TYPES OF NANOPOWDERS USED IN THE QUICK MAKING OF MECHANICAL PARTS BASED ON SELECTIVE LASER SINTERING

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Abstract. Laser sintering is already well known as a technology that ensures the fastest path from product idea to market launching of that product. Innovative companies throughout the world use this technology for a very rapid, flexible execution of parts, due to its low costs and possibility to make the part directly from an electronic format, in any stage of the production cycle.

Keywords: Selective Laser Sintering, Sintered Parts, Complex Geometries, Complex Biocompatible Parts.

1. Introduction

Initially, in direct laser sintering of metals the materials used were created solely for this purpose, being different from those used in traditional approaches of metal processing. In recent years, the range of nanopowders available and the high demand for prototypes of high quality have increased considerably, thus conducting to a subsequently rich interest in this field.

The gradually wider and more rapid acceptance of this production technology has led to the further development of materials in view of their use in direct sintering. Thus, recently, a great deal of attention was diverted to assimilating titanium and its alloys that are usually used in applications with peculiar requirements. Currently, the materials used in the process of laser sintering are very diverse, as various types of metallic powders can be processed, such as: Direct Metal DM, Direct Steel H20, Martensitic Steel MS1, Stainless Steel 17-4, Stainless Steel PH1, Cobalt Chrome MP1, Cobalt Chrome SP1, Steel 316L, Pure Titanium TiCP, Titanium Alloy Ti64, and Titanium Alloy Ti64 ELI (Table 1).

Table 1: Nanopowders used in sintering

No.	Name of the material	Type of material
1.	DirectMetal20	Bronze-based alloy
2.	Stainless Steel PH1	High resistance steel
3.	Martensitic aged steel MS1	1.2709 European Standard
4.	Stainless Steel 17-4	1.4542 European Standard
5.	Cobalt Chrome Super-alloy MP1	CoCrMo Super-alloy
6.	Cobalt Chrome Super-alloy SP1	CoCrMo Super-alloy
7.	EOS Titanium Ti64	Low weight alloyTi6Al4V
8.	EOS Titanium Ti64ELI	ELI - Extra Low Interstitials
9.	EOS Titanium TiCP	Pure Titanium

As Titanium-based parts have a high production cost and as Titanium (having a high affinity to oxygen) is difficult to mould and process, the laser sintering process deserves particular attention.

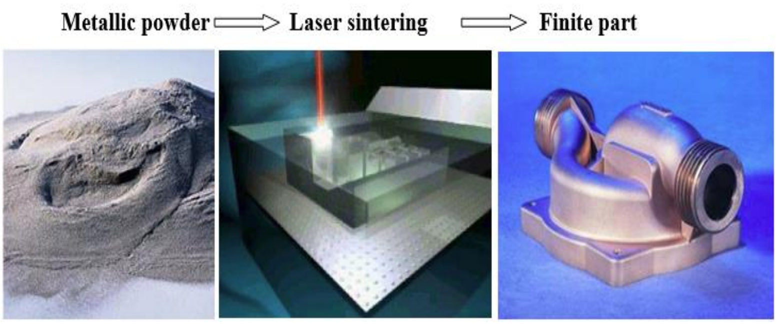


Figure 1: Technological process presented as a sequence

The rapid prototyping process by selective laser sintering is based on the materialization of a virtual 3D model (built in a CAD system) by the addition of successively melted layers (additive technology). A focused laser beam sweeps point by point the entire area of the section, sintering (melting) the fine powder coating deposited on a work plate. For each part, it is necessary to build supports that allow the detachment of the part from the work plate (Fig.1).

The main advantages of fast prototyping technology are:

• Reducing product development time;

• The possibility of checking the design of the product by adding some necessary features and removing some superfluous elements in the design phase;

• The ability to create extremely complex parts. Parts with very complicated shapes (even a part placed inside another part) can be produced through this revolutionary process.

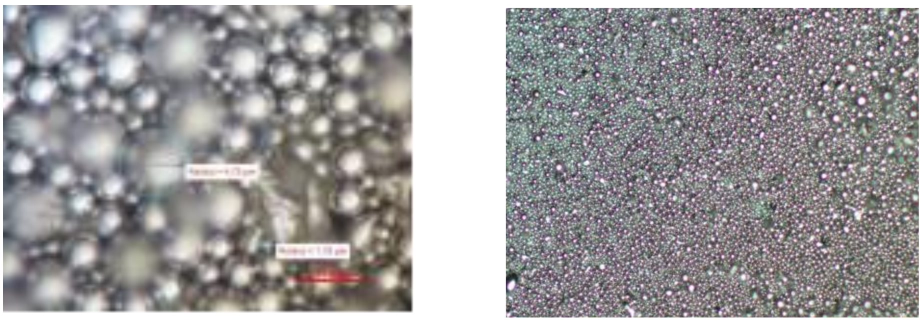
Due to all these features, the method can also be used to make components of medical prosthesis with laser sintering machines, from metal nanopowders and including the possibility of processing the titanium.

