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SINTERING THE BEAKS OF THE ELEVATOR MANUFACTURED BY DIRECT METAL LASER SINTERING (DMLS) PROCESS FROM Co - Cr ALLOY

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In this paper, two prototypes of dental elevator was made by DMLS process, using a super alloy powder of Co - Cr (ST2724G), with Phenix Systems machine, type PXS & PXM Dental, one with a threaded tail and another with a cylindrical tail. The quality obtained for the elevator is better, thanks to the material used and to the manufacturing process. For the elevator prototypes there were performed some Finite element method (FEM) analysis to identify stress locations and displacements. It was realized corrosion test in artificial saliva Fusayama Meyer (pH 5,5) at temperature of 37 ± 1 °C for 24 hours and remarks the importance of post treatment after DMLS process to obtain a better corrosion resistance in vitro.

Key words: Co - Cr super alloy, dental elevator, DMLS process, FEM, in vitro corrosion

INTRODUCTION

The Co - Cr super alloy is considered a tolerable material in medicine and presents a good balance among different properties as strength, toughness and corrosion resistance in artificial saliva. DMLS is a rapid prototyping and is ideal for smaller prototypes, high-temperature applications, custom medical and dental parts. Two prototypes of curved elevators were designed and the beaks were manufactured by DMLS process using Co - Cr alloy powders (ST2724G). All materials sintered by DMLS present a porous structure that influences the mechanical and corrosion behavior. [1 - 4] The FEM was used to determine the stress and displacements values for the beaks of curved elevators and was determined the corrosion resistance in artificial saliva Fusayama Meyer of Co - Cr alloy samples. In many biomedical engineering design problems, accurate prediction of the biomaterial mechanical response is essential in the development of many prostheses and medical devices. [5 - 8]

EXPERIMENTAL WORK

The chemical composition of Co - Cr alloy powders (ST2724G) used for DMLS manufacture is given in Table 1. The mechanical properties of Co - Cr alloy powder are: Yield strength of 1,2 × 10^9 N/m^2, Young Modulus of 2,58 × 10^{11} N/m^2, density of 8 500 kg/m^3; volume mass = 8,336 g.cm^{-3}; corrosion resistance < 4 μg/cm^2; thermal expansion coefficient = 14,5 x 10^{-6} K^{-1}.

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Table 1 **Chemical composition of Co-Cr alloy / wt.%**

Co	Cr	Mo	W	Si	Mn	Fe
54,31	23,08	11,12	7,85	1,67	1,67	<0,1

The beak of elevators and the experimental samples are designed by Solid Works program. The samples and the beaks of elevator are sintered by Phenix Systems machine type PXS & PXM Dental, the fiber laser (P = 50 W, λ = 1 070 nm). Machine soft used is Phenix Dental. The sintering temperature is 1 300 °C. The nitrogen gas is used for process.

The simulations (FEM) were performed on a computer with processor Intel Core i7-4702MQ 2,2 GHz and 16 GB RAM, operating system Windows 8.1 Pro 64-bit. [9] On the active part of the beak it was applied a distributed force of 20 N. [10] The linear polarization technique was used to determine the corrosion resistance. For corrosion resistance evaluation was used a Parstat 4000 potentiostat, controlled by a computer and a VersaStudio v.2.4.2 software. In vitro test was performed in artificial saliva Fusayama Meyer pH = 5,5, at temperature of 37 ± 1°C for 14 hours. The morphology investigation and semi-quantitative analysis of samples were performed using scanning electron microscope QUANTA INSPECT F and x-ray spectrometer for energy dispersive (EDS) with a resolution of 133 eV at MnK.

RESULTS AND DISCUSSIONS

The beaks elevators prototypes were obtained following the stages presented in Table 2. Globally, the manufacturing time of beaks is 1h, 24 minutes, 57 seconds. The beaks are made with support. The beaks of

Figure 1 Beaks of elevators sintered by DMLS

elevators obtained by DMLS manufacturing are presented in Figure 1.

The Co - Cr alloy powder has a low granulometry, the spherical grain size is approximately 20 μm.

Table 2 **Specific stages for the DMLS process**

Stages		DMLS technology
1	Preparation, orientation and position of the .STL files	Print job layout using Phenix Systems software
2	3D Printing	Machine preparation Nitrogen gas used in 3D printing process Component cooling
3	Post-processing	Part removal Part drying in the furnace at 800 °C for 30 minutes Part polishing

The low granulometry of powder allows a better control of the thermal gradient during the contact between the material and the laser.

Figure 2 shows the sintered material of Co - Cr alloy powder obtained by DMLS technology and the spectrometry for energy dispersive analysis. It can be noticed that there exists porosity in the material sintered.

