ORIGINAL PAPER

Thermal regime effect on the structure of metal component in metal-ceramic prosthesis

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Abstract
The success of dental restorations is dependent both on clinical phases of treatment to achieve fairness and on rigor to achieve technical phases. In our study we conducted research on metal parts microstructure of metal-ceramic dentures, to investigate the effect of reheating to successive deposits layers of ceramic. We analyzed molded samples and replicates on which were simulated ceramics firing. Applying such heat treatments have resulted in complete dissolution of intermetallic compounds and conducted to a homogeneous microstructure near to thermodynamic equilibrium, which leads to improved behavior in long-term operation of dental restorations.
Keywords: dental alloys, microstructure, molding flaw.

Introduction

The metal-ceramic fixed prosthetic restoration which reestablish the continuity of dental arches [1] are widely used in dentistry.

The alloys features needed for in metal-ceramic technology [2-4] are:

- high temperature resistance, which allow for no deformation during ceramics firing;
- melting temperature must be lower than 1300°C for an easy processing, and should be higher with about 150…200°C than sintering temperature interval of the ceramics which is in the range 850…1100°C;
- thermal expansion coefficient should be closed to the one of ceramic mass, to avoid share stress appearance in the interface alloy-ceramic durring prosthetic piece cooling;
- solidification shrinkage should be less than 2.5%;
- yield strength should be as high as possible;
- should allow on optimal adherence of the ceramics mass.

Dental materials interact with living tissues they come in contact with and generate local or systemic responses [5]. The biocompatibility of dental alloys is important and is considered a controversial problem for practitioner physicians [6].

Among the causes of metal-ceramic restorations failure are cited in literature: degradation by corrosion of alloys, mechanical wear and fatigue fracture [7-9].

Corrosion is described as the destruction or damage of the material under the action of aggressive environment (atmosphere and oral fluids) [10].

Metal alloys based on Chromium and Cobalt are widely used in the dentistry field [11].

The Co-Cr or Ni-Cr alloys have good corrosion comportment because of Chromium presence, which forms a stable chromium oxide layer on the alloy surface [12-18]. In addition, the allergenic potential of Cr-Co based dental alloys is very small compared with the allergenic potential of the dental alloys based on Ni-Cr [18] in patients with allergic ground.

The corrosion behavior of cast alloys is considered to be the most relevant property that complies with safety biological material [19]. For the commercial alloys, the proportion of Cr and Mo ranges between 11…25 wt. % and respectively 0…10 wt. % [20].

Modern Ni-Cr alloys chemistry has mainly Ni (60-70%) and Cr (15-20%), with some content of Mo, Al, Mn, Be, Cu, Co, Fe, W, Ti or Nb.

Nickel reduces hardness, increases malleability and elasticity of the alloy. Generally, substituting some important percentages of Fe, any alloy gets better resistance to corrosion.

Chromium improves mechanical properties, and the chromium oxide formed on the alloy surface has anticorrosive effect and offer good adhesion to ceramics. Oxidation improves the quality of metal-ceramic interface [21, 22].

Molybdenum (3-11 wt. %) increases corrosion resistance and has convenient influence on the thermal expansion coefficient. Addition of Mn, W, and Ti improves also corrosion resistance of the alloy. Beryllium addition in Ni-Cr alloys improves alloy fluidity in liquid state and increases adherence between porcelain and metal [21, 23-25].

Studies [26] showed that the corrosion products from dental alloys solubilized in adjacent gum tissues depends on the composition of the alloy restorations which influence the corrosion resistance [27-30], the structure formed during casting [20] and the subsequent combustion/firing protocols [20, 31].

Here we conducted research on components of metal alloys Co-Cr and Ni-Cr of the same shape/dimensions of metal-ceramic dentures, to investigate the effect of reheating the structure of alloys on the successive layers of ceramic deposited. We analyzed the samples comparing as cast dentures to same shape/dimensions dentures with simulated firing of the ceramics.

Experimental part

In this study were considered three alloy types: A. Co-Cr based (wt. % Co 64, Cr 21, Mo 6, W 6, Fe, Mn and Si < 1); B. Ni-Cr based (wt. % Ni 58, Cr 27, Mo 8, Si 2); and C. Ni-Cr based (wt. % Ni 63, Cr 25, Mo 9, Si 2, Nb 1). For each alloy were made two samples, each consisting of two interlocked elements: a crown shell and a body bridge.

