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# FATIGUE TESTING OF DENTAL BRIDGES ON SELECTED EXAMPLES

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**Abstract:** The paper presents example tests of the functional quality of selected designs of dental bridges. These were: porcelain bridges on a metal base (cobalt based alloy), porcelain bridges on a zirconia base (zirconia ceramic – Zirkon Zahn), and full zirconia bridges (Zirkon Zahn). For the purpose of the study, durability of bridges in cyclic fatigue testing was adopted as a measure of their quality. The tests were carried out on a Zwick Roell Z010 universal testing machine. They consisted in cyclic loading and unloading of dental bridges mounted on gypsum models at a loading force of F= 400 [N] and a frequency of load of f= 1 [Hz]. Each bridge was subjected to a cycle of 7200 loads. The results show that there are no significant differences in the functional quality of the bridges.

**Key words:** Dental Bridges, Ceramics, Durability

## 1. INTRODUCTION

Many types of materials are used in dental practice, starting from metallic materials, which currently constitute the largest group, through resins and thermoplastic materials, to ceramic materials (Bińczyk, 2003; Craig et al., 2000). Metallic materials are understood as metals and metal alloys, commonly described as dental or prosthetic alloys. The reason for the widespread use of dental alloys is, among others, the fact that they exhibit the highest mechanical strength among all prosthetic materials (Craig et al., 2000; Surowska, 2009). Metal biomaterials and metal-ceramics]. Prosthetic alloys are used for the construction of supporting structures of dental restorations, e.g. skeletons of dentures, which has a decisive influence on their strength. Ceramic materials, used to construct full structures, e.g. zirconia ceramic bridges (Craig et al., 2000; Surowska, 2009; Zhang et al., 2016; Bachhav and Aras, 2011), are currently growing in popularity. Restorations of this kind are characterized by much more beneficial aesthetic qualities in comparison with similar metal-based designs. It should be noted, however, that full ceramic dental restorations are unfortunately characterized by significantly worse mechanical properties, e.g. brittleness, in comparison with metallic designs (Chruściel-Nogalska et al., 2002; Tanasić et al., 2014; Ritzberger et al., 2010; Höland et al., 2009; Höland et al., 2008). Thus, the question arises whether real values of load and deformation of denture structures pose a hazard to the use of ceramic restorations, or there are certain areas in which these states are still safe for structures of this kind. It is also possible that biomechanics and kinematics of micromovements of these structures has an impact on their behaviour in the oral cavity, and for this reason their use is expanding. In this context, in the selection process of the appropriate alloy or dental material (metallic and non-metallic) for constructing the dental restoration, the type and complexity of denture structure should be taken into consideration, as well as the loads that the structure will be subjected to during use. Depending on whether the material is intended for the bridge, crown, or skeleton, it must meet different requirements, pertaining to, for instance, mechanical strength, elasticity, or hardness (Eisenburger and Addy, 2002; Gajdus et al., 2002; Jałbrzykowski, 2016; Żmudzki, 2012; Jałbrzykowski and Kovalova, 2009; Coray et al., 2016; Shemtov-Yona and Rittel, 2016; Shemtov-Yona and Rittel, 2014). Considering the above, this paper presents model durability tests of selected types of dental bridges. The tested bridges were based on metal, zirconia, and full ceramic prosthetic bridges.

## 2. MATERIALS AND METHODOLOGY OF RESEARCH

Metallic and ceramic dental materials were used for the tests. Own dental bridges constructed in various configurations were prepared to be used as samples for the tests. These were: porcelain bridges on a metal base (cobalt based alloy), porcelain bridges on a zirconia base (zirconia ceramic – Zirkon Zahn), and full zirconia bridges (Zirkon Zahn). Fig. 1 shows examples of the designs used for the tests.

The model durability tests were carried out by means of a Zwick Roell Z010 universal testing machine. They consisted in cyclic loading and unloading of dental bridges mounted on gypsum models (Fig. 2). The bridges were fixed to supporting pillars by means of bone cement. The bridge loading force was $F$= 400 [N], while the frequency of load was $f$ = 1 [Hz]. Each bridge was subjected to a cycle of 7200 loads. It was assumed that such a cycle roughly corresponds to a year of denture use, during which period each denture is assessed by a dentist, whatever the case.

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a)

b)

c)

**Fig. 1.** Prepared dental bridges: a) on a metal base, b) on a zirconia base, c) full zirconia; on the Fig 1a and 1b marked the area of analysis presented in Fig. 4 and Fig. 6.

