EXPERIMENTAL RESEARCH ON BIONANOPOWDERS USED IN SLS AND DMLS PROCESSES FOR MEDICAL IMPLANTS MANUFACTURING

Diana Irinel BĂILĂ[1]

The direct metal laser sintering-DMLS is a new technique, similar with SLS sintering process used to quickly fabricate a scale model of a physical part or assembly using 3D computer aided design CAD data.

This technique is used to obtain complex pieces like implants, personalized dental crown, bridges, chapels or microsurgery instruments in dentistry.

The Co-Cr alloy type powders and Ti6Al4Valloy powders are used in DMLS sintering process to obtain the medical instruments and implants, because they must present good mechanical resistance, good corrosion resistance, to be non-toxic and to have good fatigue resistance.

The Co-Cr alloys type powders are considered a tolerable material in dentistry concerning the crowns fabrication and the Ti6Al4V alloy powders is considered a biocompatible material.

Keywords: DMLS process, Co-Cr alloy powders, Ti6Al4V alloy powders, mechanical properties, electron microscopy, EDAX

1. Introduction

Metal Additive Manufacturing (AM) - also referred to 3D printing - is a revolutionary technology that produces 99.99% dense parts directly from 3D CAD data using the powder bed fusion process known as Direct Metal Laser Sintering (DMLS). Metal AM is fast, accurate and cost-effective for the production of prototypes as well as series production parts which can be used for testing or as final production components. Parts are manufactured without the financial or time costs required for conventional tooling [1].

Selective Laser Sintering (SLS) is an additive rapid manufacturing (or 3D Printing) process that builds three dimensional parts by using a laser to selectively sinter (heat and fuse) a powdered material. The printing process begins with a 3D CAD file which is mathematically sliced into 2D cross-sections. The **SLS** prototype or part is built a layer at a time until completed.

Co-Cr powder and Ti6Al4V powder permit to be process by selective laser sintering, because present good sintering properties, the process taking place with sparks.

[1] Lect. PhD. Eng., Faculty IMST, University POLITEHNICA of Bucharest, Romania, e-mail: baila_d@yahoo.com

2. The DMLS - Sintering Process

Metal AM is an 'additive' technology that works by fusing together very fine layers of metal powder using a focused laser beam. This powder bed fusion process can produce complex geometries which might not have been possible using traditional manufacturing techniques, such as:

- undercuts
- channels through sections
- tubes within tubes
- internal voids

The 'unsintered' or loose material is removed and recycled for future use, making it both economical and environmentally friendly [2].

The parts have to be anchored onto a platform so that the parts are held in place. The platform also helps to dissipate heat and contained stress during production. Supporting structures are required for most downward facing surfaces (at less than 45^0 from the build platform) because the powder alone is not sufficient to hold in place the liquid phase created when the laser is scanning the powder. Once the object is finished, in-house experts remove the support structures and carry out any other post-processing work required.

Finished parts are comparable to a good investment cast part and the mechanical properties of finished parts are equivalent to those of a cast or machined component. The process is not restrictive in its application and the components produced can be used in place of almost any conventionally manufactured part.

The advantage of the process is that the more complex or feature rich the component, the more economical the process becomes. Direct metal laser sintering process is used in different domains like: technology construction of machine, medicine, aerospace [3].

The machine used for our experimental researches for DMLS sintering is the machine Phenix Systems. The machine Phenix Systems used the power of laser to sintering the powders, making the contacts between particles. Laser beam sintered the layers of powder after the CAD/CAM model.

Fiber laser have the power P=50 W and λ=1070 nm, production volume is 100x100x80 mm. Its functional design is simplified in order to offer all the advantages of our process economically.

The Phenix Systems machine makes it possible to manufacture small complex parts with a good level of productivity.

It is also a tool that is perfectly adapted to any training modules offering the opportunity to get familiarized with this additive manufacturing process.

The ergonomics of this system has received particular care. Metal powders can be manipulated easily and in complete safety.

3. The SLS - Sintering Process

Selective laser sintering (SLS) is an additive manufacturing technique that uses a laser as the power source to sinter powdered material (typically metal), aiming the laser automatically at points in space defined by a 3D model, binding the material together to create a solid structure. It is similar to direct metal laser sintering (DMLS); the two are instantiations of the same concept but differ in technical details [4, 5].

