ABSTRACTS of PUBLICATIONS
on DSc thesis

of Assoc. Prof. Tsanka Dimitrova Dikova PhD, MSc, Mech. Eng.

1. Individual publications

1.1. Publications in scientific journals, indexed in the world databases - Thomson Reuters, Scopus, Google Scholar etc.

Book chapter

1.1.1. ***Dikova T.*** *Properties of Co-Cr Dental Alloys Fabricated Using Additive Technologies.* In Biomaterials in Regenerative Medicine, Prof. Leszek A. Dobrzański (Ed.), 2018. InTech, DOI: 10.5772/intechopen.69718. Book ISBNs 978-9-53-513776-4, 978-9-53-513777-1

Abstract:

The aim of the present paper is to make a review of the properties of dental alloys, fabricated using Additive Technologies (AT). The microstructure and mechanical properties of Co-Cr alloys as well as the accuracy and surface roughness of dental constructions are discussed. In dentistry, two different approaches can be applied for production of metal frameworks using AT. According to the first one, the wax/polymeric cast patterns are fabricated by 3D printing, than the constructions are cast from dental alloy with as printed patterns. Through the second one, the metal framework is manufactured form powder alloy directly from 3D virtual model by Selective Electron Beam Melting (SEBM) or Selective Laser Melting (SLM). The microstructure and mechanical properties of Co-Cr dental alloys, cast using 3D printed patterns, are typical for cast alloys. Their dimensional and adjustment accuracy is higher comparing to constructions, produced by traditional lost-wax casting or by SLM. The surface roughness is higher than that of the samples, cast by conventional technology, but lower comparing to the SLM objects. The microstructure of SLM Co-Cr dental alloys is fine grained and more homogeneous comparing that of the cast alloys, which defines higher hardness and mechanical properties, higher wear and corrosion resistance.

Papers

1.1.2. ***Dikova T****, Bending fracture of Co-Cr dental bridges, produced by additive technologies: experimental investigation*. Procedia Structural Integrity, 2018 Dec; 13:461-468. https://doi.org/10.1016/j.prostr.2018.12.077 ; ISSN 2452-3216.

Abstract:

The aim of this paper is to investigate the fracture during bending test of Co-Cr dental bridges, produced by additive technologies. Three groups of samples (four-part dental bridges from 1-st premolar to 2-nd molar) were produced by conventional casting with handmade wax patterns, casting with 3D printed patterns and selective laser melting (SLM). The bending test was done using *Tira Test 2300 SE/50 kN* machine and especially designed appliance, ensuring loading closest to the actual during masticatory process. The loadings until cracking and fracture were evaluated. The fractured surfaces were investigated by optical microscopy. It was established that the SLM dental bridges of *Co212-f* alloy are being destroyed in 9.255 kN loading, which is commensurable with that for cracking of the samples, cast from *Biosil-F* alloy – 9.820 kN in conventional casting and 10.171 kN in casting with 3D printed patterns. The destruction of the cast Co-Cr bridges consists of three stages – crack initiation in the most loaded area, its growth and final fracture, while the destruction of the SLM samples suddenly occurs because of a network of cracks in the entire volume. The destruction type of the Co-Cr bridges, produced by SLM and casting, is identical - ductile, but the way that fracture occurs is different due to their structure. The specific layered macrostructure, the fine

microstructure with dendritic morphology, the phase composition – the presence of ε-phase and the typical defects of the SLM Co-Cr alloy define the fracture mechanism during bending.

1.1.3. ***Dikova T****, Production of high quality temporary crowns and bridges by stereolithography,* Scripta Scientifica Medicinae Dentalis. 2019, in publishing process.

Abstract

The aim of the present paper was to establish the peculiarities for production of high quality temporary crowns and bridges by stereolithography (SLA) with digital light projection (DLP). Two groups of samples – cubic (5 mm x 5 mm x 5 mm) and four-part dental bridges (1-st premolar to 2-nd molar) were printed with different layer thickness - 35 μm and 50 μm from *NextDent C+B* polymer using *RapidShape D30.*

It was established that for effective production of temporary crowns and bridges with high dimensional accuracy and surface smoothness, it is necessary to take into account the peculiarities of the 3D printing process and to make corrections still on the stage of the virtual model generating. Individual corrections of the dimensions along the separate axes of the virtual model has to be done with correction coefficients, depending on the construction type – crown or bridge. In order to obtain high smoothness, the construction should be positioned with vertical axes of the teeth parallel to the printing direction Z-axis. The number of the supports has to be increased (≥4 per tooth) for reduction of the deformations during 3D printing and final photopolymerization.

