MICRO-NANOMETROLOGICALLY AND TOPOGRAPHIC CHARACTERIZATION OF METALLIC PIECES SURFACES OBTAINED BY LASER SINTERING

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Selective Laser Sintering is a method useful to get parts, assemblies and subassemblies with any geometric complexity, unachievable by other processing methods. A solid body of various types of materials (plastic, metal, ceramic) can be built by solidification of powder material following the successive exposure of powders layers to laser beam of different variable powers. Based on this idea, we used selective laser sintering to realize a microgripper in Rapid Prototyping Laboratory of National Institute of Research and Development in Mechatronics and Measurement Technique, Bucharest. Investigations of the obtained microgripper's surface were realized with a microscope type NTEGRA Probe NanoLaboratory NT – MDT. In this way it was possible to identify more clearly the uniformity and determining roughness parameters of the microgripper's surface. The values of determined parameters and images obtained after AFM analysis demonstrate that following the sintering process, surfaces with a medium uniformity were obtained. These are not completely uniform surfaces, but not totally non-uniform surfaces. The results obtained led to the main conclusion that the final piece obtained after selective laser sintering process requires a further micro-nanoprocessing to obtain a much higher uniformity.

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1. Introduction

"Rapid prototyping" technology proved to be a very flexible and useful tool in research work and development of prototypes.

Technological processes of rapid prototyping by selective laser sintering (SLS) lately developed are based on designing and intelligent manufacturing experience gained in stereolithography (STL) equipments, but also on the expanding of technological researches on some other special materials groups with mechanical and technological properties closer to the needs of functional assemblies of materials industry for micro-machines constructions (ceramics, ferrous and non-ferrous).

Selective Laser Sintering (SSL) is a family of technological methods that can build a solid body of various types of materials (plastic, metal, ceramic, including rare metals or with special physico-mechanical and biocompatibility properties) by solidification of powder material following the successive exposure of powders layers to laser beam of different variable powers [1].

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In this way it was possible to demonstrate that a thin layer (maximum 18 μm) of certain mixtures of powders, under the action of the laser beam can reach local, depending on the duration of exposure, the melting temperature that marks the transition of powders layer in liquid phase.

Based on the physical properties of used powders, immediately after cessation of laser beam, local solidification takes place almost instantaneously, getting a compact strap, made by directions of molecular chains, surrounded by a volume of powders unexposed to the beams mentioned.

Thus, we can get parts, assemblies and subassemblies with any geometric complexity, unachievable by other processing methods [2]. This intelligent technology is used to manufacture designs and prototypes for biomedical implantable products, functional prototypes for automotive and aerospace industry, high quality molds as well as design and static and dynamic testing possibilities of other mechanical parts for industry [3].

Moreover, the technological process is fully automated, does not require surveillance and electronic control is achieved by intelligent high-tech equipment. The main advantages are based on the fact that in this advanced technology, tools or specific tools parts are not necessary; it is not necessary any tool path generation or design of EDM electrodes; metal pieces are created directly in a single step; operation is simple and fully automatic; complex geometries such as freeforms, deep grooves and conformable cooling channels can be produced without an additional effort; unsintered powder can be reused, providing minimal waste.

Also, laser sintering technology and high-tech equipment (EOSINT) are conformable with the following standards:

- EN ISO 12100-1, Publication date: 2004-04 - Safety of machinery; Basic concepts, general principles for design; Part 1: Basic terminology, methodology (ISO 12100-1:2003); German version EN ISO 12100-1: 2003;
- EN 55011, Publication date: 2000-05 - Industrial, scientific and medical (ISM) radio frequency equipment - Radio disturbances characteristics - Limits and measurement methods (IEC/CISPR 11:1997, modified + A1: 1999); German version EN 55011:1998 + A1: 1999;
- EN 12626, Publication date: 1997-07 - Safety of machinery - Laser processing machines - safety requirements (ISO 11553:1996 modified); German version EN 12626:1997.

A series of different materials are available for use with EOSINT M systems, offering a broad range of industrial applications.

EOS CobaltChrome MP1 (table 1) is a fine powders (Co, Cr, Mo, Si, Mn, Fe, Ni) mixture for processing on EOSINT M 270 systems, which produces parts in a cobalt-chrome-molybdenum-based superalloy. This class of superalloys is characterized by excellent mechanical properties (strength, hardness a.s.o.), corrosion resistance and temperature resistance. Such alloys are commonly used in biomedical applications such as dental and medical implants (note: widely used in Europe, but much less so in North America), and also for high-temperature engineering applications such as in aero engines. This material is also ideal for many part-building applications such as metallic functional prototypes, small series products, individualised products or spares. Standard processing parameters use full melting of the entire geometry with 18 μm layer thickness. The mechanical properties are fairly uniform in all directions using standard parameters. Pieces made of EOS CobaltChrome MP1 can be proccesed, spark-eroded, welded, polished, polished and coated if required. Unexposed powder can be reused.