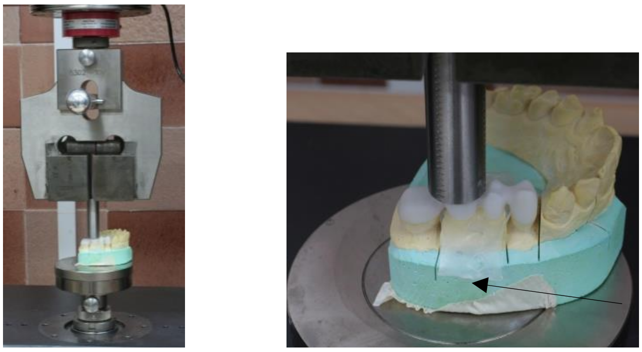


**Fig. 2.** Method of mounting of bridges for durability tests (full zirconia bridge; the arrow shows the silicone insert)

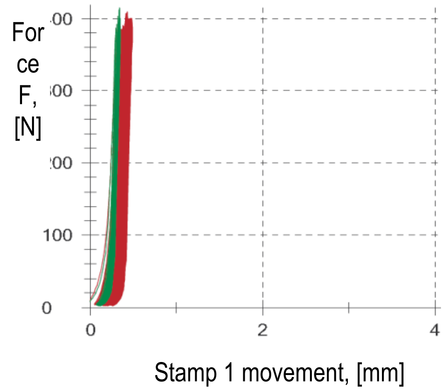
In case of any irregularities, if they occur at all, the denture is sent for repair (if possible), or constructed again. Before commencing the tests, a thin silicone foil (thickness of approx. 1 [mm]) was placed on the gypsum model, between the supporting pillars ('on toothless bed'), which would model the soft surface under the denture. In addition, after the durability tests, microscope observations of the working surfaces of the bridges were made, in order to look for possible damage. The microscope observations were performed by means of a Hitachi S-3000N scanning microscope.

## 3. TEST RESULTS

General observations of the experiment showed that the method of load application to the bridge, the value of the loading force, and the cyclical character of the process did not have a significant impact on the behaviour of bridges during their use. Fig. 3 shows example results of the performed measurements.

The data shown in Fig. 3 represent two situations. In the first case, the bridge was mounted directly on the gypsum model. In the second one, i.e. 'on toothless bed', the silicone insert was placed beforehand (Fig. 2). The obtained results show that in the case of the bridge placed directly on the gypsum model (without the silicone insert), it becomes anchored to a lesser extent than in the case of bridges anchored on the silicone insert. This situation seems obvious. It was also noticed that in the case of bridges without the silicone insert, anchoring of the bridge was more stable. In fact, the first cycles led to its natural fit under the load, then they "docked" until the maximum value of anchoring of approx. 0.5 [mm] (Fig. 3a) was reached. In the case of the bridge with the silicon insert, on the other hand, two-stage anchoring occurred. The first stage took place in steps, following a specific hysteresis loop, until a natural fit under the load was achieved. In the second stage, slow "docking" until the maximum value of anchoring of approx. 0.8 [mm] was reached occurred (Fig. 3b).

a)




b)

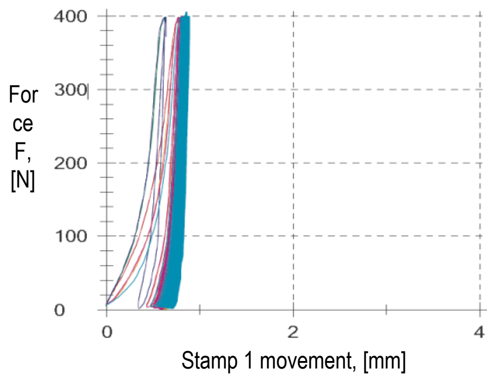



**Fig. 3.** Results of the test of cyclical loading of bridges a) without silicon insert, b) with the use of silicon insert

In all the analysed cases of bridges, no damage was observed that would render the bridges unfit for further use. All the bridges passed the test successfully and, as far as the tests performed within the framework of this paper are concerned, no differences in the functional quality of the prepared bridges were observed.

After carrying out the durability tests, microscope observations of the working surfaces of the bridges were performed. Fig. 4 shows selected photographs from the microscope analysis of the porcelain bridge on a metal base.