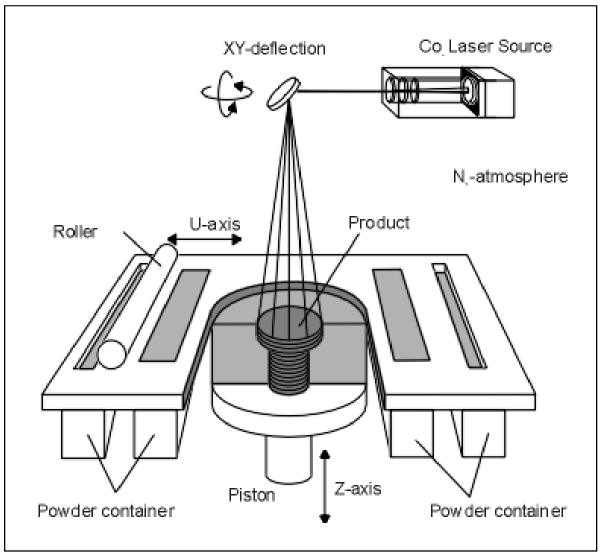

Fig.1.SLS process manufacturing [4]

The selective laser sintering machine, used for our researches is the SINTERSTATION 2000 machine. Machine used CO_2 laser to sinterfuse powdered materials to create 3D parts. Power of laser is 50W CO_2 laser. Product volume is 114x58x70 mm. The machine SINTERSTATION 200 presents 2 powder containers, a roller for powder alimentation and a piston that descend in time of process, Fig.1. Laser ray is reflected with a mirror to sinter the powder layer.

During the SLS process (selective laser sintering), the powder particles are selectively melted together by means of a laser beam. The laser energy needed to melt this powder is kept low by maintaining the powder material in the machine on a constant temperature just below the melting point. The processing chamber is continuously flushed with nitrogen to avoid oxidation of the hot powder. The SLS technology is mainly used to build prototypes. The DTM Sinterstation 2000 can also be used to make metal prototypes.

SLS technology is a new process and is used to obtain different prototypes and for complex pieces. The SLS process is controlled by computer. The components of SLS machine are process chamber, the powder feed cylinder, the part-build cylinder, the roller mechanism, the laser, the optics with different mirrors, the galvanometers, the motors, the process computer control and the environmental control unit.

4. CAD/CAM model

DMLS sintering process and SLS sintering process used CAD/CAM program for realized the pieces. In figure 2 is presented a dental implant realized on SolidWorks program. The three-dimensional CAD data must be output in the industry-standard STL format.

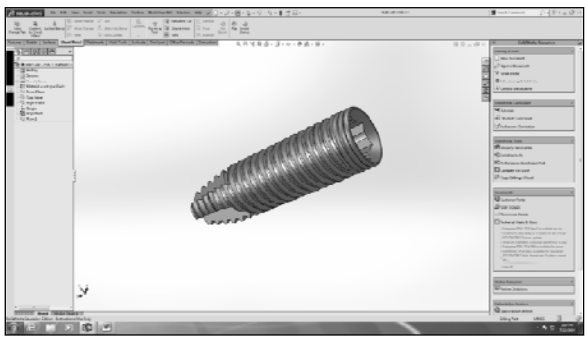

Fig.2. Dental implant 3D – CAD/CAM model

Dental implants can be realized by sintering by SLS technology or DMLS technology.

The implants can be obtained by titanium alloy Ti6Al4V or by Co-Cr alloy that are tolerable alloys used in medicine [5].

The alloy Ti6Al4V is an inert material, non toxic and presents good mechanical properties, good corrosion resistance and don’t present chemical reactivity.

5. Cobalt-Chrome powders

The Co-Cr alloy powder is a tolerable material used in medicine and can be used to realize medical implants and different instruments for microsurgical procedures. Co-Cr powder can be used for dental restorations which have to be veneered with dental ceramic material and are optimized especially for processing on Phenix Systems machine. The alloy composition of Co-Cr powder is presented in Table 1.

Table 1

Chemical composition of Co-Cr alloy

Elem	Wt%
O	10.19
Si	3.35
Cr	23.08
Mn	0.87
Fe	0.37
Co	54.31
W	7.85

Cobalt-Chrome powder is a fine powder mixture for processing on DMLS process, which produces parts in a cobalt-chrome-molybdenum-based superalloy. The powder presents a fine granulation under 20 microns. In figure 3 is presented the electron microscopy image on the Co-Cr alloy type powder and in figure 5 the EDAX qualitative and quantitative analysis results is shown..