In parallel with the development of sintering machines for metal nanopowders, sintering machines for nanopowders of plastic materials have also been developed.

As in the case of metal nanopowders, their evolution has led to the emergence of biocompatible polymers (ISO 10993-1) with high dimensional stability and meeting the requirements of cytotoxicity, genotoxicity, delayed hypersensitivity, irritation, and so on and which can be sterilized by conventional methods. They open up new horizons in the realization of medical prosthetic elements and systems.

2. Structural Transformations that Occur in Nanopowder Sintering

The microscopic appearance of titanium nanopowder is shown in the figure below:



1500x 200x

Figure 2: microscopic appearance of titanium nanopowder

Nanopowders are transformed by laser sintering into massive bodies. Sintering is a heating operation during which complete powder consolidation occurs through diffusion welding processes (Figure 3).

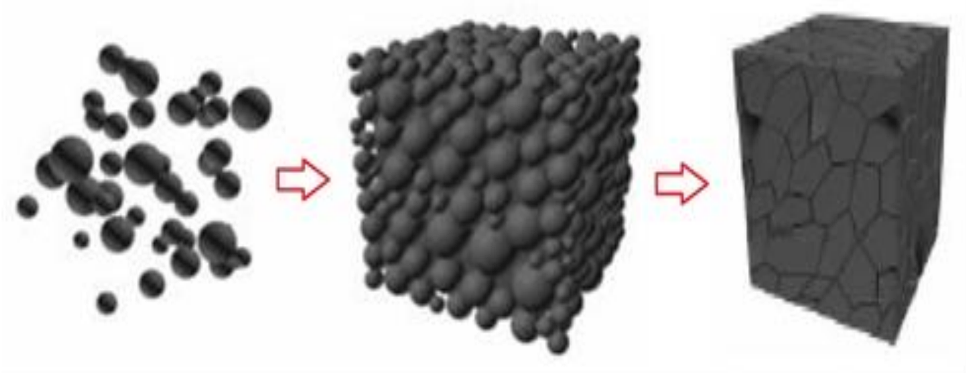


Figure 3: Powder consolidation

The heating used in sintering is performed at a temperature of 2/3 ... 4/5 of the melting temperature of the heaviest fusible component in the powder mixture. To prevent internal oxidation, the sintering operation is carried out in a controlled (reducing or neutral) atmosphere or in a vacuum. Currently, sintering is carried out in a nitrogen atmosphere, which has the advantage of producing a reduction in film oxide from the surface of the tablet particles, thereby providing clean surfaces for diffusion, and in particular titanium sintering is carried out in an atmosphere of argon. Four stages are distinguished during sintering (Figure 4):

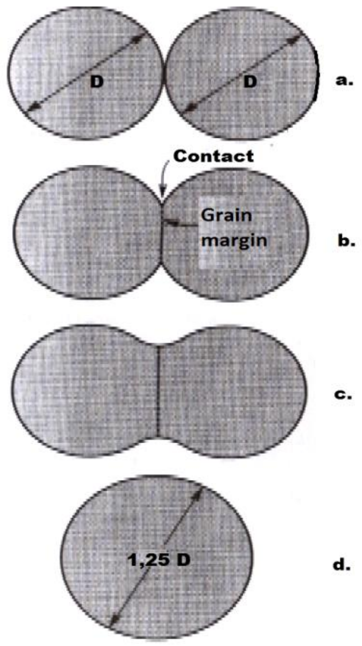


Figure 4: Stages of melting of particles during sintering
a - initial step (point-to-point bridges, unmodified porosity, distinct particles);
b - The intermediate step (connecting bridges on large contact surfaces, reduction of the porosity by maintaining the inter-comcommunication of the pores, new recrystallized grains,
c- loss of individuality of powder particles);
d - final step (consolidated material, increase of recrystallized grains)

During the sintering process also take place the following phenomena:

• Reduction of oxide films, elimination of gases and adsorbed fluids;

• Diffusion alloying of components from different particulate particles with the formation of new phases.