The performed analysis suggests a generally good adhesion of porcelain to the metallic surface (Fig. 4 a-c). However, porous spots and local lack of layer adhesion can be observed, which significantly reduces its properties (Fig. 4 d). Tab. 1 shows the results of x-ray microanalysis of areas shown in Fig. 4.

The chemical composition presented above apply to the metallic surface – Point 1, and the porcelain surface – Point 2. Obviously the contents and proportions of alloy elements vary as

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they pertain to two completely different surfaces. However, an analysis of base surfaces was performed in this particular spot, as transition structures of the metallic-porcelain type were sought. With this in mind, an x-ray analysis for the interface area was performed. Its results are shown in Fig. 5.

a)

b)

c)

d)

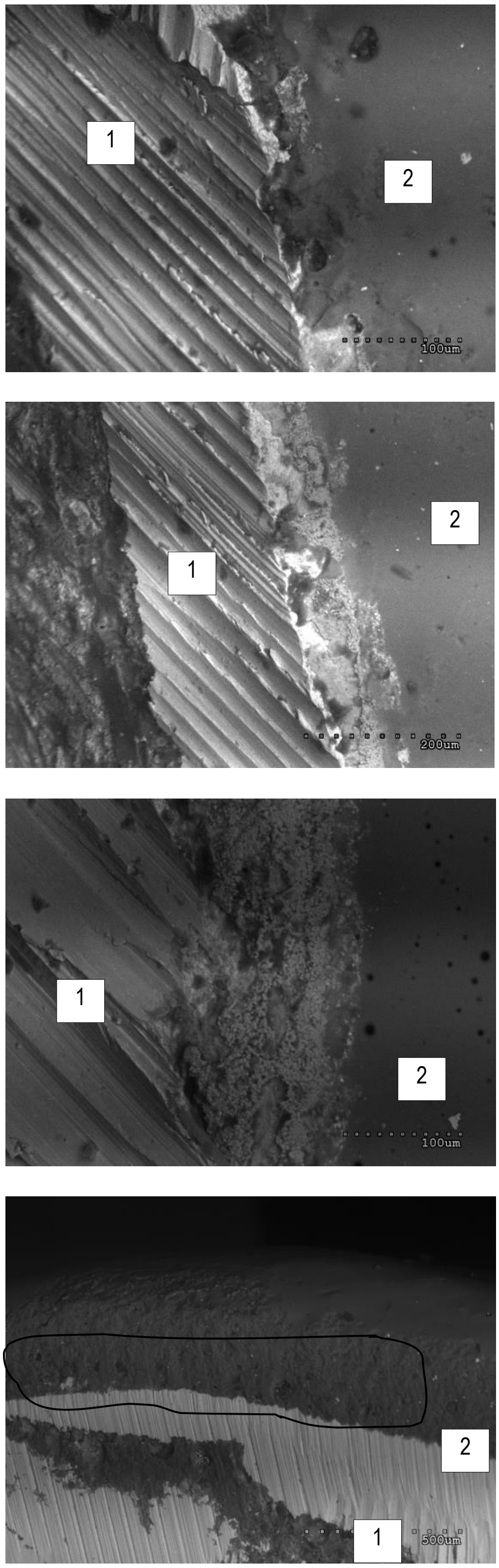


**Fig. 4.** Microphotographs of a porcelain bridge on a metal base:
a) – c) view of the lateral surface on the metal-porcelain interface,
d) view of the lateral surface; 1- metal, 2- porcelain

**Tab. 1.** Results of x-ray microanalysis of a bridge on a metallic base

| Alloy elem. cont. [% mass] / Place of analysis | O | Na | Al | Si | K | Ca | V | Cr | Co | W |
|---|---|---|---|---|---|---|---|---|---|---|
| Point 1 | - | - | 1.24 | 2.28 | 0.73 | - | 1.96 | 21.53 | 55.97 | 8.42 |
| Point 2 | 40.22 | 3.98 | 6.09 | 27/64 | 9.97 | 1.63 | - | 0.83 | 2.74 | - |
| Alloy elem. cont. [% mass] / Place of analysis | O | Na | Al | Si | K | Ca | V | Cr | Co | W |
| The marked square area | 29.47 | 1.90 | 3.24 | 12.67 | 1.93 | 0.83 | 0.63 | 5.84 | 37.08 | 3.85 |