The samples were codified as follows:

- A1: dental alloy Co-Cr as cast
- A2: dental alloy Co-Cr after ceramic firing simulation through heat treatments
- B1: dental alloy Ni-Cr 1 as cast
- B2: dental alloy Ni-Cr 1 after ceramic firing simulation through heat treatments
- C1: dental alloy Ni-Cr 2 as cast
- C2: dental alloy Ni-Cr 2 after ceramic firing simulation through heat treatments.

All the 6 samples we embedded in acrylic resin and were prepared for metallographic observations.

Metallographic preparation consisted of successive polishing on sanding paper grit 180-320-500-800-1000-1200 mm, and suspension of diamond 5, 3 and 1μm on cloth. Subsequent the prepared surfaces were etched electrochemical in oxalic acid solution 5%, 5 sec at 2 V.

The metallographic observations, normal and DIC (Differential Interference Contrast) were made with an optical microscope Reichert Univar® from Biomaterials Research Centre UPB-BIOMAT®.

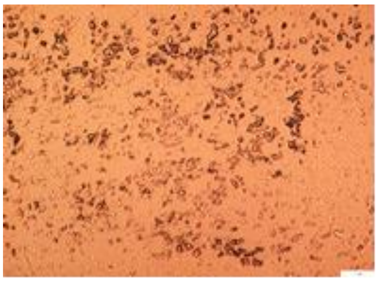
Results and discussions

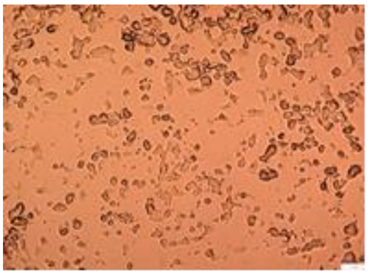
For samples A1 – as cast; crown and bridge - magnification 200×, the microstructure consists of solid solution and can be observed intermetallic compounds. In DIC image can observe slight tendency of dendrite formations in the crown and more relevant in the bridge (thicker and with more volume of material).

With magnification 500× one can observe that inter-dendritic distances are in the range 14…25μm for the bridge sample. One can be noted the presence of intermetallic compounds (figure 1).

For samples A2 – firing simulation by heat treatments; crown and bridge – magnification 200× one can observe the slight dissolution of intermetallic compounds between interdendritic arms.

With magnification 500× there are revealed that intermetallic compounds separations are discontinuous, also as a result of elements diffusion in solid state during heat treatments. The interdendritic distance is now 10…18 μm for the crown and 18…36 μm for the bridge. One can observe that dendrites are homogenized, even if there persist interdendritic intermetallic compounds (figure 2).


Crown A1; 200×


Crown A1; 500×


Crown A1-DIC 500×


Bridge A1; 200×

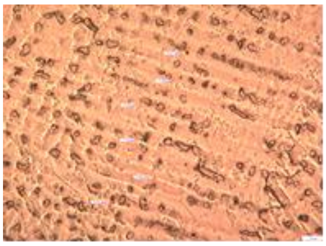

Bridge A1; 500×

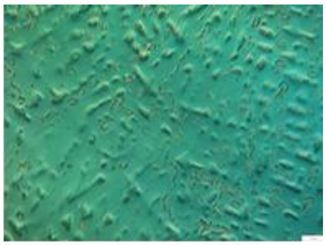

Bridge A1-DIC 500×

Figure 1.

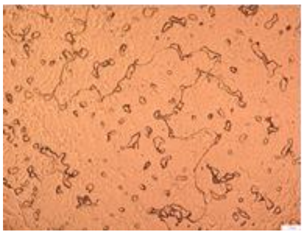
Now is clearly revealed the crystalline grains limits formation. Interdendritic segregation is less pronounced comparing with as cast microstructure, as an effect of solid state diffusion produced by heat treatments/firing.