The findings in the present study could be very helpful in development of the proper construction design and technological process for improving the quality of the temporary restorations.

1.2. Papers in scientific journals and conferences' proceedings

1.2.1. ***Dikova Ts.,*** *Factors, influencing on the quality of Co-Cr dental alloys, cast using 3D printed patterns.*[in Bulgarian] Foundry 2017;1(1):58-62; WEB ISSN 2535-0188; PRINT ISSN 2535-017X.

Abstract:

The aim of the present paper is to study the factors, influencing on the quality of Co-Cr dental alloys, cast using 3D printed patterns. Three groups of factors are discussed: the properties of the materials for 3D printing, the special features of the 3D printing process and the peculiarities of the casting. As mainly polymers are used for 3D printing of cast patterns, the right material should be chosen, which burn without residue and have no thermal expansion. The main disadvantage of 3D printed patterns is their higher roughness, which depends on the type of 3D printing process, position of the objects towards the print direction and the layers thickness. In order to obtain castings with smooth surfaces, it is necessary to use cast patterns made by stereolithography with the possible minimum thickness of the layer. Each type of 3D printer uses a specific polymer type, therefore it is necessary the investment material to be selected depending on the polymer type. The heating regime of the casting mold is determined by the type of investment material and the alloy to be cast. To obtain a quality casting, all these dependencies must be strictly observed.

1.2.2. ***Dikova Ts.,*** *Density investigation of dental bridges, produced by selective laser melting.* [in Bulgarian] Proceedings if the Int Sci Conference "Industry 4,0", 13-16.12.2017, Borovets, Bulgaria, STUME. 2017 Dec;1(1):149-152; ISSN (Print) - 2535-0153 ISSN (Online) - 2535-0161.

Abstract:

Present paper deals with density investigation of four-part dental bridges, produced from Co-Cr alloy by Selective Laser Melting (SLM). Two methods were used: measuring the samples' density by liquid displacement method and defining the dense structure/pores ratio by CAD software. The comparative analysis was done with the density of bridges, cast conventionally with wax or 3D printed patterns. It was established that the density of the dental bridges, measured by the displacement method, was lower than the alloy's density and close for the three technologies - 7.86 g/cm3 of the conventionally cast, 8.03 g/cm3 of the constructions, cast with 3D printed patterns, and

8.13 g/cm3 of the SLM samples. The investigation of the dense structure/pores ratio by CAD software showed presence of dense structure 95.94% and 94.77% in the bridges, cast with wax or 3D printed patterns respectively. While this parameter for the SLM constructions was 87.47%, as 12.53% of the volume were pores. These results were proved by observation of the microstructure, which is porous of the SLM bridges and comparatively dense of the cast ones. Therefore, the liquid displacement method is not suitable for measuring the density of porous structures. For obtaining reliable results it is necessary to be combined with other methodologies.

2. Publications in scientific journals, indexed in the world databases – Thomson Reuters, Scopus, Google Scholar etc.

2.1. ***Dikova T***, Dzhendov D, Simov M, Katreva-Bozukova I, Angelova S, Pavlova D, Abadzhiev M, Tonchev T. *Modern trends in the development of the technologies for production of dental constructions*. *J of IMAB*. 2015 Oct-Dec;21(4):974-981. doi: http://dx.doi.org/10.5272/jimab.2015214.974 ISSN: 1312 773X (Online).

Abstract:

The aim of the present paper is to make a review of the modern trends in the development of the technologies for production of dental constructions. Three are the main trends in production technologies in dentistry last 30 years: digitalization, simulation and implementation of additive technologies. The simulation occurred first and due to the computers development it underwent fast progress from the mathematical calculations and analytical analysis to the 3D modeling and visualization. Thus Computer Aided Engineering (CAE) was developed, allowing dental constructions with optimal design to be produced by optimal technological regimes.

The first Computer Aided Design (CAD) – Computer Aided Manufacturing (CAM) systems were created in 1970s as a result of the digitalization. In this mode of operation at first virtual 3D model is generated by CAD, which then is used for production of the real construction by CAM. The CAD-CAM systems allow fabrication of dental restorations which is difficult or impossible to be manufactured by conventional technologies. The development of CAD unit runs from indirect scanning of the plaster model for obtaining data for the 3D model to direct scanning of the prosthesis area. While the development of CAM unit leads to direct manufacturing of the real dental construction using subtractive or additive technologies. The future development of the CAD-CAM systems as a whole characterizes with transition from closed to open access systems, which make them more flexible.

