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The metallic component of fixed partial dentures, between classic and modern

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GENERAL PART

1. The metallic component of fixed partial dentures, between classic and modern.
Selective laser sintering and melting of metal powders

Introduction

This chapter treats the basic aspects of the laser sintering-melting process of metal powders (SLS/SLM). The main process of the rapid prototyping (RP) used for obtaining metal parts are reviewed in the beginning. Another section will refer to the general process of laser sintering/melting and its particularities are discussed in the special part of the thesis. The procedures for obtaining the metallic parts are described and the metallic powders available on the market are reviewed.

In order to understand and control the SLS/SLM process, it is important to know the physical phenomena that occur. The necessary knowledge come from different industry branches such as the conventional metallurgy, laser technology used in metallurgy etc. One of the first physical phenomena which occur in the SLS/SLM process is the heat transfer that results from the movement of the laser beam.

Another phenomena described is the binding of metal particles under laser radiation followed by the presentation of the different welding mechanism specific for the SLS/SLM process. The third aspect which influences the quality of the finite metal parts is the behavior of the metallic particles in the liquid phase of the melting process. The theory of evaporation which occurs following a high intensive radiation of the laser beam can be included. The effect of this theory over the process of SLS/SLM together with the high temperatures effects from the process is also described. Finally, aspects regarding the microstructures of the metallic components that are subject to thermal treatments and also cooling processes are described.

Rapid prototyping process

Manufacturing parts by layer manufacturing technique is generically known as rapid prototyping and it is a 20 years old technology. Solid objects are made with this technique over virtual models realized in CAD. This technique is known as additive manufacturing, solid-free form fabrication, digital manufacturing or e-manufacturing. Fabrication of the metallic parts with this digital technology is comprised in the CAD/CAM concept. The CAM component of the process comprises capturing the data with the scanner and the digital design of the part and the CAD component consists in manufacturing the part by the help of the computer (RP).

Surface reconstruction techniques

The digital data are converted in standard format so that data can be processed using CAD/CAM systems. This chapter presents the way that the obtained data are processed in useful information and formatted for the digital design and manufacturing.

Process description of Selective laser sintering / melting (SLS/SLM)

The process of selective laser sintering/melting was developed in the late 80`s. This process can fabricate ceramic, metal and polymer parts. However, it should be noted that in general it is not possible to process these materials on the same machine since they require different laser characteristics. Most machines are equipped with a Nd:YAG or CO2 laser having a Gaussian energy distribution. All commercial machines use a laser that operates in continuous mode. The laser beam is deflected by galvano mirrors, which control the movement of the laser beam over the surface of a powder bed. The velocity of the laser ranges typically from 50 to 600 mm/s. The powder particles heat up upon absorption of the laser radiation and bind to each other and to the previously scanned layer underneath. In selective laser melting (SLM) the irradiated powder is fully molten and parts with nearly full density can directly be produced. In selective laser sintering (SLS) no melting or only partial melting of the powder takes place.

Commercially available metal-based powders for SLS/SLM

Various metal-based powders that are developed for SLS/SLM are currently on the market. In this chapter are described in brief the most important metallic powders used in the selective laser sintering process and the main application domains will be listed.

Physical aspects in selective laser sintering and melting of metal powders

In this chapter the physical phenomena which occurs in the metallic powders under the laser radiation are described. During SLS/SLM the thermal cycles produced by the moving heat source cause physical state changes, metallurgical phase transformations, thermal stresses and eventually fluid motion.

SPECIFIC PART

2. The comparative study of the mechanic characteristics of the fixed partial dentures obtained by sintering, respective casting

The aim of the study is to analyze some mechanical characteristics of the metal frames of some fixed partial dentures manufactured by casting and sintering. The objective is to identify the existence of strength differences and the validation of the results obtained through the numerical simulation of finite elements method.

Material and method

Most of the studies propose standard of the samples with a imposed geometry. To be closer to the clinical reality as authors we propose a non-standard protocol in which the samples are similar to the finite products with applicability in dental prosthodontics.

In order to fabricate the metallic frame a demonstrative model made of extra-heavy class IV plaster Geller model (Ivoclar). The metallic frames for fixed partial dentures were manufactured using ST 2724G metallic powder produced by SinT-TecH (France). The sinterin g machine was PXS dental installation produced by Phenix Systems. In order that the cast frames to be dimensionally similar to the sintered ones we used the wax milling machine CoriTec 250I. The STL file created to manufacture the sintered frame was exported and by 5 axis milling the wax moulding were created. For the conventional cast frames we used Cr-Co alloy, Wirobond 280. The 10 casted sample frames and the 10 sintered were tested on the installation for dynamic tests for torsion-compression Walter Bai LFV 10. In order to obtain relevant results the metallic frames were mounted on an individualized conjugate fixing device realized by casting in the dental laboratory. The tests consisted in applying a bending force, on the intermediary part of the frames using a steel plate. The test

determines the maximal force that the partial denture can withstand. The force is applied in a way that simulates the maximum masticatory force.