Crown A2; 200×


Crown A2; 500×


Crown A2-DIC 500×


Bridge A2; 200×


Bridge A2; 500×

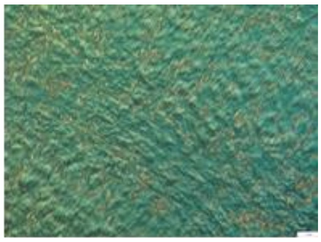
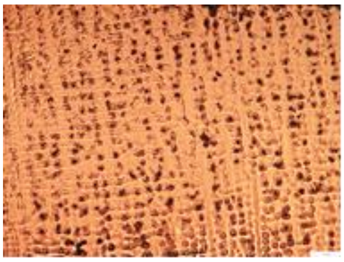
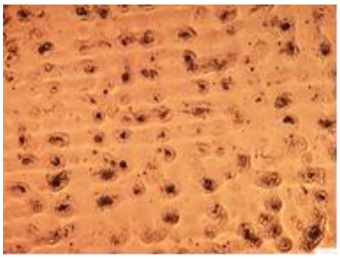
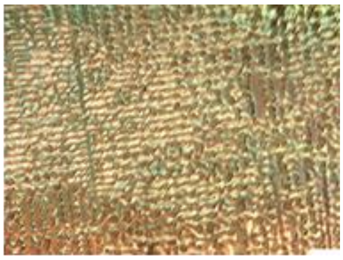

Bridge A2-DIC 500×

Figure 2.

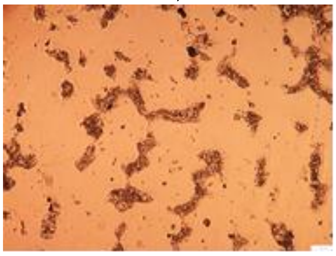
For B1 samples, the interdendritic arms distance is in the range of 60…90 µm for the bridge. For the crown there are evident only the solid solution non-homogeneous in as cast state. This dental alloy presents no intermetallic compounds (figure 3).


Crown B1; 200×


Crown B1; 500×


Crown B1-DIC 500x


Bridge B1; 200×


Bridge B1; 500×

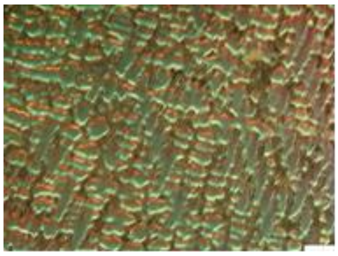
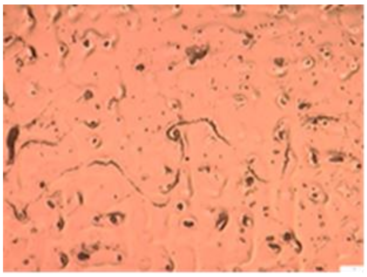

Bridge B1-DIC 500×

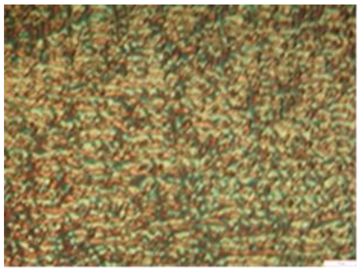
Figure 3.

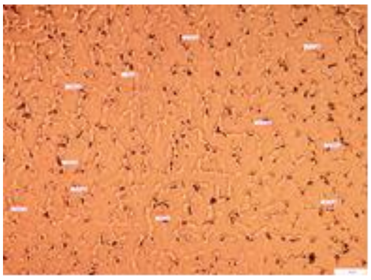
In DIC images one can observe more clear the solidification dendrites (in depth) and interdendritic zones (in relief).

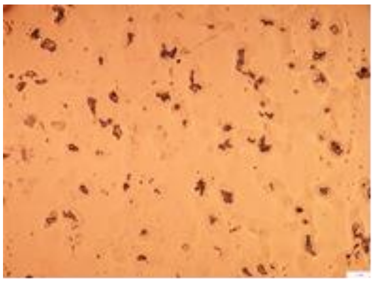
For the bridge in sample B2 (heat treated), the distance between dendrite arms is in the range 35…55 μm, and the crown is more homogenized. The primary dendrites are visible, but the secondary ones are hardly observed as a result of homogenization through heat treatments (figure 4).


Crown B2; 200×


Crown B2; 500×


Crown B2-DIC 500×


Bridge B2; 200×


Bridge B2; 500×

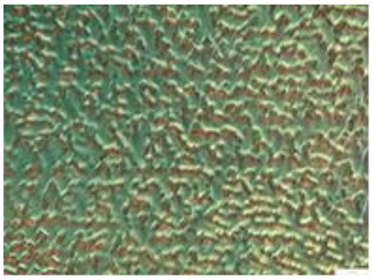
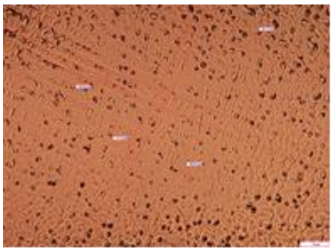

Bridge B2-DIC 500×

Figure 4.