In the late 1980sthe new approach to the production of constructions appeared – by addition of material layer by layer. The additive technologies were developed. They characterize with building of one layer at a time from a powder or liquid that is bonded by means of melting, fusing or polymerization. Stereo lithography, fused deposition modeling, selective electron beam melting, laser powder forming and inkjet printing are the methods, mostly used in dentistry. Due to the great variety of the additive manufacturing processes various materials can be used for production of different dental constructions for application in many fields of dentistry.

The simulation, digitalization and implementation of additive technologies in dentistry led to fast development of the technologies for production of dental constructions last decade. As a result many of manual operations were eliminated, the constructions' accuracy increased and the production time and costs decreased.

2.2. ***Dikova Ts.,*** Dzh. Dzhendov, M. Simov, *Microstructure and Hardness of Fixed Dental Prostheses Manufactured by Additive Technologies*, Journal of Achievements in Mechanical and Materials Engineering, 2015 Aug;71(2):60-69; ISSN: 1734-8412.

Abstract

Purpose: The additive technologies characterize with building of one layer at a time from a powder or liquid that is bonded by means of melting, fusing or polymerization. The methods, mostly used in dentistry, include selective laser sintering, selective laser melting and 3D printing. The aim

of the present paper is to investigate the microstructure and hardness of fixed dental prostheses produced by three different technologies.

Methodology: Four-part dental bridges were manufactured of Co-Cr alloy by standard lost-wax process, casting of 3D printed wax models and Selective Laser Melting (SLM). The microstructure was investigated by optical microscopy and SEM. EDX and EPMA analyses and Vickers microhardness measurements was done.

Findings: It was established that the microstructure of cast samples is dense, inhomogeneous, consisting of large grains with dendrite morphology, while the microstructure of the SLM bridges is porous. Pores, elongated along the direction of the melted layers were observed. The microhardness investigations showed highest average hardness of the samples, produced by SLM (356HV-407HV), followed by the hardness of the samples, cast by 3D printed models (327HV-343HV) and these, manufactured by standard lost-wax process (251HV-274HV). The measurements along depth of the samples showed nearly even microhardness distribution in the bridges, produced by SLM, and fluctuations of the microhardness values along the depth of the cast bridges due to the inhomogeneous microstructure.

Research limitations/implications: As the additive technologies for production of dental restorations from wax, polymers and metal alloys are developed last years, additional investigations are needed for development of more precise technological regimes.

Originality: The comparison between the microstructure and hardness of dental prostheses made by lost-wax process and SLM reveals the peculiarities of the constructions produced by new technology.

2.3. ***Dikova T***, Dzhendov D, Katreva I, Pavlova D, Simov M, Angelova S, Abadzhiev M, Tonchev T. *Posibilities of 3D printer Rapidshape D30 for manufacturing of cubic samples.* Scripta Scientifica Medicinae Dentalis. 2016;2(1):9-15; DOI: http://dx.doi.org/10.14748/ssmd.v1i1.1565 ; ISSN 2367-7236 (Print) ISSN 2367-7244 (Online).

Abstract

The purpose of the present paper is to establish experimentally the possibilities of the 3D printer Rapidshape D30 for manufacturing of standard cubic samples from different types of monomers and to evaluate their geometrical accuracy and roughness.

Standard cubic samples with dimensions 5 mm x 5 mm x 5 mm were printed from all the materials, given by the producer, in two ways of dimensional orientation according to the base – horizontally and inclined at 45^{o}. They were manufactured with 3D printer Rapidshape D30, working on the stereolithography principle with LED light.

It was established that:

- The samples, made of NextDent Surgical Guide, have the highest dimensional accuracy and the lowest deviation interval in the both ways of placement. This polymer characterizes with the highest thickness of the polymerization layer – 0,100 mm, but it is transparent, thus ensuring the entire polymerization throughout the whole layer's depth. NextDent C+B, intended for manufacturing of temporary crowns and bridges, occupies a middle position compared to the other 6 materials.
- Nearly in all the materials the surface roughness of the cub with horizontal placement is lower than that of the cub printed inclined (average values of Ra 0,46-2,69 μm and Ra 1,74-2,77 respectively).
- In 3D printing the surface roughness depends on the thickness of the polymerization layer and the inclination to the printing direction. The thicker the polymerization layer and the larger the slope, the higher the surface roughness.

2.4. ***Dikova Ts***., Dzhendov D., Katreva I., Pavlova D. *Accuracy of polymeric dental bridges manufactured by stereolithography.* Archives of Materials Science and Engineering. 2016; 78(1):29-36; ISSN: 1897-2764.

Abstract

Purpose of this paper is to investigate the accuracy of dental bridges produced via digital light projection stereolithography process.