Table 1. The characteristics of the basic materials used in the laser sintering process [4]

Cobalt Chrome MP1	
Composition	Co 60 - 65 %
	Cr 26 - 30 %
	Mo 5 - 7 %
	Si max. 1,0 %
	Mn max. 1,0 %
	Fe max. 0,75 %
	C max. 0,16 %
	Ni max. 0,10 %
Average size	20 μm
Standard size	8,2 g / cm^3

The chemistry of EOS CobaltChrome MP1 conforms to the composition UNS R31538 of high carbon CoCrMo alloy. Pieces built from this material are nickel-free (< 0.1 % nickel content), sterilisable and suitable for biomedical applications, and are characterized by a fine, uniform crystal grain structure. They fully meet the requirements of ISO 5832-4 and ASTM F75 for molten CoCrMo alloys of implant, as well as the requirements of ISO 5832-12 and ASTM F1537 for wrought CoCrMo alloys of implants.

Other materials, available for EOSINT M systems, are, for example, stainless steel MS1, PH1, Ti64, TiCP.

2. Materials and methods

A "microgripper" has been made by the laser sintering method in Rapid Prototyping Laboratory of National Institute of Research and Development in Mechatronics and Measurement Technique INCDMTM, Bucharest.

The laboratory is based on “High-tech EOS M 270 [5] - Laser sintering system for metal powders” (fig. 1). EOSINT M 270 Titanium Version is a system for Direct Metal Laser-Sintering (DMLS), that works basing on the principle of carrying-out pieces made up of sintered metallic powders (toughened by local melting) with the aid of a laser beam. It builds metallic pieces directly on the basis of 3D CAD data, fully automatically, without requiring any tools and in just a few hours. The pieces are built up layer by layer by melting a fine metal powder using a laser beam, thereby allowing even extremely complex geometries to be created. This is a modelling process for high quality and resolution pieces generation, with great surface finishing and mechanical features similar to those obtained by applying conventional infusion proceedings. The ability to produce such pieces very quickly enables flexible and economic manufacture of individual or batches pieces, which in turn enable the identification of design or manufacturing problems at an early stage of product development and shortening of time to market.

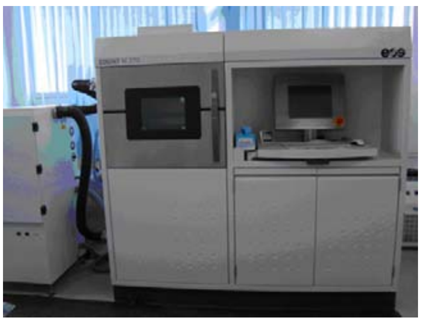


Fig. 1. Selective laser sintering machine (rapid prototyping) EOS M 270 Titanium Version

In the Xtended installation mode the EOSINT M 270 Titanium Version comprises the machine, an external recirculating filter system that draws inert gas out of the process chamber, purifies it and then feeds it back to the process chamber, as well as an external waste gases filter system connected downstream of the recirculating filter system, that purifies the flow of waste inert gas from the recirculating filter system. EOSINT M 270 Titanium Version contains many features to ensure high productivity and quality of piece, for example: powerful Yb laser fiber (200W); variety of metal materials optimized for various applications; building volume up to 250 mm x 250 mm x 215 mm (including building platform); high speed, high precision scanner with active cooling and directive sensor; F-Theta objective lens for precise laser beam focussing; dual focus system for optimal combination of details resolution and productivity; optimised exposure strategies; removable building platform for immediate reload.

Selective Laser Sintering equipment EOSINT M270 Titanium Version is in accordance with the following European standards:

- Machinery Directive 98/37/EC, Annex II A;
- Low Voltage Directive 73/23/ECC;
- EMC Directive 89/336/ECC.

With this system implemented at INCDMTM a “microgripper” was made. Surface of this piece was characterized to evaluate the uniformity obtained after selective laser sintering process.