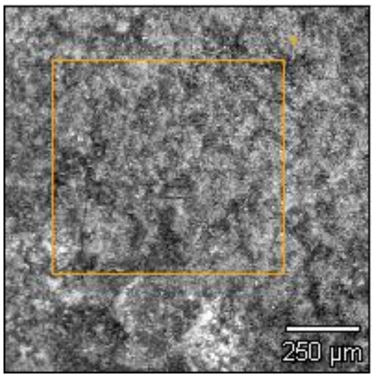


**Fig. 5.** Results of x-ray microanalysis at the metal-non-metal interface

The results of x-ray analysis from the metal-non-metal interface shown in Fig. 5 indicate the presence of all the elements, both from the metallic and the porcelain areas. This may indicate ‘mixing’ of the materials and the appearance of new transition structures. It is possible that these new structures acquire the structure of a ‘composite’ with aggregated properties and this is why the tested dental bridges behave so well in durability tests. It is also possible that the transition structure that appears is an excellent dampener of dynamic actions and through the specific mechanical properties, it allows the structure to work safely in the adopted biokinematic system. A detailed analysis in this area, however, was not performed.

Similar effects were obtained during the analysis of porcelain bridges on a zirconia base. Fig. 6 shows selected photographs of the analysed areas of bridges of this type. Fig. 6a-6c show the surface structure of a bridge at the interface. It can be observed that the rough structure of the zirconia base (Fig. 6b, area marked as 1) is probably a good base for the top porcelain layer (retention through porosity). Moreover, some few pores in the upper porcelain layer were noticed (Fig. 6d). This may be the result of careless porcelain preparation, a faulty porcelain firing process, or other reasons. It should be added that a porous structure of porcelain was also noticed in the case of bridges on a metallic base (Fig. 4d).

Tab. 2 compiles the results of analyses of the chemical composition for the zirconia and porcelain layers.

In the case of the zirconia surface, the main alloy elements are: Zr, O and N. In the case of the porcelain structure, on the other hand, these are: Si, O, K, Al, Na. Knowing what the main alloy elements for these phases are, transition areas were looked for, similarly to the case of the bridge on a metallic base. To achieve this, an analysis of the areas marked in Fig. 7 were performed.

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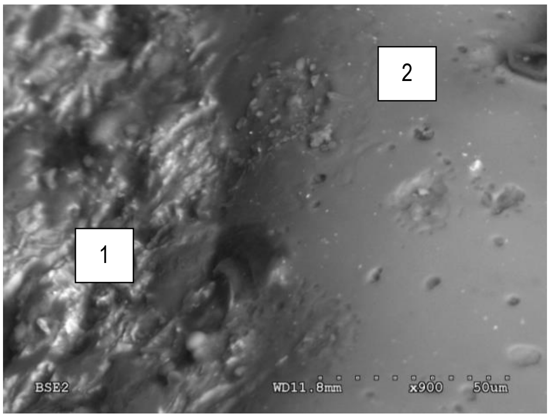
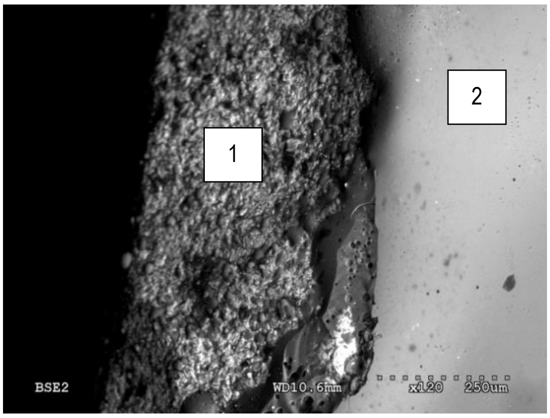
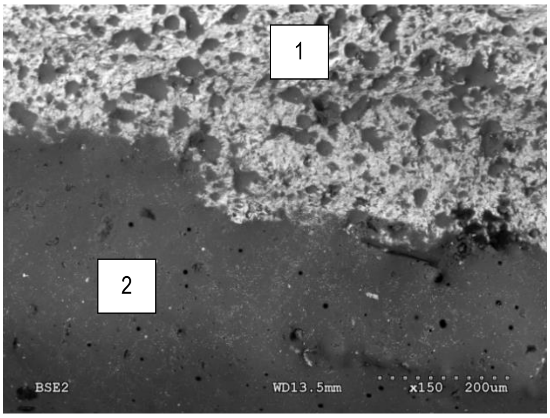
a)




b)




c)




d)