Results

The results showed significant differences between cast and laser sintered removable partial dentures. The most significant difference is at the value of the maximum force. The cast RPDs fail at about 3,2 kN (range 2.87 kN - 3.62 the medium value being 3.22 kN), while the sintered ones can take a maximum load of 100% higher - about 7.5 kN (range 7.02 kN – 8.82 kN average value being 7.60 kN).

Advancing into the study the experimental results for sintered frames were validated.

General considerations regarding the numerical analysis

The numerical modelling known as simulation represents the most rapid, cheap and flexible method to geometrically and functionally optimisation for the strength structures.

Experimental determination of the mechanic characteristics of the sintered alloy

To be certain of a valid model it is necessary to experimentally determine the mechanic characteristics of the alloy. The tension solicitation test was made according to the American standards ASTM E 8M-04 (standard test methods for tension testing of metallic materials). Tension tests were realised on an installation for tension-compression solicitation of 100 kN produced by LBG, TC 100. For conclusive results 10 specimens were tested. The experimentally determined tension-resistance (Rm) test was of 586 MPa, significantly lower than the value indicated by the producer 815 MPa.

Simulation of the maximal masticatory bite force over the intermediary of the metallic frames

In order to obtain the calculus model we used the tri-dimensional solid created for the manufacturing by sintering of a fixed partial denture metallic frame. The program used for simulation was ANSYS11. The material properties obtained experimentally (E=226Gpa; v=0.299) were assigned to the geometrical model. At the internal surfaces of the aggregation elements incastrations were defined (no movement possible) and a vertical force of 800N was applied on the intermediary. (approximate value for maximal masticatory bite force). According to the results the greater tensions are localized in the connectors between the intermediary and the abutment cap. The simulations offer converging results with the experimental ones the rupture is localised exactly in the same spot. Also the maximal tensions observed are reaching the value of 301.13 MPa, way beyond the fracture resistance of the material experimentally determined (586 MPa).

Discussions

Beside the bibliographic study concerning the comparison of the mechanic and physical characteristics of cast Cr-Co alloys and the sintered ones an original experimental program was initiated which conferred the possibility of an objective comparison of two sets

of samples obtained by different manufacturing technologies. Following the comparative study of the mechanical properties of the cast Co-Cr alloy respectively sintered a very distinctive difference can be observed in favor of the sintered samples. The maximum force applied on the sintered samples was two times higher than the cast ones, major differences appeared also regarding their rigidity. An experimental program for mechanical characterization was developed for Cr-Co sintered alloy.

The two experimental studies were valued by issuing and validating a numerical model for analyzing the tension and deforming status for the metallic frames of an fixed partial denture.

Conclusions

Following simulation of the maximal masticatory biting force applied on the intermediary of the metal frame we can establish some general conclusions.

1.The finite element method simulation offers the possibility to easily make some studies of resistance, durability or optimization of any type of dental fixed prosthesis.

2.Applying an 800N force over the intermediary of an fixed partial denture does not compromise the integrity of the prosthesis, the maximal tensions reaching a little over 50% of the material strength resistance.

3.The deformations that occurs following this extreme solicitation shouldn`t affect the overlaying ceramic layer.

3. The evaluation of the tumor necrosis factor for some Cr-Co dental alloys used in selective laser sintering and melting

Materials for dental applications have to meet unique requirements including suitable mechanical properties and acceptable biocompatibility, as they are to be placed in the oral environment with a variable pH. Systemic and local cytotoxicity, allergy, and carcinogenicity result from elements in the alloy being released into the mouth during corrosion. The two main characteristics regarding the biocompatibility are given by the integrity and the degradation of the material as well as the reaction of the host`s organism (toxic effects and allergenic responds). The systemic and local cytotoxicity as well as the allergenic response and the carcinogenicity are the results of the effects of the elements from which the metal alloy is constituted and which are released in the oral cavity during corrosion. Nowadays in the literature there is an insufficient number of proofs to sustain the worries given by the possible systemic toxicity of the cast alloys.

Aim

The aim of this study was to comparative evaluate the tumor necrosis factor (TNF alfa) which corresponds to a Cr-Co alloy used in casting and also in sintering.

Material and method

The study was carried over 24 subjects who were prosthetic rehabilitated (12 with fixed partial denture with cast metallic structure and another 12 with fixed partial denture with sintered metallic structure). 5 ml of peripheral venous blood on anticoagulant support was gathered before the prosthetic treatment as well as after (Heparin 15000UI/5ml, Biochemie GmbH, Kundl-Austria).

Results

The TNF alfa values obtained from the serum resulted by processing the peripheral processed blood were bigger (between 9-11 pg/ml) than the normal values (25 pg/ml). Even though the values obtained are lower than the values obtained in the situations that present an inflammatory status which show values of 50-60 pg/ml.

Conclusions

The results of the study demonstrate that the level of TNF alfa from the peripheral venous blood to the subjects with fixed partial denture with cast metallic structure is statistically significant different to those who benefited by fixed partial denture with sintered metallic structure. The statistically analysis revealed significant statistical differences ($p=0.002316$) between the two analyzed groups, the TNF alfa values being lower in on the subjects of the first group. Even so the values are not clinically significant.