Precise investigations of the microgripper’s surface were realized with a microscope type NTEGRA Probe NanoLaboratory NT – MDT [6]. Following this microtechnological investigation, it was possible to identify more clearly the uniformity and determining roughness parameters of the microgripper’s surface. Working principle of Atomic Force Microscope (AFM) is to measure the interaction force between tip and sample surface using special measuring probes, made of a cantilever with a pointed end. AFM images were processed using Nova SPM software. In this way, the roughness and some other tribological parameters of the studied surfaces were obtained (see „Results”).

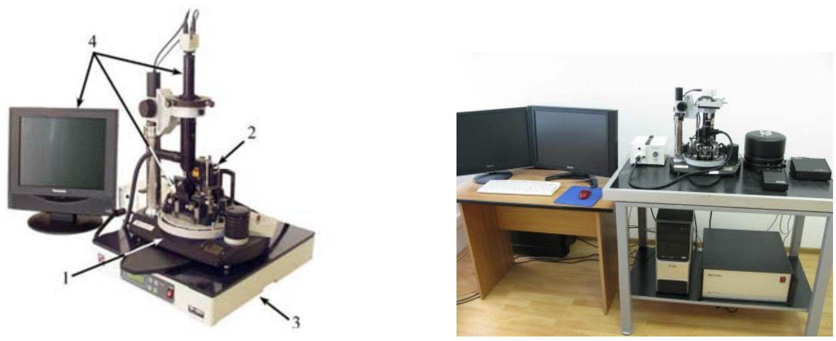
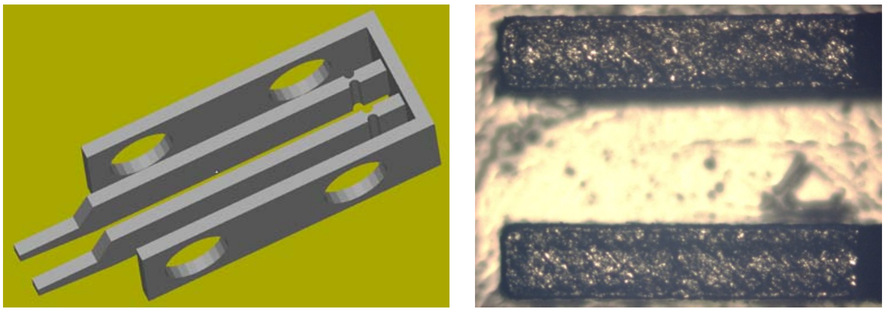


Fig. 2. AFM Microscope, NTEGRA Probe NanoLaboratory NT – MDT. a) 1 – base unit; 2 – measuring head; 3 – vibrations isolation system; 4 – optical viewing system.

3. Results

"Microgripper" [7] produced by the laser sintering method at INCDMTM is shown in Fig. 3 (a, b). For a complete characterization, the microgripper was divided into three sections whereon were performed micro-nanometrological and topographic characterizations using atomic force microscopy AFM. Fragments of 5 x 5 mm were characterized. The surfaces of both arms were also characterized in terms of topographic and metrological.



(a)

(b)

Fig. 3. Microgripper produced using EOS M 270 Titanium Version laser sintering system. (a) General view; (b) Microgripper arms seen using AFM.

Using AFM measurements surfaces roughness was accurately determined and all surfaces protrusions were observed. As is shown in the following examples, the roughness has different values (in different parts of the same microgripper). In fig. 4 are presented some of the results obtained after characterization of microgripper's surface. Values of average roughness of 123.54 nm were obtained. Topographic characterization of microgripper arms is presented in Fig. 5. For these, values of average roughness of 137.041 nm (arm 1) and 169.751 nm (arm 2) were obtained. These values and images presented demonstrate that following the sintering process, surfaces with a medium uniformity were obtained. These are not completely uniform surfaces, but not totally non-uniform surfaces.

We believe that it is possible to achieve a high uniformity surface after processing the surface obtained by selective laser sintering. Pieces obtained by this method can be further processed, if this is considered necessary, by any known mechanical process: milling, turning, drilling, boring, grinding, broaching, super-finishing.