Design/methodology/approach: 3D printer Rapidshape D30 was used for manufacturing of two groups of samples – temporary four-part bridges and cast patterns for permanent bridges. The temporary bridges were made of NextDent C+B polymer, while the cast patterns - of NextDent Cast. The samples were manufactured with different layer's thickness (0.035 mm and 0.050 mm). The geometrical and adjusting accuracy were investigated by measuring of the samples' dimensions and silicone probe, while the surface roughness was studied out by profile meter and optical microscopy.

Findings: It was established that the dimensions of the temporary bridges and the cast patterns, printed with layer thickness 50 μm, are larger than that of the virtual 3D model with 0.1-0.3 mm. Decreasing the layer thickness to 35 μm leads to 0.29%-1.10% smaller sizes of dental bridges and cast patterns in comparison to that of the virtual 3D model. The average roughness deviation Ra of the 3D printed temporary bridges and cast patterns is larger than that of the initial model. As the surface roughness depends on the layer's thickness, the samples with 0.035 mm layer characterize with lower Ra values. The silicone probe shows that the temporary bridges as well as the cast patterns need additional adjusting in the dental office or corrections during design of the virtual 3D model and 3D printing process in the dental laboratory.

Research limitations/implications: As the additive technologies for production of dental restorations from wax, polymers and metal alloys are developed last years, additional investigations are needed for development of more precise technological regimes.

Practical implications: The stereolithography as part of CAD/CAM manufacturing process characterizes with high accuracy as a whole. But present study reveals that additional adjusting or preliminary corrections of the design of 3D printing process are needed for dental constructions produced by SLA.

Originality/value: The geometrical and fitting accuracy as well as the surface roughness of dental bridges, produced by stereolithography were evaluated. The data, shown in the present study, will help dentists and dental technicians to precise the manufacturing regimes for production of dental constructions with high accuracy.

2.5. Vasilev T, ***T Dikova***, D Dzhendov, E Ivanova, *Simulations of Cast and Selective Laser Melted Dental Bridges with Chewing Load*, Scripta Scientifica Medicinae Dentalis. 2016;2(2):7-11. DOI: http://dx.doi.org/10.14748/ssmd.v2i2.1909 ISSN 2367-7236 (Print) ISSN 2367-7244 (Online).

Abstract

The aim of the present paper is to evaluate and compare the strength properties and deformation characteristics of cast and Selective Laser Melted (SLM) Co-Cr dental alloys by using CAD/CAE software. The *Solid Works Simulation* software is used for simulation of chewing loading of the virtual 3D model of four-part dental bridge. Two Co-Cr dental alloys, cast and SLM were used in this study. During simulation process by means of linear static analysis the displacements, strains, stresses, and reaction forces under the effect of the applied load were calculated. As a result, the equivalent von Mises stresses, Factor Of Safety (FOS) and displacements were evaluated in this study.

It was established that the highest values of the equivalent von Mises stresses of cast and SLM bridges are situated in the connectors between the teeth, i.e. the zones with the lowest areas of the cross sections. They are in the range 95-162 MPa, which is lower than the stress limits for the both materials. The minimum FOS of the both materials is higher than 1. In the cast bridges it is 1.32-2.64 in the zones with the highest loading, while in the SLM samples it is 2.61-5.68. As FOS shows the reserve strength of the material for the applied load, it is obvious that the SLM bridge possesses twice

higher reserve strength. This allows optimization of the construction, economy of material and possibility for manufacturing of objects with porous structures.

2.6. ***Dikova T***, Vasilev T, D Dzhendov, E Ivanova, *Investigation the fitting accuracy of cast and SLM Co-Cr dental bridges using CAD software*, J of IMAB. 2017 Jul-Sep;23(3):1688-1696; DOI: 10.5272/jimab.2017233.1688; ISSN: 1312 773X (Online).

Abstract:

The aim of the present paper is to investigate the fitting accuracy of Co-Cr dental bridges, manufactured by three technologies, with newly developed method using CAD software. The four-part dental bridges of Co-Cr alloys were produced by conventional casting of wax models, casting with 3D printed patterns and selective laser melting. The marginal and internal fit of dental bridges was studied out by two methods – silicone replica test and CAD software. As the silicone replica test characterizes with comparatively low accuracy, a new methodology for investigation the fitting accuracy of dental bridges was developed based on the *SolidWorks* CAD software. The newly developed method allows study of the marginal and internal adaptation in unlimited directions and high accuracy. Investigation the marginal fit and internal adaptation of Co-Cr four-part dental bridges by the two methods show that the technological process strongly influences the fitting accuracy of dental restorations. The fitting accuracy of the bridges, cast with 3D printed patterns, is the highest, followed by the SLM and conventionally cast bridges. The marginal fit of the three groups of bridges is in the clinically acceptable range. The internal gap values vary in different regions – it is highest in the occlusal surfaces, followed by that in the marginal and axial areas. The higher fitting accuracy of the bridges, manufactured by casting with 3D printed patterns and SLM, compared to the conventionally cast bridges is good precondition for their successful implementation in the dental offices and laboratories.