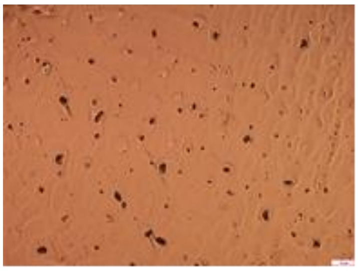
With higher magnification (500×), one can observe the grain limits; so the microstructure of the casted material was clearly homogenized.

In casted samples C1, the distance between secondary dendritic arms is in the range 30…35 μm for the crown and 35…55 μm for the bridge. The corresponding alloy for these samples, even in as cast state, has a microstructure less segregated (figure 5).

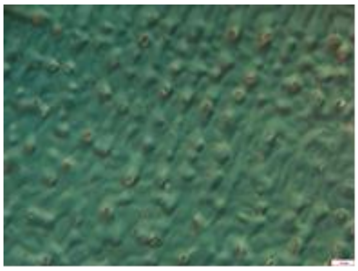
For the C2 samples, one can be observed a good homogenization after firing simulations through heat treatments (figure 6).



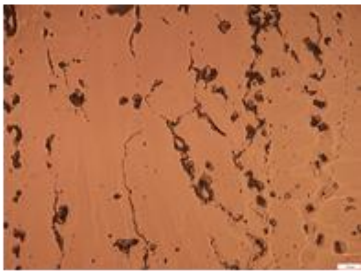
Crown C1; 200×



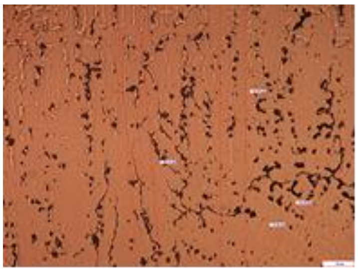
Crown C1; 500×



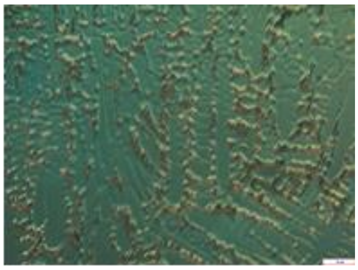
Crown C1-DIC 500×



Bridge C1; 200×

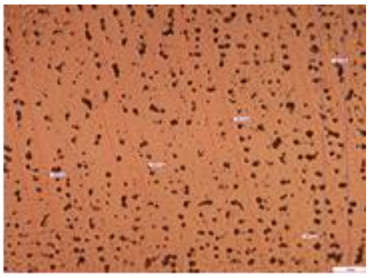


Bridge C1; 500×

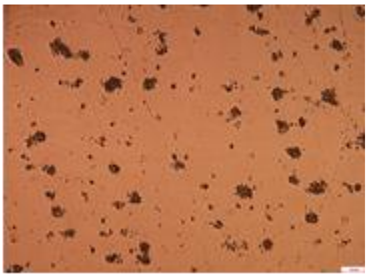


Bridge C1-DIC 500×

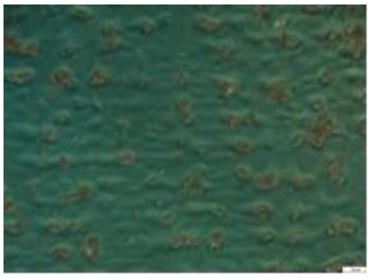
Figure 5.



Crown C2; 200×

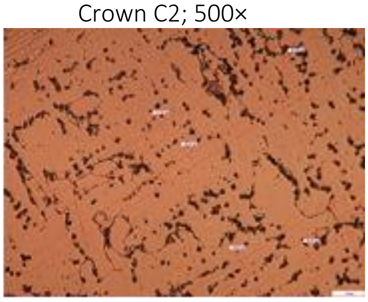


Crown C2; 500×

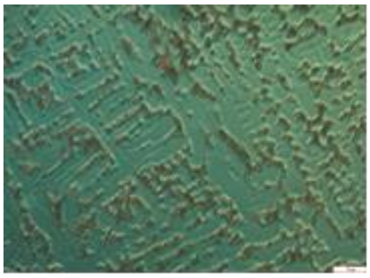


Crown C2-DIC 500×

Bridge C2; 200×



Bridge C2; 500×



Bridge C2-DIC 500×

Figure 6.

