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DEVELOPMENT AND MECHANICAL CHARACTERIZATION OF A MANDIBULAR PROSTHESIS IN TITANIUM ALLOY FABRICATED BY DIRECT METAL LASER SINTERING (DMLS)

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Abstract. *Rapid prototyping is being used in various areas of human knowledge to assist in the study and often in the usual component manufacturing. Today, with the advancement of software, you can easily create three-dimensional images, or even, capture these images of equipment such as computed tomography and magnetic resonance imaging. You able to reproduce any part of the human body with great perfection and it's used in the manufacture of implants, scaffolds (tissue engineering), material aid and preparation for surgery (biomodels). The main materials used in the manufacture of implants today are: pure titanium, titanium alloys, stainless steel, polyethylene, PMMA, the cobalt-chromium alloys and ceramics. This paper proposes to do: mechanical studies of alloy Ti-6Al-4V obtained by rapid prototyping process in direct metal laser sintering (DMLS). Also, make the development of a custom condylar plate used for diseases of TMJ (temporomandibular joint) disorders, assessing its geometry by ANSYS® software with the help of computerized tomography(CT) and the software to build three-dimensional images INVESALIUS®.*

Keywords: **Rapid prototyping; Implants; Titanium; Bioengineering; Biomaterials.**

1. INTRODUCTION

1.1 Rapid Prototyping

Nowadays the access to technology is becoming closer and closer to the population. What once existed only in the minds of great scientists today it becomes real. When, in the recent past, we could imagine that any kind of object conceived by the human mind can be made in a matter of minutes. Just for this a drawing of this model on a PC (Personal Computer) and transmit it to a specific machine manufacturing. What a few years ago would be considered surreal, today is feasible and called Rapid Prototyping.

Rapid prototyping (RP) is a productive process, still considered by many innovative. Consists in the fabrication of objects, models, implants, with the use of high technology. The name rapid prototyping is the most commonly used, but other terms are also used, perhaps more comprehensive. Some technologies terms available on the market today are:

- ✓ Layer Manufacturing;
- ✓ Solid Freeform Fabrication;
- ✓ Desktop Manufacturing;
- ✓ Rapid Manufacturing;
- ✓ 3D Printer;
- ✓ AF - Additive Fabrication.

The prototyping process can be performed as follows: it should be draw up the desired part with a CAD (computer aided design), saving this drawing to the extent of reading machine that will perform prototyping, usually "STL"

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(Standard Triangulation Language). After that the file is opened in software prototyping equipment, the operator will perform the manufacturing strategy of the physical model. Thus begins the process, conducted in layers, where the smaller the layer thickness higher dimensional accuracy of the object to be produced is obtained. However, also its production time is increased. The object to be produced has in its design conditions the desired accuracy what it will determine the layer thickness, and other factors of construction. Logically the equipment has limitations in the construction parameters, but these features will become increasingly refined with the advancement of technology (VOLPATO, 2007).

The Prototyping in medicine are based on actual anatomical structures, such as the jaw of a patient. This basically engineering builds three-dimensional (3D) images from magnetic resonances (MRI) or computed tomography (CT) scans transforming two-dimensional (2D) slices in 3D objects that you want to work. The data acquired by CT scans are first worked in 3D specific visualization and analysis software and then saved in STL files. Usually these images are also worked in CAD programs (SANTA BARBARA, 2006).

1.2 Direct Metal Laser Sintering – DMLS

The process DMLS uses a CO2 laser of high power for sintering the powder material to be prototyped. In this process the metal is sintered directly without the aid of binders. The atmosphere in the chamber construction is controlled by an inert gas, usually argon. The chamber is heated to mitigate residual stresses generated during solidification of material and the laser is focused on the material, heating it in proper proportion to obtain a point where the alloy material melting point less is present liquefied generating a "wettability" adequate of the solid by the liquid, which constitute the solid piece in the desired geometry to build the physical model. This entire process is done layer by layer as in all prototyping processes and a roller spreads the powder in each vertical movement of the chamber construction, in the end has a physical model that was built from 3D drawing or acquired by some process such as CT or MRI (ESPERTO; OSÓRIO, 2008).