4. The analysis of the marginal fit of the fixed partial dentures using Optical Coherence Tomography *en face* . *In vitro* study.

The aim of this study was to present the advantages of executing dental alloy frames by selective laser sintering/melting with underline on the marginal fit compared to the conventional techniques of casting and also to investigate the marginal fit using optical coherence tomography (on face OCT).

Material and method

To undergo this study 25 sintered metallic frames and 25 cast metallic frames were made. The mould was realized out of epoxydic resin (Crystal Bredent). Selective laser sintering technology was used to generate metallic infrastructure. All the samples were sintered with the Phenix PXS Dental Machine (Phenix System) and the mould was scanned with the D700 Scanner from 3 Shape Dental (Denmark). For the manufacturing of cast samples Cr-Co alloy was used (Realloy-C).

The mould was sectioned in the area of the prosthetic frame in order to obtain the interest areas for scanning. Afterwards, the marginal fit evaluation of the metallic frames was carried out by OCT.

Results

The depth of the scanning was around 1.5 mm. All the samples were scanned in the cervical area to evaluate the marginal fit with Time Domain OCT and 2D slices were obtained. The images were imported in the Image J Program and calibrated to establish the thickness of the cement layer between the abutment and the metallic frame. The thickness of the cement layer corresponds to the fit of the frame on the abutment. The values determined were on average of 92.84 microns for the cast frames and 42.56 microns for the sintered frames. The midline value was 90 microns for cast frames and 40 microns for sintered frames. The Tstudent test indicated a significant statistically difference between the two groups.

Conclusions

This in vitro study shows that the metallic dental prosthetic frames performed of laser sintering have a higher precision on the marginal fit, superior to those made by conventional technology such as casting. Though, laser sintering can be considered an efficient method for manufacturing metallic infrastructures for the porcelain fused to metal fixed partial dentures and represents a valuable alternative when choosing the manufacturing technology.

The research stated that the OCT in time domain is a non-invasive domain and represents a method to analyze the marginal fit of the prosthetic dentures being a useful tool *in vivo* and *in vitro*. A main disadvantage of this analytical method is the high price of the instruments.

THE CONCLUSIONS OF THE PhD THESIS

1.Due to the advantages regarding costs and the standardized possibilities, the digitalization and the automatization gained an important place in the manufacturing of metal parts. However, many dental metal parts are still being produced by manual and inefficient conventional methods.

2. No existing CAD/CAM system can totally replace the traditional dental practices, but emerging technologies may expand the capabilities of future systems.

3. .The finite element method simulation offers the possibility to easily make some studies of resistance, durability or optimization of any type of dental fixed prosthesis when is simulated a masticatory bite force applied with maximal intensity on the intermediary of the metallic frame.

4.Applying an 800N force over the intermediary of an fixed partial denture does not compromise the integrity of the prosthesis, the maximal tensions reaching a little over 50% of the material strength resistance. The deformations that occurs following this extreme solicitation shouldn`t affect the overlaying ceramic layer.

5.Following the comparative study of the mechanical properties of the cast Co-Cr alloy respectively sintered a very distinctive difference can be observed in favor of the laser sintered samples. The maximum force applied on the sintered samples was two times higher than on the cast ones, major differences appeared also regarding their rigidity.

6.As a personal contribution to this study I would mention that in order to be closer to the clinical reality I propose a non-standard protocol in which the samples are similar to the finite products with applicability in dental prosthodontics, compared to the standard testing methods of the samples which impose a certain geometry.

7.The results of the clinical study over the biocompatibility of the fixed dental prosthesis manufactured by laser sintering technique demonstrated that even if the values of TNF alfa were higher at this group comparing to the group that benefited of cast fixed partial dentures, the values are irrelevant from the clinical state of view.

8.Nowadays, there are a very few number of studies that analyze the biocompatibility of laser sintered fixed prosthetic rehabilitations (from my knowledge this is the first study that compares TNF alfa for subjects who received fixed partial denture with cast metallic structure and for subjects who received fixed partial denture with sintered metallic structure before and after treatment).

9. The Optical Coherence Tomography in time domain is a non-invasive domain with applicability in different medical areas and as we proved in the study it represents a method to analyze the marginal fit of the prosthetic dentures being a useful tool *in vivo* and *in vitro*.

10.This in vitro study that analyses the marginal fit of the metal frames with Optical Coherence Tomography shows that the metallic dental prosthetic frames performed of laser sintering have a higher precision on the marginal fit, superior to those made by conventional technology such as casting.

11. Laser sintering can be considered an efficient method for manufacturing metallic infrastructures for the porcelain fused to metal fixed partial dentures and represents a valuable alternative when choosing the manufacturing technology.

12. Also, the Optical Coherence Tomography is considered an alternative tool to analyze the investigation marginal fit for the metal prosthetic frames, a great disadvantage of this analytical method is the high price of the instruments.