a special oven at the temperature of 1410°C took 8 hours. During that time there occurs technological shrinkage of the entire crown accounting for about 20% of the crown volume. The material after sinterization is snow-white and shows a significant increase in the mechanical properties parameters. Fig. 2 presents the geometry of the specimens after the process of sinterization. After synthetization one receives specimens for tests about 1.5 mm x 1.5 mm x 12 mm in size.

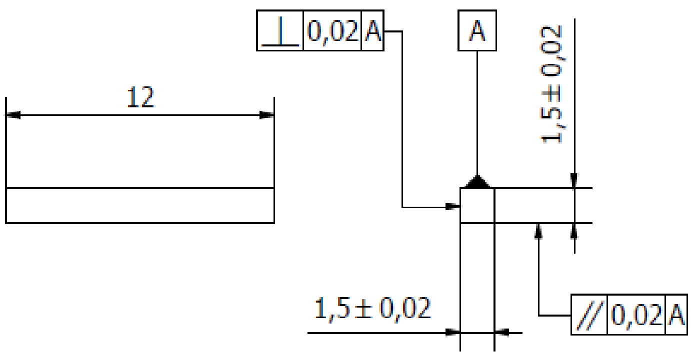

Fig. 1. Specimens geometry

The material tested in dental clinics is used to make single crowns, 3- and 4-point bridges and implant connectors. The advantage of the zirconium dioxide is high strength, excellent and natural aesthetics. The material also ha a very good translucency and biocompatibility and its structure shows a lack of metals. When providing functional descriptions it is considered dental ceramics for the representatives of which in Table 1, against the density, the basic mechanical parameters are given. Interestingly, the materials broken down in the table, except for zirconium dioxide, must be placed – surface-welded on meal cups and only when the crowns are prepared that way etc. they can be glued to the natural tooth.

Table 1. Mechanical properties of selected dental ceramics

Ceramics	Bending strength [MPa]	Vickers hardness [GPa]	Density (g/cm^3)
Reinforced with mica	71 -107	3.72 – 4.46	2.56
Reinforced with leucite	109 – 154	6.57 – 6.67	2.50
Aluminium trioxide	601 – 687	15	2.47
Zirconium dioxide	840 - 1200	12.17 – 13.70	5.56 – 6.1

Static bending strength study

The studies of bending strength were performed compliant with the PN-EN 843-1:2006 norm. The norm provides the guidelines how to make a specimen of an assumed geometry, perform research for 3- and 4-point bending and to make auxiliary devices during strength testing. Thirty specimens to be tested were made in a form of cuboid beams 1.5mm x 1.5mm x 12mm in size. The 3-point bending study was performed using the strength testing machine Instron 8874 with the use of strain dynamometer with the measurement range of ±5kN. The speed of the dislocation of the upper arm (machine actuator) was 0.5 mm/min, which made it possible to meet the normative guideline that the time of the specimen load until breaking should fall within the range from 5 to 15s. The beams of the support tangent to the specimen corresponded to 1.5 of the specimen thickness, which is also a normative requirement.
Breaking stresses have been calculated from the following formula:

$$\sigma_f = \frac{3Fl}{2bh^2}$$

where:

σ_f – breaking stress in [MPa];

F – maximum force upon breaking in [N];

b – specimen width in [mm], mean for three records;

h – specimen thickness expressed in [mm], mean for three records;

l – distance between the centres of external supporting rollers in [mm] [5].

Fig. 2 demonstrates the plot of the damage probability in the normal distribution network. A high value of the coefficient of determination clearly points to the possibility of making assumption that the variation in strength undergoes normal distribution. The analysis used the results reported in the studies for 23 specimens, compliant with the norm described, 7 results have been rejected as deviating.