It can be noticed that the elevator with thread tail presents some holes in the beak, necessary for material economy. Also, the manufacturing time is shorter. The curved elevators with cylindrical shanks have a better mechanical resistance and a better assembly between beak and the handle. Both curved elevator prototypes can be used successfully in dentistry surgery.

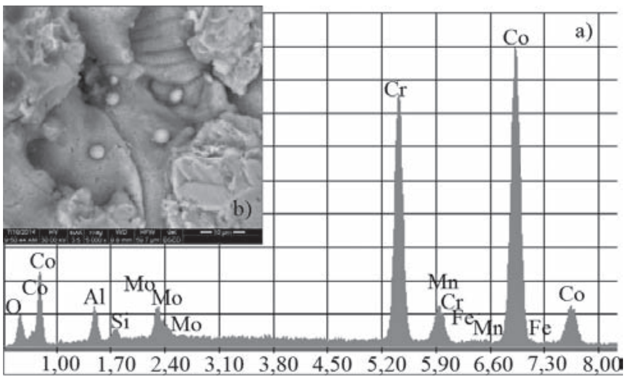

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Figure 2 a) Energy dispersive spectroscopy (EDS)
b) Scanning electron microsopy (SEM) of Co - Cr alloy sintered by DMLS

Mechanical simulations for beaks of curved elevator prototypes

On the active part of the beak it was applied a distributed force of 20 N on an area of 42 mm^2, resulting a pressure of 4,7 × 10^5 N/m^2.

In order to analyze the beaks of elevators through a FEM analysis, a mesh of points and elements is defined in CATIA v5, with a high precision for the beak (size = 0,7 mm, sag = 0,7 mm, Parabolic type). As a result, after the simulations, in the beak is was identified a maximum stress of 2,97 × 10^8 N/m^2. An interest area with high stress is located in the beak shank, with values of 8,94 × 10^7 N/m^2 to 1,2 × 10^8 N/m^2, but also the appearance of some stress principal tensors with a maximum value of 1,53 × 10^8 N/m^2, like in Figure 3.

As a remark, after the FEM analysis, is that the stress located in the beak is smaller than the

Co - Cr alloy material yield strength. The FEM results obtained in this study have an error percent of 7,2 % for the beak.

After applying the distributed force, the elevator assembly is elastically deformed, the maximum displacement area is located in the beak's end edge, with the value of 1,28 mm, being a normal value, being verified by usual tests on other commercial elevators.

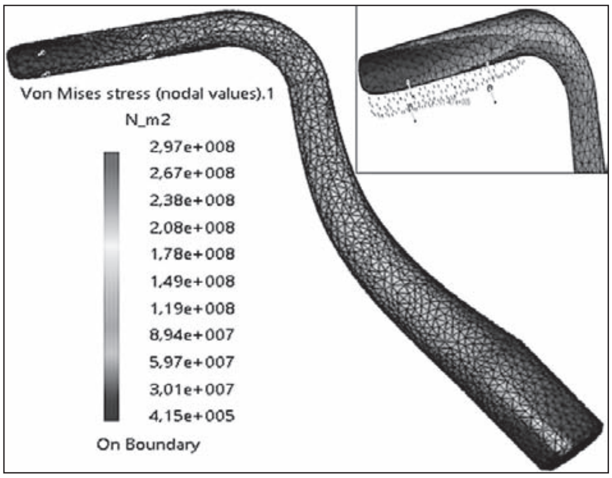

Figure 3 Stress distribution in the beak

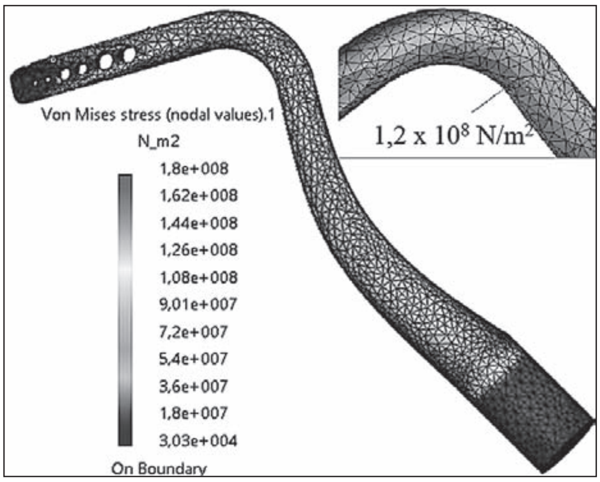

Figure 4 Stress distribution in the beak with holes

In the second set of simulations, another beak variant was used having 6 holes, with diameters from 0,2 mm to 0,5 mm. This variant was conceived and obtained to reduce the material consumption, but also to certify the resolution of the sintering RP machine in order to make in the future more implant parts. The initial FEM setup is also applied to this second part, and the results are: the beak presents a maximum stress value of $1{,}8 \times 10^8$ N/m^2 which is located in the holes area (Figure 4) and a maximum displacement of 2,3 mm for the end edge. This displacement value permits for the elevator only the removal of ligaments from tooth that implies a smaller force.