The main technological parameters of the sintering operation are: temperature and time.

At INCDMTM, comparative research was carried out on the structure of sintered materials, obtained from metal nanopowers.

The study of the crystallographic structure is shown in the images of Figure 5, in which the microstructure of the titanium alloy is presented as follows:

• Ti-6Al-4V rolled bar (Figure 5a). This material is used by Technomed Impex S.A., a Romanian manufacturer of dental implants and medical devices;

• Is shown the microstructure of a sintered sample (Figure 5b) of the titanium alloy EOS Ti64 obtained with the M270 Extended machine.

Crystallographic studies resulted in two major conclusions:

• There are more pores in the bar obtained by rolling and used to obtain dental implants than in the case of sintered parts, which makes the structure obtained by additive manufacture finer;

• The micrograph of the sintered sample reveals a crystal structure oriented in preferential directions, which coincides with the direction of the laser beam weeping. The structure thus obtained is a denser one, with predictable influence on the fatigue resistance of the studied material.

a. Rolled bar b. Sample obtained with sintering

Figure 5: crystal structure of the alloy Ti-6Al-4V (800x)

3. Process Equipment and Working Software

At the National Institute for Research Development in Mechatronics and Measurement Techniques, was purchased a rapid prototyping laser sintering machine type EOS M270 (Figure 6).

This machine, equipped with a high-performance laser system and optics with excellent, high-resolution focusing, make it possible to produce high-quality, high-resolution parts. The variable focusing diameter increases productivity by reducing processing time, and the controlled atmosphere of the workspace allows the use of a wide range of materials.

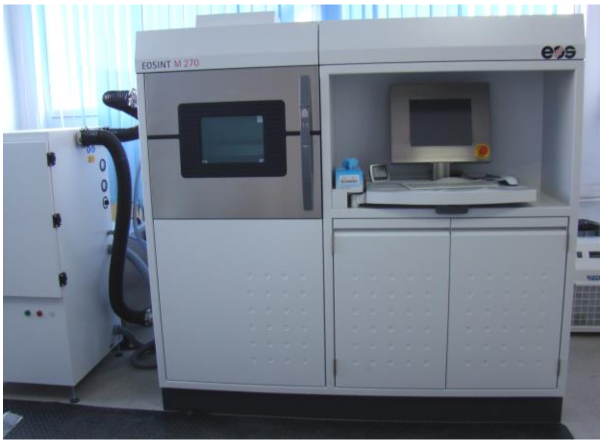


Figure 6: High-tech EOSINT M 270 Titanium Version equipment owned by INCDMTM

The equipment works with STL (Standard Tessellation Language - a format of files for polygonal patterns used in rapid prototyping), and there are various software solutions of which the most complete and most used is Magics from Materialise Software, Belgium.

This program is characterized by ease of use and proven effectiveness when it comes to working with 3D data files - surfaces and volumes.

This software has specialized tools and a high degree of automation for handling STL 3D files.

Moreover, this kind of files can be corrected in just a few minutes with the help of special tools that can interact directly on defective triangles.

The program allows handling STL files by providing the following functions (Figure 7):

- Viewing, repairing, measuring parts and modifying STL files;
- Making holes, extruded surfaces, making holes;
- Boolean operations, reducing the number of triangles that approximate the surface, smoothing surprises, collision detection;
- Generating media and exporting them for prototyping;
- Colouring parts.