2.7. ***Dikova T.,*** Dzhendov D., Katreva I., Tonchev T. *Study the precision of fixed partial dentures of Co-Cr alloys cast over 3D printed prototypes.* Archives of Materials Science and Engineering. 2018 March;90(1):25-32; ISSN: 1897-2764.

Abstract

Purpose of this paper is to investigate the accuracy of Co-Cr dental bridges, manufactured using 3D printed cast patterns.

Design/methodology/approach: Four-unit dental bridges are fabricated from the alloys *i-Alloy* and *Biosil-f* by lost-wax process. The polymeric cast patterns are 3D printed with different layer's thickness (13 μm, 35 μm and 50 μm). Two 3D printers are used: stereolithographic "*Rapidshape D30*" and ink-jet "*Solidscape 66+*". The geometrical and fitting accuracy as well as the surface roughness are investigated.

Findings: It is established that Co-Cr bridges, casted from 3D printed patterns with 50 μm layer thickness, characterize with the largest dimensions - 3.30%-9.14% larger than those of the base model. Decreasing the layer thickness leads to dimensional reduction. The dimensions of the bridges, casted on patterns with 13 μm layer thickness, are 0.17%-2.86% smaller compared to the primary model. The average roughness deviation *Ra* of the surface of Co-Cr bridges, manufactured using 3D printed patterns, is 3-4 times higher in comparison to the bridge-base model. The greater the layer thickness of the patterns, the higher *Ra* of the bridges. The silicone replica test shows 0.1-0.2 mm irregular gap between the bridge retainers and abutments of the cast patterns and Co-Cr bridges.

Research limitations/implications: Highly precise prosthetic constructions, casted from 3D printed patterns, can be produced only if the specific features of the 3D printed objects are taken in consideration.

Practical implications: Present research has shown that the lower the thickness of the printed layer of cast patterns, the higher the dimensional accuracy and the lower the surface roughness.

Originality/value: The findings in this study will help specialist in dental clinics and laboratories to choose the right equipment and optimal technological regimes for production of cast patterns with high accuracy and low surface roughness for casting of precise dental constructions.

2.8. Katreva I, ***Dikova T,*** Tonchev T. *3D printing – an alternative of conventional crown fabrication: a case report.* J of IMAB. 2018 Apr 1;24(2):2048-54. DOI: 10.5272/jimab.2018242.2048; ISSN: 1312-773X (Online).

Abstract

The present paper is a case report of prosthetic treatment built upon 3D technologies for manufacturing of dental restorations.

The case shows laboratory protocol of 3D printed full coverage provisional crowns and cast patterns for press ceramic crowns for a patient with need of replacement of the old prosthetic constructions of his upper left first and second molars. The working process is presented in details at each step, starting with the impression scanning into the *3 Shape D750* laboratory scanner, throughout the virtual constructing (CAD) and the result - additive manufacturing of models, patterns for press ceramic crowns as well as provisional crowns in the 3D printing machine *Rapidshape D30*.

One of the most frequently applied additive technology in the dental field- the stereolithographic approach, is compared to conventional crown fabrication. Thus it appears to be clear that advantages of 3D printing are much more. Among most important are: time saving, precise accuracy and fitting of the constructions, no risk of distortions and laboratory mistakes, production of complex shapes with no need of special tools or gypsum working models with removable dies, almost no waste material, etc.

2.9. ***Dikova Ts.,*** Dolgov N., Vasilev T., Katreva I. *Adhesion strength of ceramic coatings to dental Ni-Cr alloy fabricated by casting with 3D printed patterns* [in Russian] Deformacia I razrushenie materialov. 2018 Sep.;9:33-39; ISSN 1814-4632.

Abstract

Experimental investigation results of the adhesion strength of IPS InLine ceramic to the dental cast Ni—Cr alloy Wiron light are presented. Tensile tests were carried out for flat coated specimens. The numerical simulation and the multicriterial optimization by MADMML software were also performed. The cast patterns were printed at angles from 0° up to 90° with the layer thickness 35 μm and 50 μm, using the 3D printer Rapidshape D30. It was found out that the 3D printing with optimal conditions ensures the adhesion strength of ceramic coating 77.9—79.9 MPa.