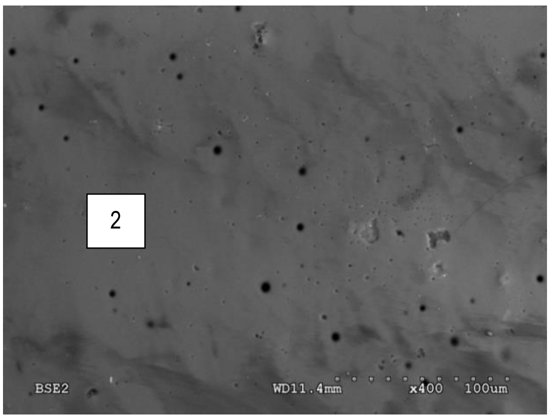



**Fig. 6.** Selected microphotographs of the surface of a porcelain bridge on a zirconia base: a)-c) pictures at the zirconia-porcelain interface, d) porous surface of the porcelain phase; 1 – zirconia phase, 2 – porcelain phase

**Tab. 2.** Results of chemical composition analysis

| **Alloy elem. cont. [% mass]** / **Place of analysis** | N | O | Al | K | Ca | Y | Zr |
|---|---|---|---|---|---|---|---|
| Zirconia surface | 4.98 | 29.01 | 1.22 | 0.20 | 0.22 | 2.51 | 51.81 |
| **Alloy elem. cont. [% mass]** / **Place of analysis** | O | Na | Al | K | Ca | Si | Ba |
| Porcelain surface | 41.45 | 6.41 | 5.85 | 9.29 | 2.86 | 28.74 | 3.12 |

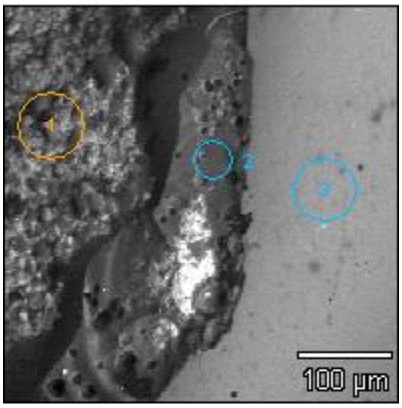



**Fig. 7.** Places of analysis of chemical composition – porcelain bridge on a zirconia base

Tab. 3 shows the results of analyses for the areas marked in Fig. 7. Analysing the results in Tab. 3, mixing of chemical compositions of the basic structures can generally be noted, probably caused by harmonizing porcelain penetrating micropores of the zirconia base. A curious issue, however, is the total absence of signal from the presence of the zirconia phase. It is possible that porcelain covers the zirconia layer very tightly. In order to better understand the issue of creation of transition structures, transverse metallographic specimens cutting through two phases perpendicular to the increase of their thickness should have been prepared. A detailed analysis at this stage, however, was omitted.

**Tab. 3.** Results of tests of chemical composition of areas from Fig. 7

| **Alloy elem. cont. [% mass]** / **Place of analysis** | O | Na | Al | Si | P | Cl | K | Ca | Ti | Ba |
|---|---|---|---|---|---|---|---|---|---|---|
| Area “1” | 44.95 | 3.46 | 4.56 | 15.59 | 8.52 | 0.29 | 3.70 | 2.69 | - | - |
| Area “2” | 45.80 | 7.75 | 5.69 | 25.03 | 0.92 | 0.21 | 5.57 | 1.90 | 0.07 | 1.28 |
| Area “3” | 33.13 | 7.48 | 4.36 | 27.48 | 0.88 | 1.04 | 7.79 | 2.01 | 0.45 | 3.39 |

## 4. CONCLUSIONS

The performed tests and their analysis allowed to formulate the following general conclusions:

– Results of the model durability tests did not reveal significant differences in the behaviour of the tested dental bridges. All designs (on metal, zirconia, and full zirconia bases) passed the test successfully with no discernible damage

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- When performing the tests attention was paid to the dual character of bridge anchoring. In the first case, slow constant anchoring of the bridge until the maximum value of approx. 0.5 [mm]. In the second case, anchoring occurred at two stages. First, anchoring in steps that followed a hysteresis loop down to approx. 0.6 [mm] took place. Then, similarly to the first case, slow constant anchoring occurred until the value of. 0.8 [mm] was achieved.
- The character of anchoring probably depends on susceptibility of the bed on which the bridge is anchored.
- Analysis of the chemical composition of selected areas of bridges indicates the presence of regions with a chemical composition that comprises elements from the metallic and the non-metallic phases. This may indicate the creation of transition structures which contain both phases. It is possible the newly formed structure acquires the character of a composite with combined properties and has a beneficial impact on the behaviour of brittle porcelain on a susceptible metallic base. This issue, however, was not analysed.
- Microporosity of the top layer of porcelain was noted, both on metal- and zirconia-based bridges. This may be the result of careless porcelain preparation, a faulty porcelain firing process, or other reasons, however, this is not was analyzed.