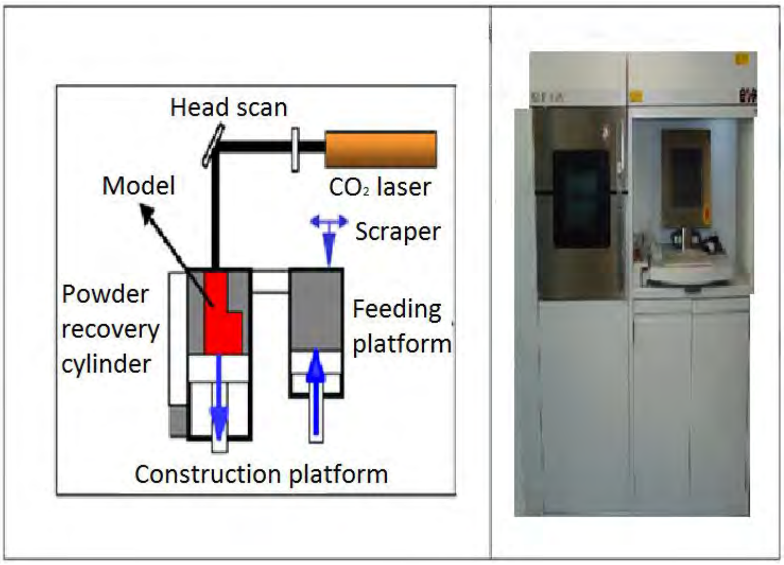

Fig. 1 - Schematic diagram of the DMLS process and EOSINT prototyping machine.

Source: Esperto; Osório (2008) and author's own data

2. MATERIAL AND METHODS

The alloy used in the study was provided by the laboratory of biomanufacturing (INCT-BIOFABRIS). The samples were received as specimens already made in idealized geometry in alloy Ti-6Al-4V prototyped. These samples in the state "as cast".

In figure 2 is shown the machine EOSINT M270 DMLS rapid prototyping. The parameters used in the construction of the prototyped samples are recommended by the manufacturer equipment EOSINT for the titanium alloy Ti-6Al-4V. These parameters are shown in Table 1.

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Fig. 2 - Rapid Prototyping Machine (EOSINT M270).

Source: author's own data

Table 1 - Parameters used in the construction (EOSINT M270).

Parameters of the machine - DMLS	
Laser Power	170 W
Scan Speed	1250 mm/s
Layer Thickness	30 µs
Spacing	100 µs
Scan Angle	45°
Construction Strategy	Line (Alternately X-Y)

Source: author's own data

2.1 Tensile Test

Was used the norm ASTM-E8 for manufacturing the specimens tensile. The tensile test was performed at DEMA/FEM/UNICAMP in a MTS tensile machine with clamp measurement (strain gauge). All specimens were tested to failure obtaining the yield stress, the tensile strength and elasticity modulus.

2.2 Microhardness Vickers Test

The Vickers hardness test was performed at the DEMA/FEM/UNICAMP where they were used specimens prototyped. The equipment used for the measurement was a "Micro Hardness Tester" (HMV) from Shimadzu®. The parameters used for the test were of 0.5 kgf load in the indenter and time of 15 seconds. This machine uses a penetrator type square pyramidal diamond, measurements were made outside the sample to the center and then to the opposite side. The markings were made at a spacing of at least three spaces penetration.

2.3 Dimensional Acquisition

This work will intends to develop a mandibular implant for TMJ disorders using for it the acquisition of computed tomography (CT) images, these files were provided by the laboratory INTC-BIOFABRIS in DICOM format. The files were handled in InVesalius® software to generate 3D images emanating from the 2D slicing performed by CT. The figure 3 shows the image generated by InVesalius®. In figure 3 can see the perspective of the patient's skull and also the three two-dimensional views that are named slices axial, coronal and sagittal. The axial slice is the upper left quadrant, the coronal slice is in the lower left quadrant, the sagittal slice is in the right upper quadrant and the perspective of the image in the lower right quadrant.