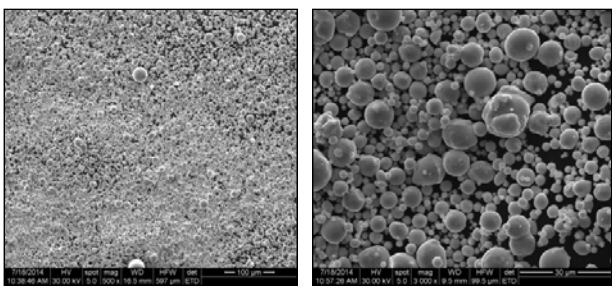

Fig.3. SEM of Co-Cr alloys powder (x500, x3000)

Fig.4.Analogues implants by DMLS

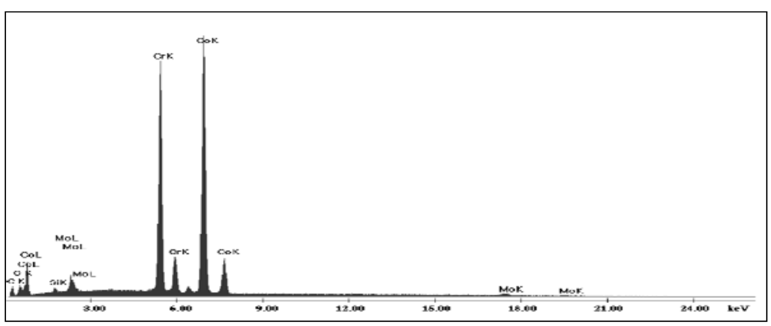

Fig.5. EDAX analysis obtain by Co-Cr alloys powders

The Co-Cr powder was sintered using the DMLS process with the Phenix Systems machine. This class of superalloy is characterized by having excellent mechanical properties (strength, hardness), corrosion resistance and thermal resistance. The Co-Cr alloy powders can be used in biomedical applications such as dental and medical implants. In Fig.4 are presented the analogues implants obtained by Co-Cr alloy type powder using Phenix Systems machine. The quality of the analogues implants is very high, the pieces present complex shapes and after sintering process, don't need other rectification operations.

In table 2 are presented the mechanical properties of the Co-Cr powders used for DMLS sintering.

Table 2

General material properties[6]

Minimum layer thickness	20 μm
Surface roughness	Ra=10 μm, Ry=40-50 μm Ra=0,39 μm, Rz=1,6 μm After polishing Rz<1 μm
Density with standard parameters	8,3 g/cm^3
Mechanical properties	
Tensile strength	1100MPa
Yield strength	600 MPa
Elongation at break	20%
Young's modulus	200 GPa
Hardness	35-35 HRC
Fatigue life	>10 million cycles
Thermal properties	
Maximum operating temperature	1150 ^{0}C

This material is ideal for many part-building applications (DirectPart) such as functional metal prototypes, small series products, individualized products or spare parts. Standard processing parameters use full melting of the entire geometry with 20 μm layer thickness. Using standard parameters the mechanical properties are fairly uniform in all directions.

6. Titanium alloy powders

Titanium Ti6AlV4 alloy (6%Al, 4%V) in fine powder form can be used for sintering by SLS process with the machine SINTERSTATION 2000 [6].

In figures 6 is presented the Ti6Al4V alloy powder and one can remark the irregular shapes of the powder that permit the laser sintering through the formation of liaisons welding connection. The powder was conditioned with resin for realize better the liaisons welding connection, for selective laser sintering process.

In figure 7 artificial phalangeal implants of Ti6Al4V alloys obtained by SLS process, using SINTERSATION machine are presented. The implants obtained by SLS and DMLS process present pores with dimensions between 50 and 150μm that favors the formation of osteoblasts. The optimal dimension is 150 μm. In the case when the contact zone is viable, the tissue cells growth and extend the contact surface.

In figure 8 is presented the EDAX results (qualitative and quantitative analysis) of the Ti6Al4V alloys and one can remark the purity of the powder used for the sintering process.