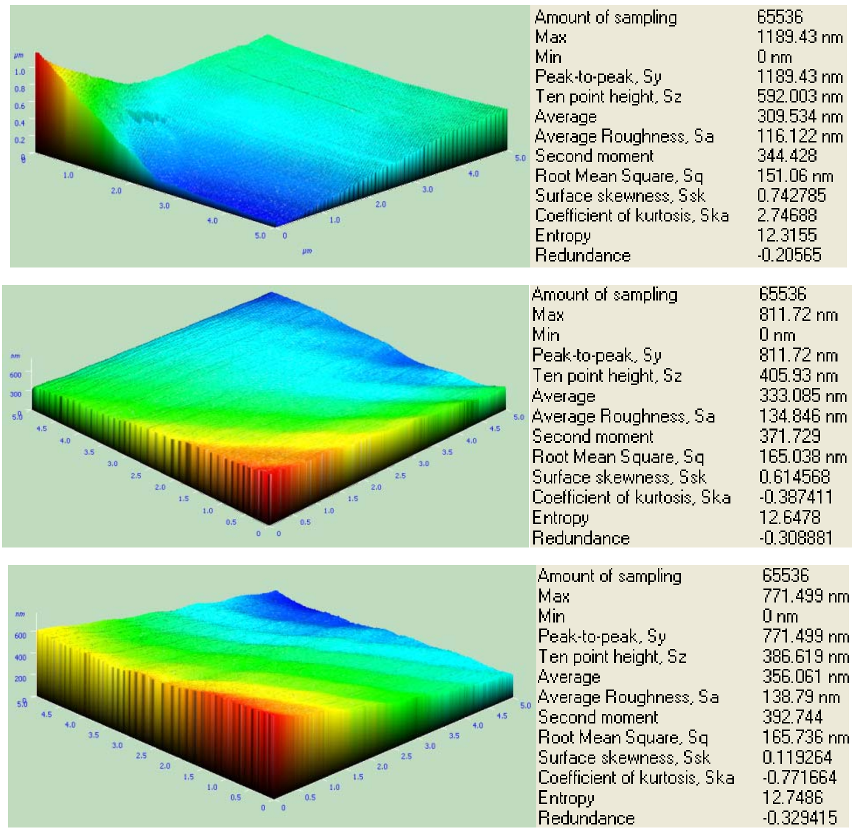
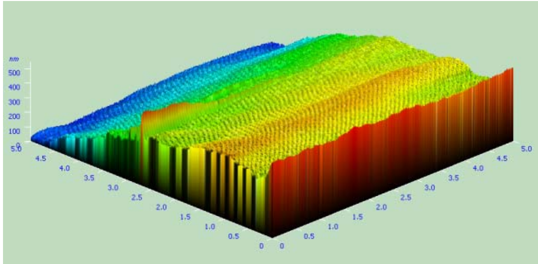
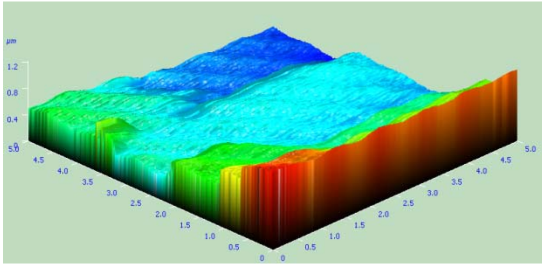


Fig. 4. Roughness of microgripper's surface measured using NTEGRA Probe NanoLaboratory



Amount of sampling	65536
Max	548.348 nm
Min	0 nm
Peak-to-peak, Sy	548.348 nm
Ten point height, Sz	273.849 nm
Average	298.981 nm
Average Roughness, Sa	108.844 nm
Second moment	324.48
Root Mean Square, Sq	126.089 nm
Surface skewness, Ssk	-0.715453
Coefficient of kurtosis, Ska	-0.802805
Entropy	11.9906
Redundance	-0.318185

1st arm



Amount of sampling	65536
Max	1218.68 nm
Min	0 nm
Peak-to-peak, Sy	1218.68 nm
Ten point height, Sz	609.541 nm
Average	404.37 nm
Average Roughness, Sa	189.89 nm
Second moment	471.234
Root Mean Square, Sq	241.96 nm
Surface skewness, Ssk	0.973417
Coefficient of kurtosis, Ska	0.597145
Entropy	12.9202
Redundance	-0.260514

2nd arm

Fig. 5. Roughness of microgripper arms surfaces measured using NTEGRA Probe NanoLaboratory

To check this, further researches and AFM microscopy studies will be conducted after processing the surface obtained by sintering.

4. Conclusions

This study is based on atomic force microscopy AFM. This was used to characterize the surface of pieces obtained by selective laser sintering.

Selective Laser Sintering, used to manufacture designs and prototypes for biomedical implantable products, functional prototypes for automotive and aerospace industries, molds and other mechanical pieces for industry, has many advantages.

Measurements performed in this study demonstrated the possibility of eliminating the disadvantage related to surface non-uniformity of piece obtained. The results obtained led to the conclusion that the final piece obtained after selective laser sintering process requires a further micro-nanoprocessing to obtain a much higher uniformity.

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