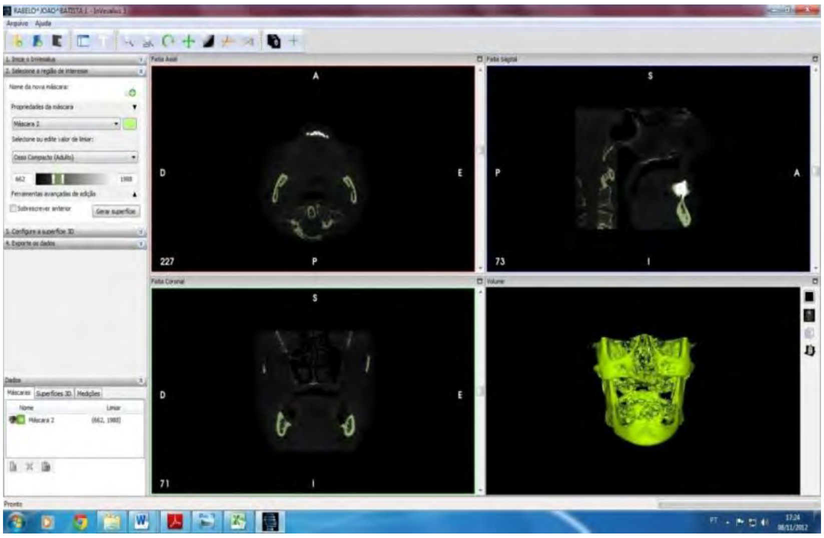

Fig. 3 - Manipulation of TC in *InVesalius*®.

Source: author's own data

2.4 Development and Testing of the Implant

After the generation of 3D files was used Rhinoceros® software for working with images, the software can be downloaded directly from the website of the company and allows you to make 25 saves files to free. In the construction of the implant were used for images modeling, the software Solidworks®, the license is owned of laboratory INCT-BIOFABRIS.

The finite element simulation was performed in the developed implant in Ansys® software using the failure criterion of Von-Mises stresses and considering the jaw muscle forces found in the literature. The license of this software belongs to the area of numerical simulation of the FEIS/UNESP.

3. RESULTS AND DISCUSSIONS

The analyzes performed in this work are intended to demonstrate the possibility of using rapid prototyping as a manufacturing technique cranial and maxillofacial implants. In this work was also conducted a study of image acquisition and 3D modeling to develop a new customized maxillofacial implant with ideal geometry and mechanical strength satisfying to use, customized for the patient.

3.1 Tensile Test

The table 2 shows the data obtained for the alloy Ti-6Al-4V prototyped by DMLS. The results of the tensile test for the prototyped alloy were provided by LAROSA (2012). The data of tensile test shows that the alloy prototype has a high mechanical strength in the state as cast compared with the standard material (ASTM F-136) where the state is annealed.

Table 2 - Mechanical properties of Ti-6Al-4V prototyped by DMLS.

Samples Ti6Al4V	Yield Stress (MPa)	Tensile Strength (MPa)	Elasticity Modulus (GPa)	Elongation – 50mm (%)
Prototype by DMLS	957,0	1172,0	108,0	11,0
Standard Material	795,0	860,0	---	10,0

Source: Larosa (2012) and ASTM F-136

3.2 Microhardness Vickers Test

The Vickers hardness test is intended to demonstrate that the prototyped alloy has excellent mechanical strength and hardness properties, that are linked directly.

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The table 3 shows the microhardness data with the values found, it is noted that the alloy prototyped has hardness constant in all area, of the sample analized. The values found in the work are higher than those found in the literature for the commercial alloy Ti-6Al-4V ELI (ASTM F-136), this confirms the higher tensile strength previously checked in tensile test.

Table 3 - Vickers hardness data.

Samples	Prototype (HV)
1	390
2	409
3	401
4	399
5	399
6	396
7	389
8	381
9	363
10	376
11	370
12	409
Average	**390,17**
Std. Deviation	**14,92**

Source: author's own data

3.3 Image Acquisition and Three-Dimensional Modeling

The files in DICOM format were received in the laboratory INCT-BIOFABRIS. These TC files were imported into the software InVesalius®.

The file had 576 tomographic images slicing which is indicated by the software. In this step can be used all slices or eliminated 5 slices to each 6 slices of scan.

After this step you must choose the type of material that will be revealed through the program to produce the biomodel or customized implant. There are the following options to choose:

- ✓ Bone
- ✓ Enamel
- ✓ Epithelial Tissue
- ✓ Soft Tissue
- ✓ Muscle Tissue
- ✓ Etc...

To reveal the structure was chosen the "Bone" which can also be customized so as to generate a cleaner three-dimensional image of the patient's anatomy. After selecting the region of interest generates the three-dimensional image as is shown in figure 3.

The resulting geometry was saved in a file with STL format. This file was exported to Rhinoceros® software that allowed the generation of a mirror surface of the mandible as shown in Figure 4.

Fig. 4 - Mirror surface of the mandible.