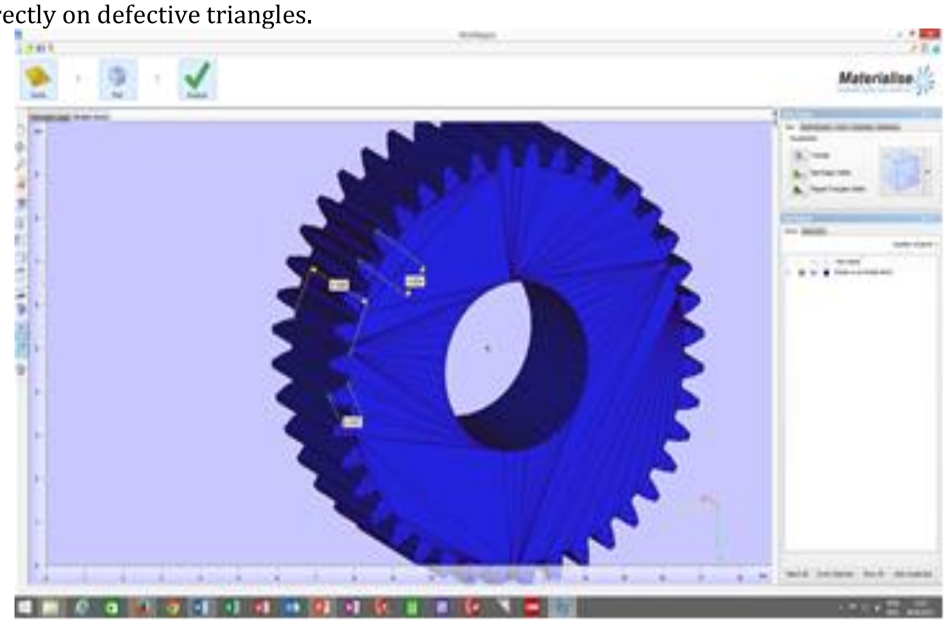


Figure 7: Toothed wheel model highlighting the triangulation

Magics is the only software dedicated and fully optimized for the individual needs and features of fast prototyping processes.

3D efficient functionalities and commands of Magics RP (Magics Rapid Prototyping) ensures obtaining a quality of excellence of the prototypes in the shortest of times ensuring also obtaining the whole documentation of the process.

The Magics software is ISO 9001 certified and is in compliance with EC and FDA legislation and provides full control over STL files.

Mechanical Parts made by Selective Laser Sintering

Below are some examples of industrial applications in the mechatronic field.

1. Manufacturing of functional prototypes for the automotive and aerospace industry (Figure 8);
2. Making high quality precision mechanics parts (Figures 9 and 10);
3. Manufacturing of models and prototypes of dedicated surgical instruments or parts of medical devices (Figures 11 and 12);
4. Making complex geometries impossible to generate by other metalworking processes (Fig.13).

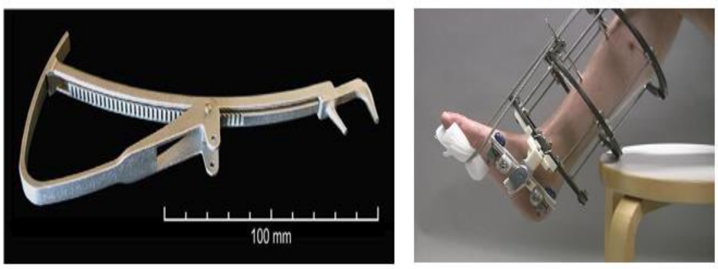
Figure 8: Element made of Stainless Steel CoCr

Figure 9: Specialized micro-mechanical element

Figure 10: High precision elements in the field of precision mechanics made at INCDMTM

Rapid prototyping tends to become a unanimously accepted solution in making complex mechanical components difficult to generate by classical means, but also in various surgical instruments or parts of medical devices. This latter field of use is related to the development of orthopaedic surgery that has increased the need for customized disposable instruments, which can also be made using additive technology.

It is also possible to make dedicated surgical instruments (Fig.11a) or parts that fall in the area of medical devices such as post-operative external prosthetic supports (Fig.11.b), guides, and so on.



a. b.

Figure 11: Customized instrumentation and medical device components

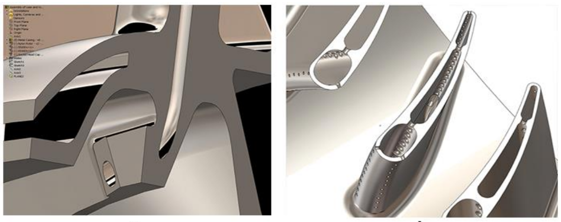
By perfect fit with patient anatomy, personalized instrumentation shortens the duration of surgery, reducing both the required amount of aesthetic and the risk of an infection. It also allows precise placement of the implant, minimizing the risk of a new corrective intervention, thus facilitating the surgeon's work. Using CAD - CAM - CAE methods instrumentation with anatomical forms such as disposable drilling guides for both dental and orthopaedic fields can be generated quickly and efficiently (with reasonable cost).

Rapid prototyping of biocompatible plastic powders opens new paths in prosthetics and orthopaedics, allowing conceptual models and functional prototypes to be obtained (Figures 12 and 13).

It should be noted that the implantable elements are made mostly of titanium alloys and the mechanical and bonding elements and components for a better physico-mechanical behavior are made of stainless steel or aliases from Co-Cr.

a. b.

Figure 12: Drilling guides



a. b.