## REFERENCES


1. **Bachhav, V.C., Aras, M.A.** (2011), Zirconia-based fixed partial dentures: a clinical review, *Quintessence International*, 42 (2), 173-182
2. **Bińczyk F.** (2003), *Structural cast alloys*, Wydawnictwo Politechniki Śląskiej, Gliwice.
3. **Chruściel-Nogalska M., Światłowska M., Uchacz H.** (2002), Analysis of the reasons for damage of removable mucous-borne dentures anchored on the basis of clinical material, *Protetyka Stomatologiczna*, LII, 3, 62-166.
4. **Coray, R., Zeltner, M., Özcan, M.** (2016), Fracture strength of implant abutments after fatigue testing: A systematic review and a meta-analysis, *Journal of the Mechanical Behavior of Biomedical Materials*, 62(1), 333-346.
5. **Craig R. G., Powers J. M., Wataha J. C.** (2000), *Dental Materials*, Wydawnictwo Urban&Partner, Wrocław.
6. **Eisenburger M., Addy M.** (2002), Radiological examination of dental castings – a review of the method and comparisons of the equipment, *Journal of Oral Rehabilitation*, 29(7), 609-614.
7. **Gajdus P., Hędzelek W., Joniak S.** (2002), Assessment of mechanical strength of palatal plates – cast cobalt chrome and acrylic reinforced with steel mesh, *Protetyka Stomatologiczna*, LII, 6, 362-367.
8. **Höland, W., Rheinberger, V., Apel, E., Ritzberger, C., Rothbrust, F., Kappert, H., Krumeich, F., Nesper, R.** (2009), Future perspectives of biomaterials for dental restoration, *Journal of the European Ceramic Society*, 29 (7), 1291-1297.
9. **Höland, W., Schweiger, M., Watzke, R., Peschke, A., Kappert, H.** (2008), Ceramics as biomaterials for dental restoration, *Expert Review of Medical Devices*, 5(6), 729-745.
10. **Jałbrzykowski M.** (2016), The influence of type and design of denture attachment on its efficiency of operation in model tests, *Key. Eng. Mater.*, 687, 185-190.
11. **Jałbrzykowski M., Kovalova E.** (2009), The problems of exploitation reliability estimation of dental prosthetics elements, *Solid State Phenomena*, 147-149, 794-800.
12. **Ritzberger, C., Apel, E., Höland, W., Peschke, A., Rheinberger, V.M.** (2010), Properties and clinical application of three types of dental glass-ceramics and ceramics for CAD-CAM technologies, *Materials*, 3(6), 3700-3713.
13. **Shemtov-Yona, K., Rittel, D.** (2016), Random spectrum loading of dental implants: An alternative approach to functional performance assessment, *Journal of the Mechanical Behavior of Biomedical Materials*, 62(1), 1-9.
14. **Shemtov-Yona, K., Rittel, D.** (2014), Identification of failure mechanisms in retrieved fractured dental implants , *Engineering Failure Analysis,* 38, 58-65.
15. **Surowska B.** (2009), *Metal biomaterials and metal-ceramics connections in dental applications*, Wydawnictwo Politechniki Lubelskiej, Lublin, 9-13.
16. **Tanasić, I., Šojić, L.T., Lemić, A.M.** (2014), Biomechanical interactions between bone and metal-ceramic bridges composed of different types of non-noble alloys under vertical loading conditions, *Materiali in Tehnologije*, 48(3), 337-341.
17. **Zhang, Z., Chen, J., Li, E., Li, W., Swain, M., Li, Q.** (2016), Topological design of all-ceramic dental bridges for enhancing fracture resistance, *International Journal for Numerical Methods in Biomedical Engineering*, 32(6), 1, 1-13.
18. **Żmudzki J.** (2012), *Material conditionings of functional efficiency of mucous-borne complete denture, Open Access Library, Volume 4/10, 1-176.*


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