Source: author's own data

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After generating the surface must save the file in the Rhinoceros® in IGES format (*.igs), enabling export the files to SolidWorks® software for the production of the final modeling of the implant.
Already with the surface in the SolidWorks® was performed the implant design which can be seen in Figures 5 and 6.

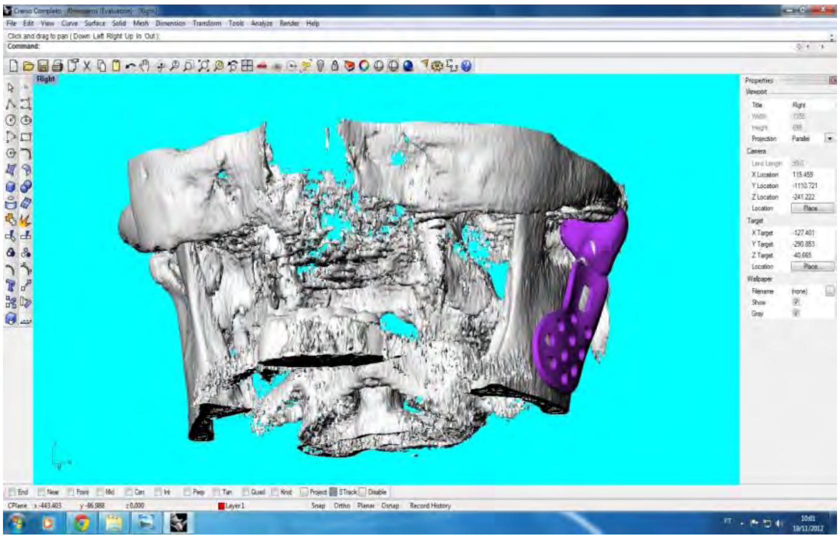

Fig. 5 - The final implant developed in simulation in the patient's anatomy.
Source: author's own data

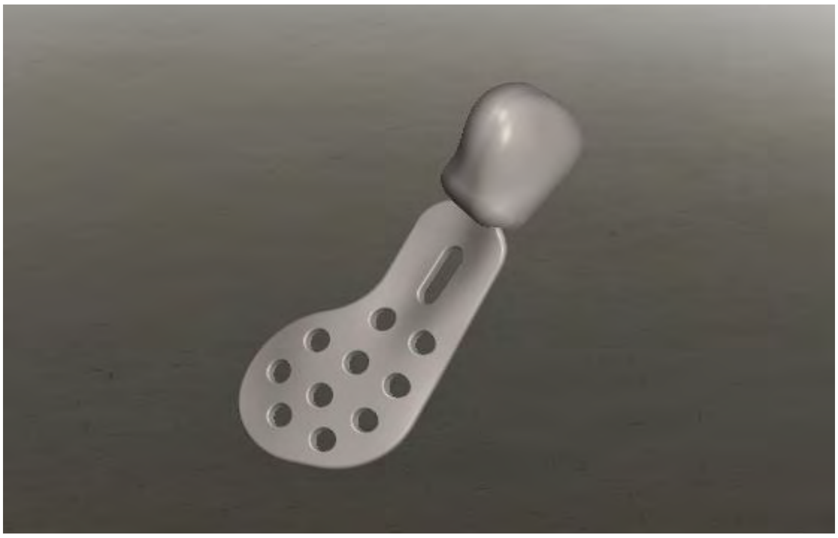

Fig. 6 - Custom finished condylar plate.
Source: author's own data

After completion of the implant design was tested on the patient's anatomy as can be seen in figure 5. This ensures a perfect fit of the implant in the clamping area of the patient.

3.4 Finite Element Analysis

The analysis developed here it is a simple approximation of conditions in which the implant is located. For this we used forces obtained in the literature that are attributed to movements of the human mandible. As boundary conditions will be used a maximum force applied to the condylar head of 1000 Newtons which is the largest response shown in the literature considered in this analysis as the critical case. The fixing will be made with simulation of three bone screws stabilizing the pattern of holes in the central area as shown in figure 6. To simplify the problem will be considered the implant constructed in alloy Ti-6Al-4V as a material isotropic, homogeneous and linearly elastic and having the following properties:

- ✓ Yield strength: 957 MPa
- ✓ Tensile strength: 1172 MPa

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- ✓ Modulus of Elasticity: 108 GPa
- ✓ Poisson ratio: 0.33

The mesh generated after multiple simulations of convergence to the stress, and wich element size of 0.5 mm, showed the following conditions. The element used to simulate was the tetrahedral solid (*Ansys*® Solid187).