Figure 13: Parts with complex geometries

Rapid prototyping guarantees engineers and designers the greatest freedom of three-dimensional construction. The volume of construction is almost the only relevant criterion that will dictate the cost. On the other hand, the complexity of the design is not very relevant in terms of actual construction costs. It is often possible even to reduce these costs because less material is used (the parts are exposed selectively to the laser beam, so the un-exposed powder can be reused).

The complexity of a certain mechatronic component is no longer dictated by the manufacturing process, but rather by the function it has to serve in a mechatronic assembly.

4. Conclusions

As a conclusion to the above, the more complex the geometry of a component, the more useful the laser selective sintering is.

It seems, however, that the future belongs to organ manufacturing based on stem cells and additive manufacturing technologies. There are already experimental attempts that are quite encouraging and the early field of tissue engineering is advancing rapidly. Stem cells are undifferentiated progenitor cells, from which a complex and fully functioning organ can develop. Although the processes are still far from being fully understood, stem cells may contain all the proteins necessary to create a complex organ, such as the heart or liver, provided that the cells are positioned in a porous geometric structure (Fig. 14).

Figure 14: Complex structure parts made from metallic nanopowders made and tested in INCDMTM laboratories

A main feature of the products made by rapid prototyping technology (small or unique series) is the possibility of approaching a range of products of high geometric complexity in short time with low costs compared to those produced by classical mold processing technologies such as rolling, forging and, machining. Thus, this technology is recommended for building complex products (often impossible to makewith classical technologies), preferably unique or very small series being very well adopted by the medical necessities of the necessity of personalizing of prosthetic and implantable elements, depending on the biometric specificities of each patient. It has been found that with the use of metal nanopowders, the obtained components exhibit physical properties superior to that of the cast components, exhibiting properties similar to those which have undergone hardning heat treatmens.

The complex laser selective sintering equipment allows the making of products with different physico-mechanical properties depending on the final destination of equivalent products.

Thus, in the case of toothed gears, flank consolidations have been achieved by increasing the number of passages of the laser spot on the desired area, thus achieving superior characteristics equivalent to conventional heat treatments. This way, we were able to build products capable to meet the requirements of use, which have exhibited several different areas of increased tenacity and high hardness areas obtained in a single forming process by using the laser selective sintering process.

We have noticed the increased efficiency of the process due to the high speed of transposition of the idea into a finished product with great possibilities of approaching complex geometries and their realization from metal nanopowder materials which, depending on necessity, can be of high hardness or implantable biocompatible materials satisfying a huge range of uses.

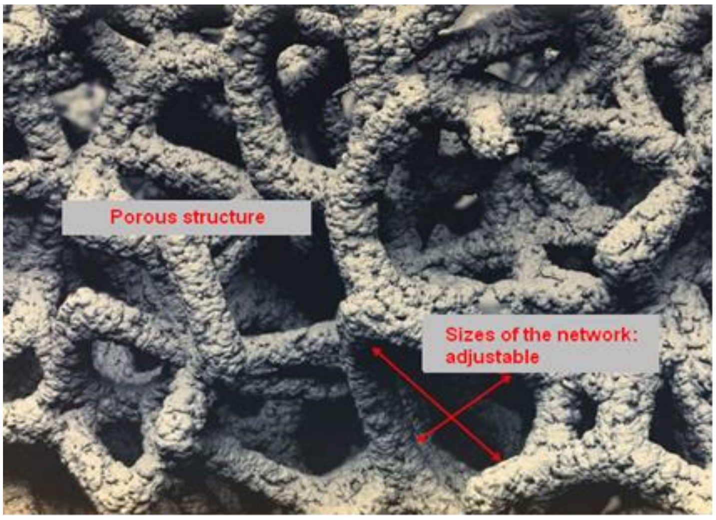


Figure 14: Porous geometrical structure

Such structures can be created using rapid prototyping, but the materials from which they are made should be bio-resorbable and must have the capacity to "melt" (metabolize), as the organ develops. Such requirements are met by bio-resorbable polymers such as polylactic acid and caprolactone, but their introduction in prototype manufacturing is still in the research phase.

Operating system to accomplish the construction of hardware system as well as the base development of software system, which realized the parallel and real-time control of multiple functional modules, solved the problem of synchronization and mutual exclusion between the modules and deadlock detection issue, and achieved the generation of multi-path time–varying signals and the high-speed serial dual-channel double-mode communication. This study proposed and designed a novel embedded intelligent video analysis system featured by stable operation, clear pictures and high transmission speed. But the system remains to be further improved due to the presence of many problems.

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