2.10. ***Dikova T.,*** Vasilev T. *Bending fracture of Co-Cr dental bridges, produced by additive technologies: simulation analysis and test.* Engineering Fracture Mechanics, под печат.

Abstract

Present paper deals with investigation bending fracture of Co-Cr four-part dental bridges by simulation analysis and test. Samples were fabricated by selective laser melting (SLM), casting with 3D printed patterns and conventional lost-wax process. It was established that distribution and magnitude of displacements, normal and equivalent stresses are similar for the alloys produced by SLM and casting. Highest normal and equivalent stresses are located at connectors and cervical area of the pontics. Stresses distribution indicated the possible failure site - connector between two pontics. Simulation analysis, proven by the experiment, gave adequate model of bending fracture of four-unit dental bridges.

2.11. ***Dikova T.,*** Vasilev T., Dolgov N. *Failure of ceramic coatings on cast and selective laser melted Co-C r dental alloys under tensile test: Experiment and finite element analysis*. Engineering Failure Analysis, под печат.

Abstract

Present paper deals with investigation the failure of ceramic coatings on cast and selective laser melted (SLM) Co-Cr dental alloys by tensile test and finite element analysis (FEA). It is established that the failure mode of porcelain coatings is mixed/cohesive in SLM alloy and mixed/adhesive in cast. In both alloys, maximum shear and normal stresses are concentrated at coating free edge on the porcelain-metal interface. Stresses distribution indicates the possible sites of coating fracture

initiation and the way it will start - adhesively in the cast alloy due to lower bond strength and cohesively for SLM alloy. Coating failure is cohesive along the sample's length, due to change of maximum stresses location from the coating free edge through its thickness to the surface. The FEA gave an adequate explanation of the failure mechanism of porcelain coatings on cast and SLM Co-Cr dental alloys upon tensile test.

3. Papers in scientific journals and conferences' proceedings

3.1. Dzhendov D., Pavlova D., Simov M., Marinov N., Sofronov Y., Diokva Ts., Todorov G., Kalachev Y. Geometrical accuracy of fixed partial dentures manufactured by additive technologies. [in Bulgarian] Proceedings of the 8th Int. Sci. Conference for young scientists "Technical Science and Industrial Management", 15-16.09.2014, Varna, Bulgaria, STUME. 2014;1:13-17; ISSN 1310-3946.

Abstract

The aim of the present paper is to investigate the geometrical accuracy of fixed dental prostheses, manufactured by additive technologies. Four-part dental bridges were produced of Co-Cr alloy by three different techniques. The first one includes standard lost-wax technology, using silicon key for wax models manufacturing. During the second, wax models, produced by prototyping technology, were used for casting of the metal bridges. The last samples were produced directly from 3D model by Selective Laser Melting (SLM). The elements of the all samples were measured and their accuracy was estimated. The adjustment accuracy was evaluated by silicone test and the surface roughness was investigated by profile meter and optical microscopy. It was established that the average sizes of the bridges, produced by the classic technology are 0,1-0,2mm larger than that of the base model. While the average sizes of the samples, manufactured by the rest two technologies are smaller with about 0,1mm (wax prototyping technology) and up to 0,23mm (SLM) comparing to that of the base model. The fixed prostheses, cast by models, produced by wax prototyping technology, possess relatively satisfactory roughness and the highest accuracy of the shape, sizes and adjustment. The SLM bridges characterize with the highest roughness and comparatively satisfactory adjustment accuracy. The highest roughness and the teeth morphology does not allow their masticatory surfaces to be finished with no defects, so SLM technology is not quite suitable for all metal restorations. But the rough surfaces of as received SLM dental bridges make this technology very suitable for production of metal-ceramic restorations.

3.2. ***Dikova Ts***., Dzhendov D., Simov M., Pavlova D. *Defects of dental bridges, manufactured by casting and selective laser melting*, Nauchni izvestia, STUME, 2015 April;3(166):82-86; ISSN 1310-3946.

Abstract

The aim of the present paper is to investigate the surface and microstructural defects of four-part dental bridges, manufactured of Co-Cr alloy by three different technologies: standard lost-wax casting, using silicon key for wax models preparation; casting of wax models, produced by prototyping technology; Selective Laser Melting (SLM). The surface and microstructural defects were observed by optical microscopy, while the surface roughness was investigated by profile meter. It was established that the defects of the dental bridges were typical for the technology used. Draws of about 0,5mm – 3,5mm on the surface of the bridge bodies are the most characteristic for the castings, while pores and laminations of 0,1mm-1,2mm are most typical for the constructions, produced by SLM. The surface roughness also is influenced by the technology used. Thus the bridges produced by lost-wax process characterize with the smoothest surface (Ra=1,312μm), followed by that, casted of prototyped wax models (Ra=3,387μm), while the highest roughness was found on the surface of the bridges produced by SLM (Ra =4,24μm). The defects of dental bridges can be eliminated by strict compliance with the operation rules and proper adjustment and selection of the technological regimes.