Corrosion test in artificial saliva Fusayama Meyer

The sintered DMLS samples used for corrosion test have diameter of 10 mm and height of 2 mm. A part of samples supported a post treatment in the furnace at 800 ^{o}C during 30 minutes. The technique consists of linear polarization curves involving the following steps: measuring the open circuit potential (E_{OC}) for a duration of 14 hours and tracing potentiodynamic polarization curves from - 1 V at + 1 V, with a scan rate of 1 mV/s. From the polarization curves were determined following parameters characterizing the corrosion resistance of samples investigated: open circuit potential (E_{OC}); corrosion potential (E_{COR}); corrosion current density (I_{COR}).

Table 3 **Main parameters of the corrosion process**

Sample	E_{OC}/mV	E_{COR}/mV	I_{COR}/A/cm^2
Co - Cr DMLS	70	- 645	$6{,}22 \times 10^{-6}$
Co - Cr DMLS post treatment	49	- 331	$141{,}19 \times 10^{-9}$

In Table 3 are presented the main process parameters electrochemical corrosion. E_{OC} values permit to determine the character "noble" of the investigated samples. To provide clearer evidence of potentiodynamic curves were overlapped thus obtaining a graph for all investigations, like in Figure 5. The corrosion resistance of the samples was examined based on multiple evaluation criteria. Electrochemical measurements, in terms of the values of E_{OC}, showed that the Co - Cr alloy obtained by the method DLMS present a value less electropositive than the alloy after post treatment. Consequently, Co - Cr alloy before post treatment has a more noble character in this regard but only 21 mV value higher than heat treated. The corrosion potential values E_{COR} more electropositive show better corrosion behaviour, like Co - Cr alloy after post treatment (- 331 mV).

The I_{COR} value less indicates a good resistance to corrosion. The post-treated alloy shows the lowest I_{COR} = 141,19 nA comparing with the alloy before performing the treatment thermal I_{COR} = 6,22 μA. In conclusion, after evaluating main parameters of the corrosion process, can consider that Co - Cr alloy after post treatment

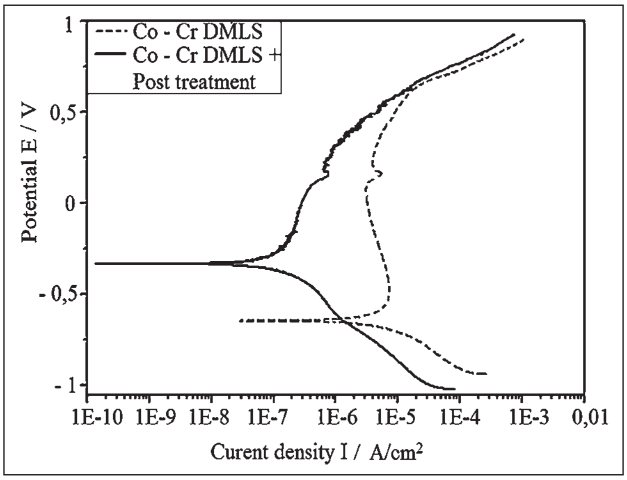

Figure 5 Potentiostatic curves of Co - Cr sintered samples obtain by DMLS (without and with sintered post treatment)

shows better corrosion behavior in artificial saliva Fusayama Meyer.

CONCLUSION

The precision of elevator prototypes obtained by DMLS is very good, by microns order. The FEM analysis show that the beaks realized from Co - Cr alloy powder by DMLS process present an enough resistance necessary to removal the ligaments from tooth. The full beak resist better that the beak with holes. The beak with holes used less material and can realized some economy of powder. After the FEM analysis, the full metallic beak has the stress located $2{,}97 \times 10^8$ N/m^2, smaller than the Co - Cr alloy material yield strength, $1{,}2 \times 10^9$ N/m^2 and the elevator beak has a good mechanical resistance.

In vitro test of corrosion resistance in artificial saliva presents an excellent resistance according to the different parameters that were measured E_{OC}, E_{COR}, I_{COR}. Both curved elevator prototypes can be used safely in surgical dentistry.

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Note: Responsible for English language is Valduțu Lorena-Maria, Bucharest, Romania