It is obvious the formation of a new generation of crystalline grains after firing simulation.

In all these images the casting defects could be pores due to solidifying contraction and micro-cracks specific to dendritic microstructures [32]. Only a few papers report about the influence of metal casting process on corrosion resistance of dental alloys [33, 34]. It seems that Co-Cr based alloy have more non-convenient microstructural aspects, than Ni-Cr based alloys.

In our study, there were applied thermal regimes similar to ceramic firing cycles, and microstructural and compositional homogenization of the samples were examined.

According to the results obtained in other research [35], thermal cycles for firing the ceramics acts favorably to metal component and allow for the homogeneity of the restoration.

The homogenization of the products diminish the contours of the dendrites due to the diffusion carried out in the solid state during firing.

Conclusions

Application of a heat treatment (annealing for homogenization) will produce the complete dissolution of the intermetallic compounds and so is possible to obtain a microstructure of thermodynamic equilibrium. This correspond to the ideal shape of uniform crystalline grains, compositional and dimensional homogeneous.

Applying the firing cycles of the different ceramic layers it manages to produce approximately similar effect, which leads to improved operational behavior of dental restorations.

As a result of compositional and structural homogenization, dental restorations supports better the mechanical associated with thermal stress mechanical, and, especially, the combined effect of corrosive effect on metal-ceramic restorations in the oral cavity.

Conflict of interest: None to declare.

References

1. Comaneanu RM, Hancu ID, Coman C, Hancu V, Barbu HM, Cotrut MC, Cernusca Mitariu M, Maris M, Comparative study on the corrosion of Ni-Cr and Co-Cr alloys in the presence of Ti6Al4V implant abutment. REV CHIM. (Bucharest), 2016;67(10):1940-4.
2. Bratu D, Nussbaum R. Bazele clinice şi tehnice ale protezării fi×e. București: Ed.Medicală; 2006. P.319-328.
3. Leinfelder K.F., New developments in resin restorative systems J Am Dent Assoc. 1997;128(5):573-81.
4. van Noort R, Brown D, Clarck EC, et al. Dental Materials: 1992 literature review. J.Dent. 1994;22(1):5-28.
5. Hancu V, Comaneanu RM, Coman C, Filipescu AG, Ghergic DL, Cotrut MC. In vitro studies regarding the corrosion resistance of NiCr and CoCr types dental alloys. REV CHIM. (Bucharest), 2014;65(6):706-9.
6. Mareci D, Sutiman D, Cretescu I, Cailean A, Rosca M. Electrochemical characterization of some cooper based dental materials in accelerated test solution. REV CHIM. (Bucharest), 2008;59(8):871-7.
7. Schweitzer PA. Corrosion engineering Handbook. 2nd edition. New York: CRC Press; 2007.P 96.
8. Shreir LL, Jarman RA, Burstein GT. Corrosion: Metal/Environment Reactions. Vol. 1. Boston:Newness-Butterworth; 2000. P. 237.
9. Zamfir S, Vidu R, Brinzoi V. Coroziunea materialelor metalice. București:Ed. Didactică şi pedagogică RA;1994. P.201.
10. Porojan S, Porojan L. Evaluation of Co-Cr dental alloys welds corrosion. REV CHIM. (Bucharest). 2015;66(3):357-9.
11. Minciuna MG, Vizureanu P, Achitei DC, Ghiban N, Sandu AV, Forna NC. Structural characterization of some COCRMo alloys with medical applications. REV CHIM. (Bucharest). 2014;65(3):335-8.
12. Giacomelli FC, Giacomelli C, Spinelli A. Behavior of Co–Cr–Mo biomaterial in simulated body fluid solutions studied by electrochemical and surface analysis techniques. J. Braz. Chem. Soc. 2004;15 (4):541 -7.
13. Hodgson AWE, Kurz S, Virtanen S, Fervel V, Olsson COA, Mischler S. Passive and transpassive behavior of CoCrMo in simulated biological solutions. Electrochimica Acta. 2004;49:2167 - 78.
14. Hsu RW, Yang C, Huang C, Chen Y. Electrochemical corrosion studies on Co–Cr–Mo implant alloys. Mater. Chem. Phys. 2005;93:531 - 8.
15. Kelly JR, Rose TC. Non-precious alloys for use in fi×ed prosthodontics J Prosthet Dent. 1983;49: 363 - 7.
16. Kocijan A, Milosev I, Pihlar B. Cobalt-based alloys for orthopedic applications studied by electrochemical and ×PS analysis. J Mater Sci Mater Med. 2004;15:643 - 50.
17. Metikos-Hukovic M, Babic R. Passivation and corrosion behaviors of cobalt and cobalt chromium–molibdenium. Corros Sci. 2007;49:3570 -9.
18. Roberts HW, Berzins DW, Moore BK, Charlton DG. Metal–ceramic alloys in dentistry: a review. J. Prosthodont, 2009;18:188 - 94.
19. Wataha JC. Biocompatibility of dental casting alloys: A review. J. Prosthet. Dent. 2000;83:223 - 34.
20. Wylie CM, Shelton RM, Fleming GJ, Davenport AJ. Corrosion of nickel-based dental casting alloys. Dent Mater. 2007;23:714 - 23.
21. Anthony DH, Burnett AP, Smith DL, Brooks MS. Shear test for measuring bonding in cast gold alloy-porcelain composites. J. Dent. Res. 1970;49:27 - 33.