3.3. Dolgov N.A., ***Dikova Ts***., Dzhendov D., Pavlova D., Simov M. *Mechanical Properties of Dental Co-Cr Alloys Fabricated via Casting and Selective Laser Melting*. Int. Journal "Materials Science. Non-Equilibrium Phase Transformations". 2016;2(3):3-7; Print ISSN 2367-749X ; Online ISSN 2534-8477.

Abstract

The aim of the present paper is to investigate the mechanical properties (hardness and tensile strength) of dental Co-Cr alloys fabricated via casting and selective laser melting (SLM). Two groups of metallic specimens (four-part dental bridges and standard tensile test specimens) made of Co–Cr dental alloys were produced by lost-wax casting and SLM processes. Vickers hardness distribution along the depth of the dental bridges as well as the Rockwell hardness and tensile strength of the samples were studied out. The hardness of Co–Cr dental alloys are dependent on the manufacturing technique employed. It was established that the average Vickers hardness of the samples, produced by SLM, was higher than that of the cast samples 382 HV and 335 HV respectively. The nearly even hardness distribution in the bridges, produced by SLM, and fluctuations of the hardness values along the depth of the cast bridges were observed. The Rockwell measurements confirmed the higher hardness of the SLM samples – 39 HRC in comparison with that of the cast ones – 33 HRC. The tensile strength is in good agreement with the hardness values. Due to the unique microstructure, the yield strength and tensile strength for the SLM samples were higher than those of the as-cast alloy.

3.4. Atapek H., ***Dikova Ts.,*** Aktaş G., Polat Ş., Dzhendov Dzh., Pavlova D. *Tribo-Corrosion Behavior of Cast and Selective Laser Melted Co-Cr Alloy for Dental Applications*, Int. Journal "Machines, Technologies, Materials". 2016;10(12):61-64; Print ISSN 1313-0226, Online ISSN 1314-507X.

Abstract

Cobalt-chromium based alloys are widely used in dental applications due to their excellent mechanical properties, high corrosion resistance and good biocompatibility. Although they are generally fabricated by casting for dental restorations, recently selective laser melting (SLM) has become an attractive production method since it allows complex geometries. Recent studies revealed that Co-Cr alloys formed by SLM, provided better corrosion resistance as well.

In this study, tribo-corrosion behavior of a Co-Cr-Mo alloy produced by casting (Biosil-Degudent) was compared with the one (Co212-f ASTM F75) produced by SLM. The wear properties were investigated by tribo-corrosion tests in a Fusayama-Meyer artificial saliva solution using a "ball-on-disc" type tribometer. Polished surfaces were tested against zirconia balls at the same sliding speed, distance and load. Friction coefficient values were determined and the worn surfaces were evaluated using microscopes to compare the wear and tribo-corrosion resistance through wear tracks. SLM proved to be a promising manufacturing method for dental applications.

3.5. ***Dikova T***, Dzhendov D, Katreva I, Pavlova D, Tonchev T, Doychinova M. *Geometry and Surface Roughness of Polymeric Samples Produced by Stereolithography*, Int. Journal "Machines, Technologies, Materials". 2017;11(4):201-205; Print ISSN 1313-0226, Online ISSN 1314-507X.

Abstract

The purpose of the present paper is to evaluate the geometric accuracy and surface roughness of polymeric samples manufactured by Digital Light Projection (DLP) Stereolithography. The standard cubic samples with dimensions 5 mm x 5 mm x 5 mm were printed of two polymers: NextDent C+B (white-yellowish color A3.5, VITA shade guide) and NextDent Cast (dark-red color), in two ways of placement to the base – horizontally and inclined at 45°. The samples were printed with two different layer's thickness – 35 μm and 50 μm. It was established that the samples of both polymers, manufactured in horizontal position with the lower layer's thickness (35 μm) possess highest dimensional accuracy and lowest interval of deviation. The most accurate are the dimesons parallel to the basis, while these, parallel or inclined to the print direction, have the highest deviations. The interval of the deviations of the dimensions of samples, manufactured inclined at 45°, is nearly

2-3 times higher, as the interval of the samples, made of NextDent Cast, is more than 50% higher than that of NextDent C+B. The horizontally printed samples have 1.5-2 times lower surface roughness compared to the samples, printed inclined at 45^{o}. The surface roughness of the samples, made of NextDent Cast, is 30-50% higher than that of NextDent C+B independently of the layer's thickness. The increase of the thickness from 35 μm to 50 μm leads to 1.5-2 times higher surface roughness in the two samples' positions. The optical properties of both polymers in the research strongly influence the geometric characteristics, dimensional accuracy and surface roughness of the objects, manufactured by DLP stereolithography.