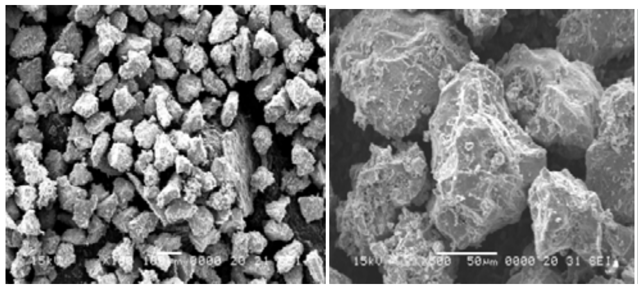
Fig.6. SEM of Ti6Al4V powder (x100, x500)


Fig.7. Artificial phalangeal implants

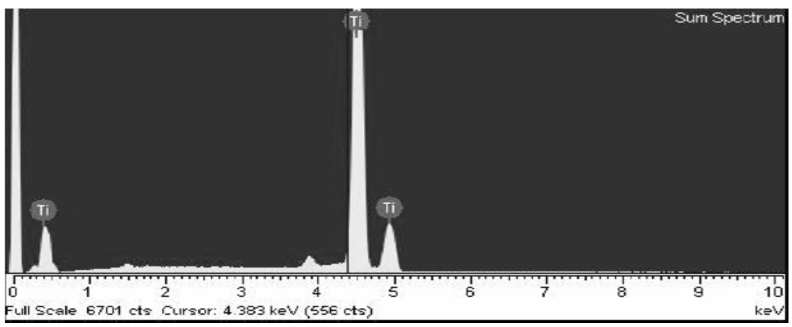

Fig.8. EDAX analysis obtain by Ti6Al4V powder

In table 3 are presented the mechanical properties of the Ti6Al4V powders used for SLS sintering.

Table 3

General material properties [6]

Minimum layer thickness	30 µm 1,20 mil
Min. wall thickness	0,3-0,4 mm
Surface roughness	Ra= 9-12 µm, Rz=40-80 µm Ra= 0,36-0,48µm, Rz=1,6-3,2 µm
Density	4,43 g/cm^3
Tensile strength	1150 MPa
Yield strength (Rp 0,2%)	1030 MPa
Elongation at break	11%
Young's modulus	110 GPa
Hardness	400-430 HV (41-44 HRC)
Maximum long-term operating temperature	350^{0}C

7. Conclusions

The DMLS process is a new technology and is more used that SLS process. DMLS and SLS process are similar with small differences. Both processes permit realization of complex pieces with good mechanical properties. After manufacturing pieces by sintering, after process is not necessary others rectifications.

The cobalt chrome powders present excellent mechanical properties, a good density, temperature resistance and good fatigue life and is used specially in dental domain. The powder presents high mechanical properties in elevated temperatures (500-1000^{0}C), good corrosion resistance and high strength or stiffness.

Co-Cr powders can be successfully used for DMLS manufacturing of personalized dental implants, dental crowns, bridges, chapels, because is a tolerable material. Co-Cr alloys sintered probes present good mechanical resistances, good adherence to the ceramic teethes, is non-toxic material and the time to obtain the dental crowns is little.

The titanium alloy powders present excellent mechanical properties, corrosion resistance, good biocompatibility and are used for biomedical implants and medical surgery.

Ti6Al4V powder can be used by SLS and DMLS process in implantology, for mandibular implant, artificial phalangeal implants because is a biocompatible material.

Acknowledgment

This work is supported by the Sectorial Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and the Romanian Government, under the contract number POSDRU/159/1.5/S/138963 – PERFORM.

R E F E R E N C E S

[1]. *John Hewitt*, "3D printing with metal: The final frontier of additive manufacturing", Extreme Tech, 2012;

[2]. http://www.phenix-systems.com;

[3]. http://en.wikipedia.org/wiki/Direct_metal_laser_sintering;

[4]. *Berce P.* & others, „Fabricarea Rapidă a Prototipurilor" (Rapid Prototyping Manufacturing), Editura Tehnică, Bucarest, 2000 – (In Romanian);

[5]. *Fathi M, Ahmadian M, Bahrami M, Dent Res J*, "Novel bioactive Co-based alloy/FA; nanocomposite for dental applications", PubMed, 2012;

[6]. *Băilă Diana-Irinel*, "Cercetari teoretice şi experimentale privind asimilarea de noi materiale prelucrabile prin tehnologiile Rapid Prototyping, (Theoretical and experimental researches

concerning the assimilation of new biocompatible materials manufacturing by Rapid Prototyping Technologies", Doctoral Thesis, june 2009 – (In Romanian).