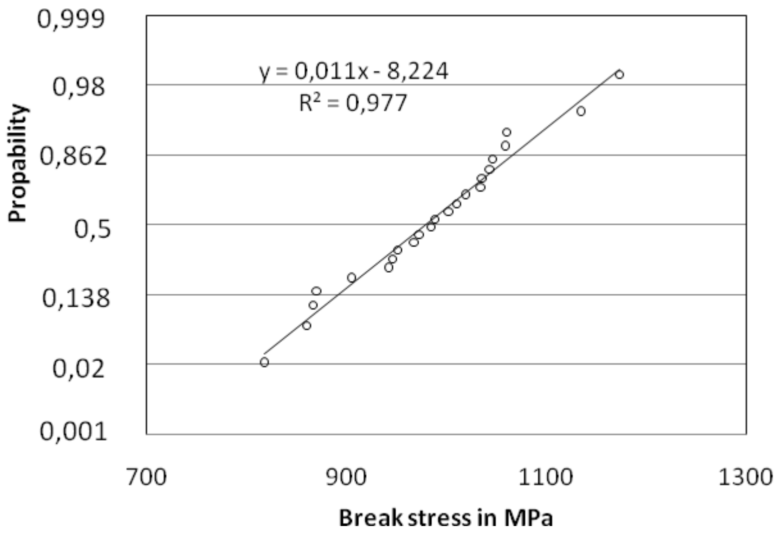

Fig. 2. Specimen damage probability.

Table 2 presents the results from the static 3-point bending test. One can note a considerable scatter of the results. An attempt has been made to identify the dependence between the cross-section of the specimen and the values received. No such dependence was observed.

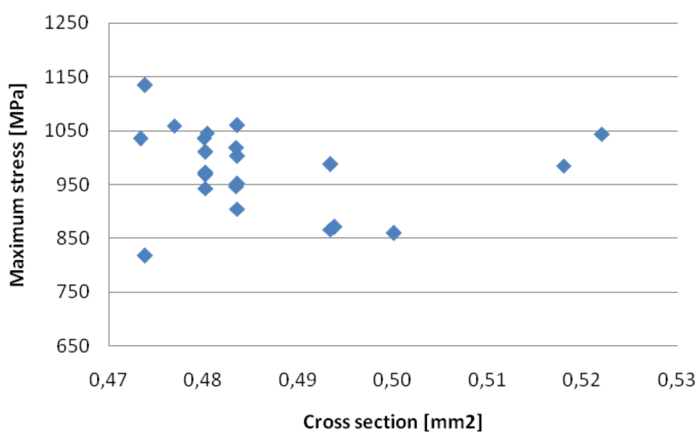

Fig. 3. Dependence of the break force to the coefficient of strength of the cross-section to bending.

Quite a high scatter of the results can suggest that other factors were essential, including a considerable shrinkage of the material, heating and cooling pattern or material homogeneity.

Table 2. Results of static 3-point bending studies

Range of breaking stresses	Mean value	Standard deviation	Relative standard deviation
817 ÷ 1134MPa	986MPa	78.3MPa	8 %

Weibull analysis

The reliability analysis of the zirconium dioxide ceramics was performed using the Weibull distribution based on the guidelines provided for in PN-EN 843-5:2006. Distribution function P_f of the Weibull distribution is described with the following relationship:

$$P_f = 1 \cdot \exp\left[-N\left(\frac{\sigma - \sigma_u}{\sigma_o}\right)^m\right]$$

where:

P_f – damage probability; N – specimen number; σ – breaking stresses; σ_u – location parameter; σ_o – size parameter; m – shape parameter; e – constant = 2.718… [6].

Table 3 presents the number of specimen N, characteristic strength σ_o, coefficient of determination R^2 and the Weibull modulus m for zirconium dioxide Lava provided by 3M.

Table 3. Breakdown of results for the analysis of the Weibull distribution

N	σ_o	R^2	m
22	1026,7	0,955	14

Fig. 3 presents the plot of linear approximation after the logarithmic conversion of the strength results into 3-point bending, the regression equation and the coefficient of determination are presented.