3.6. ***Dikova T***., Dolgov N., Dzhendov D., Simov M. *Adhesion strength evaluation of ceramic coatings on cast and selective laser melted Co-Cr dental alloys using tensile specimens*, Int. Journal "Materials Science. Non-Equilibrium Phase Transformations". 2017;3(2): 49-52; Print ISSN 2367-749X ; Online ISSN 2534-8477

Abstract:

Studying the fracture characteristics of porcelain coatings plays a main role in selection of materials for metal-ceramic restorations. The aim of this work is to study the effect of the substrate manufacturing process on the adherence of the porcelain. The coatings of porcelain IPS.Inline (Ivoclar Vivadent) are fused onto dental Co-Cr alloys fabricated via casting (Biosil F) and Selective Laser Melting (SLM) (Co212-f). The adhesion strength of the ceramic coatings is studied under tensile load of flat specimens. The interfacial shear strength is determined using experimental results. The shear stress distributions in the metal-ceramic interface at the critical load are evaluated by analytical approach. It is established that the interfacial shear strength values of ceramic coating are 67.5 MPa for cast Biosil F alloy and 83.8 MPa for SLM Co212-f alloy. The higher shear strength of the porcelain to the SLM samples is due to the nearly two times higher surface roughness, which is reason for increasing both the mechanical and the chemical adhesion. The nature of the fracture of the ceramic coating on the Co-Cr alloys, produced by casting and SLM, is similar and is mixed adhesive–cohesive mode. The higher adhesion strength of the porcelain coating to the SLM dental alloy is a good precondition for the SLM application in production of metal-ceramic fixed partial dentures for areas with heavy loads.

3.7. Vasilev T., ***Dikova Ts.,*** Dzhendov D., Ivanova E. *New methodology for measuring the fitting gap of fixed partial dentures using CAD software*. [in Bulgarian], Proceeding of the 3rd Int. Sci Conference "Materials Science. Nonequilibrium Phase Transformations", 11-14.09.2017, Varna, Bulgaria, STUME. 2017 Sep;1(1):88-91; ISSN (Print) - 2535-0218 ; ISSN (Online) - 2535-02.

Abstract

The necessity of precise estimation of the gap between the crowns-retainers and abutments of dental bridges requires the development of new methods for their measurement. The introduction of rapid prototyping technologies, including 3D scanning and printing, enables trouble-free creation of virtual models of complex objects in terms of form. The determining of the gap between the bridges and abutment structures in CAD systems leads to difficulties mainly due to their complex shapes. The new methodology, based on engineering CAD software, was developed in this study, which overcome these difficulties. By applying the proposed approach for virtual adjusting between the dental constructions, it is possible to determine the gap between the bridge-retainers and the abutments in enclosed spaces, which are alternatively determined by indirect methods. The main advantages of the new methodology are: 1) complete tracking of the variation of the distance between the surfaces of the bridge-retainers and the abutments; 2) measurement of distances between the surfaces along the three axes and perpendicular; and 3) higher accuracy of the measurements.

3.8. Vasilev T., ***Dikova Ts.,*** Ivanova E. *Methodology for designing of appliance for bending test of four-part dental bridges*. [in Bulgarian] Proceeding of the Int. Sci. Conference "Industry 4,0", 13-16.12.2017, Borovets, Bulgaria, STUME. 2017 Dec;1(1):125-128; ISSN (Print) - 2535-0153 ISSN (Online) - 2535-0161.

Abstract

The four-part dental bridges from 1st premolar to 2nd molar are the most loaded during the chewing process. In addition, they are characterized by complex geometry of the teeth surface and complicated way of load distribution. The aim of the present paper is to develop a methodology for designing of appliance for bending test of four-part dental bridges that achieves the load of the bridge bodies close to the actual load. The using of CAD software allowed determining the shape and sizes of the pistons, the distance between the centers in the two main directions and the angle, at which the device must be located relative to the test specimen. The designed device provides contacts between the spherical tips of the punches and the teeth - bridge bodies in the most loaded areas in occlusion and a loading scheme that only produces normal stresses in the bridge construction during bending. As a result, appliance for bending test of four-part dental bridges was designed, produced and used in the next experiment.

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(Assoc. Prof. T. Dikova)