22. Johnson T, van Noort R, Stokes CW. Surface analysis of porcelain fused to metal systems. Dent. Mater. 2006;22:330 - 7.
23. Bezzon OL, de Mattos MG, Ribeiro RF, Rollo JM. Effect of beryllium on the castability and resistance of metal-ceramic bonds in nickelchromium alloys. J Prosthet Dent. 1998;80:570 - 4.
24. Reclaru L, Unger RE, Kirkpatrick CJ, Susz C, Eschler PY, Zuercher MH, Antoniac I, Lüthy H. Ni–Cr based dental alloys - Ni release, corrosion and biological evaluation. Mater Sci Engineer C. 2012;32:1452 - 60.
25. Setcos JC, Babaei-Mahamani A, Di Silvio L, Mijör IA, Wilson NHF. The safety of nickel containing dental alloys, Dent. Mater. 2006;22(12):1163 - 68.
26. Wataha JC, Lockwood PE, Schedle A. Effect of silver, copper, mercury, and nickel ions on cellular proliferation during e×tended, low-dose e×posure. J Biomed Mater Res. 2000;52:360 - 4.
27. Ardlin BI, Dahl JE, Tibballs JE. Static immersion and irritation tests of dental metal-ceramic alloys. Eur J Oral Sci. 2005;113:83 - 9.
28. Elshahawy W, Watanabe I, Koike M. Elemental ion release from four different fi×ed prosthodontic materials. Dent Mater. 2009;25:976 - 81.
29. Hanawa T. Metal ion release from metal implants. Mater Sci Eng. 2004;24:745 - 52.
30. Huang TH, Ding SJ, Min Y, Kao CT. Metal ion release from new and recycled stainless steel brackets. Eur. J. Orthodont. 2004;26:171 - 7.
31. Lin HY, Bowers B, Wolan JT, Cai Z, Bumgardner JD. Metallurgical surface and corrosion analysis of Ni–Cr dental casting alloys before and after porcelain firing. Dent Mater. 2008;24:378 - 85.
32. Fossati A, Borgiolo F, Galvanetto E, Bacci T. Corrosion resistance properties of plasma nitrided Ti6Al4V10 alloy in nitric acid solutions. Corrosion Sci. 2004;46:917 - 27.
33. Kim SJ, Ko YM, Choe HC. Pitting corrosion of TiNi coated dental cast alloy with casting methods. Adv Mater Res. 2007;15(17):164 - 8.
34. Mulders C, Darwish M, Holze R. The influence of alloy composition and casting procedure upon the corrosion behaviour of dental alloys: An in vitro study. J Oral Rehab. 1996;23:825 - 31.
35. Hancu V, Comăneanu RM, Coman C, Târcolea M, Barbu HM, Bechir A, Miculescu F, Lorean A, Microstructure and Chemical Homogeneity of cast dental crowns made from CoCrMoW alloy and ceramic mass. REV CHIM. (Bucharest). 2015;66(9):1327-30.

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