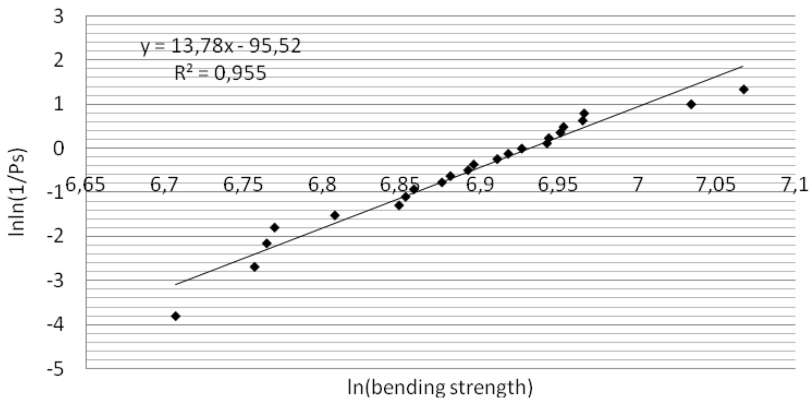

Fig. 4. Approximation of the distribution of probability of strength to 3-point bending of zirconium dioxide

Fig 4 presents the plot of empirical function of reliability; the Weibull distribution functions and in terms of bending strength. The plot shows an additional line of damage probability P_f – 0.632 which corresponds to strength σ_o.

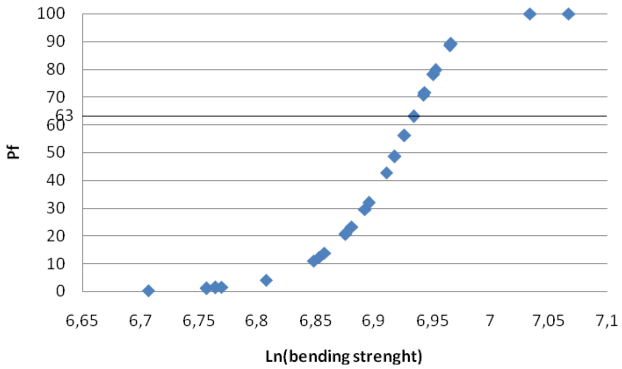

Fig. 5. Function of reliability of zirconium dioxide in terms of bending strength

Summary

The statistical analysis of the results of the present research can facilitate taking the decision of evaluating the risk taken every day in dental surgeries. As for dental materials used for that purpose, the Weibull distribution analysis is used. The distribution is one of the models of probability distribution for damage analysis. The Weibull distribution modulus, referred to as the shape parameter, is assumed as an element of variation in the material strength. The other parameter, referred to as the Weibull distribution scale parameter $\sigma_{0,}$ defines a characteristic material strength value for which 63.2% of the elements made from a given material get damaged. As for our studies, it was found, by a comparison of the descriptions of with normal and the Weibull distribution, that a slightly statistically stronger description provides the use of normal distribution. One could therefore claim that recommending the normative application of the Weibull distribution for the analysis of the results of 3-point dental materials, including zirconium dioxide, has not been confirmed.

At that stage it is difficult to evaluate the cause of a considerable scatter of the studies results and in the scope investigated the variation in the size of the cross-section of the specimens in terms of the size effect on the strength results.

References

[1] A. M. Niewczas, D. Pieniak, P. Ogrodnik, *Analiza niezawodnościowa wytrzymałości kompozytów stomatologicznych poddanych zróżnicowanym procedurom fotopolimeryzacji*, Eksploatacja i niezawodność, Vol 14, No. 3, (2012) p. 249 - 264

[2] Pick B., Meira J.B.C., Driemeier L., Braga R.R. *A critical view on biaxial and shortbeam unaxial flexural strength tests applied to resin composites Rusing Weibull, fractographic and finite element analyses* Dent Mater 2010; 26: 83-90

[3]Della Bona A. *Characterizing ceramics and the interfacial adhesion to resin: I – The relationship of microstructure composition, properties and fractography* J Appl Oral 2005; 13: 1-9

[4] Ritter J.E. *Critique of test methods for lifetime predictions* Dent. Mater. 1995; 11: 147-151

[5] Norm PN–EN 843 – 1: *Techniczna ceramika zaawansowana, Właściwości mechaniczne ceramiki monolitycznej w temperaturze pokojowej, Part 1: Oznaczanie wytrzymałości na zginanie*

[6] Norm PN–EN 843 – 5: *Techniczna ceramika zaawansowana, Właściwości mechaniczne ceramiki monolitycznej w temperaturze pokojowej, Part 5: Analiza statystyczna*