Statistics	
Nodes	448.689
Elements	317.020

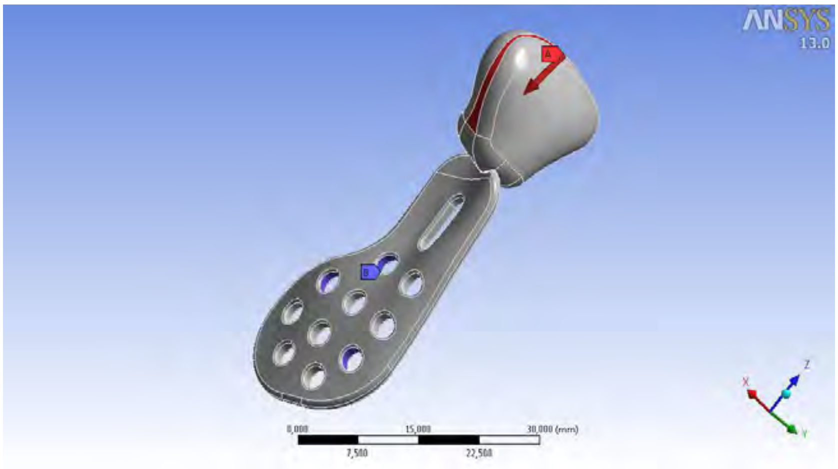

Fig. 6 - Simulating with three fixing screws.

Source: author's own data

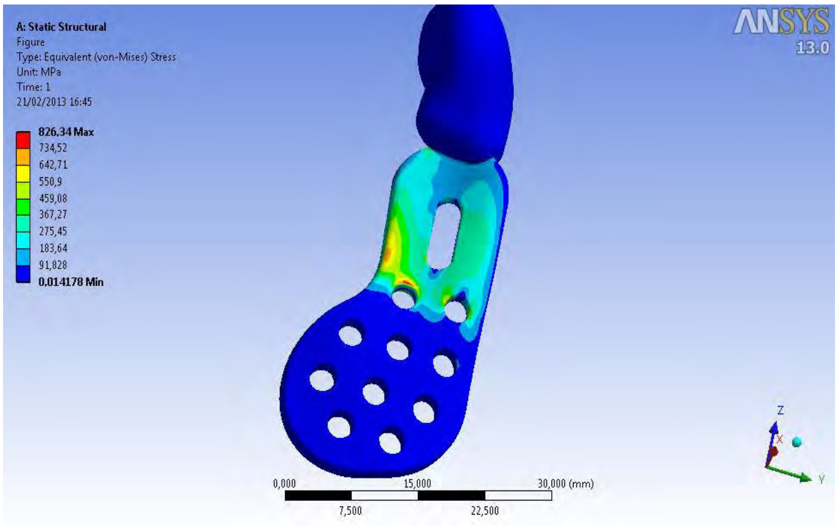

Fig. 7 - Finite element analysis of the Von-Mises stresses for three screws.

Source: author's own data

In this work was used the failure criterion of Von-Mises (Criterion of Distortion Energy).

The interactions for problem solving were stopped when an error has been achieved the value less than 1.0e-08. The average processing time for the simulations was 175 seconds.

The maximum Von-Mises stress was achieved by simulation of the plate with three screws on the order of 826.34 MPa below the yield stress of the material, which can be considered an interesting aspect.

The stress distributions show that the highest concentration is at the interface between the connection the plate with the condylar head. This area can be studied to minimize tensions and optimize the product performance. The stress were also detected in the internal regions where the holes the screws are allocated, it can be seen in figure 7. The first two mounting holes closest to the condylar head are receiving the highest level of applied stress.

4. CONCLUSION

- ✓ In this work was possible to develop a customized implant through the process proposed;
- ✓ Mechanical tests proved, as a great option, the use of prototyped technology in craniofacial and maxillofacial implants;
- ✓ In tensile test the alloy prototyped shows a superior strength in compare the alloy standardized, obtaining a yield strength of 957,0 MPa to 795,0 MPa of the conventional alloy;
- ✓ The finite element test presented data that attest to the strength of the prosthesis to use in human mandibles.

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7. RESPONSIBILITY NOTICE

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