International Conference
1ST International Conference on Innovations, Recent Trends and Challenges in Mechatronics, Mechanical Engineering and New High-Tech Products Development
MECAHITECH'09
Bucharest, 8-9 October 2009

The New Generation of Rapid Prototyping Technology in Selective Laser Sintering for Metal Powders

Prof. Univ. Dr. Ing. Gh. Ion Gheorghe[1], Drd. Ing. Ciobota Nastase-Dan[1], Prof. Dr. Igor Drstvensek[2]
[1]National Institute of Research and Development for Mechatronics and Measurement Technique
Sos. Pantelimon 6-8, Sector 2, 021631, Bucuresti, ROMANIA
[2]University of Maribor, Faculty of Mechanical Engineering, Slovenia

ABSTRACT

In this paper will be presented a new technology, using new materials especially designed for complex geometries, extensively used in research-development and innovation area. Even highly complex geometries are created directly from 3D CAD data, fully automatically, in just a few hours and without any tooling. It is a net-shape process, producing parts with high accuracy and detail resolution, good surface quality and excellent mechanical properties.

Keywords: mechatronics, biomechanics, rapid prototyping, new materials and alloys, 3D modelling, CT scanning

INTRODUCTION

In this paper will be presented a new technology, using new materials especially designed for complex geometries, extensively used in research-development and innovation area. In order to do this we will go through presentation of the basic principles for the rapid prototyping technology, materials and capabilities.

This technology use the EOSINT M270 machine, which is an laser-sintering system for the production of tooling inserts, prototype parts and end products directly in metal.

Laser-sintering is the key technology for e-Manufacturing.

The implementation of this technolgy took place on Biomechatronics Department in National Institute of Research and Development for Mechatronics and Measurement Technique, Bucharest, Romania.

The Laser-Sintering System for metal powder is in conformity with the provisions of the European Union as follows:

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

We were the first Romanian entity to install DMLS equipment, and yearly demand for laser-sintering services has increased. We expect interest in titanium parts to follow the same strong demand curve.

Since 2007, INCDMTM work to identify product applications and introduce our systems to the manufacturing industry.

With the purchase of this new titanium-based system, INCDMTM stays among the leading suppliers who are willing to explore DMLS (Direct Metal Laser Sintering) and the breakthroughs it holds for innovative companies.

The EOSINT M 270 system uses laser-sintering to additively manufacture parts layer-by-layer. A range of metal materials is available, including steels, cobalt- and nickel-based superalloys and titanium alloys. EOS Titanium Ti64 is a pre-alloyed Ti6AL4V alloy with excellent mechanical properties and corrosion resistance, low specific weight, and biocompatibility.

Parts built from this alloy can be machined, spark-eroded, welded, micro shot-peened, polished and coated as needed. Typical uses include dental, orthopedic, and airframe applications.

We are also very pleased to become cooperation with one of the EU country, namely with Slovenia.

Prof. Dr. Igor Drstvensek from University of Maribor, Faculty of Mechanical Engineering established a wide cooperation between mechanical and medical research fields and develop several methods for custom implant production that helped surgeons to shorten the operating time and rise the outcome probabilities with better preoperative planning.

Together, we want to create an excellence research centre with a favourable climate for research and development of new technologies linked to medical imaging, 3D geometric modelling of osteo-articular structures, computer-assisted surgery and quantitative assessment of orthopaedic and surgical corrective methods.

Metal parts directly from CAD data

A number of different materials are available for use with EOSINT M systems, offering a broad range of e-Manufacturing applications. EOS CobaltChrome MP1 is a multi-purpose cobaltchrome-molybdenum-based superalloy powder which has been optimized especially for processing on EOSINT M 270 systems. Other materials are also available for EOSINT M systems, including a special-purpose cobalt-chrome-molybdenum-based superalloy for dental veneering application, and further materials are continuously being developed - please refer to the relevant material data sheets for details.

The ability to produce such parts very quickly enables flexible and economic manufacture of individual parts or batches, which in turn enables design or manufacturing problems to be identified at an early stage of product development and time to market to be shortened.

This new technology is used in top domains of engineering and medicine, both for civil and military purposes. The most advanced engineering entity, National Aeronautics and Space Administration (NASA), use the EOSINT M270 machine, Titanium Version.

CATEGORIES OF METAL POWDERS THAT CAN BE USED

Superalloy EOS CobaltChrome MP1 for EOSINT M 270

EOS CobaltChrome MP1 is a fine powder mixture for processing on EOSINT M 270 systems, which produces parts in a cobalt-chrome-molybdenum-based superalloy. This class of superalloy is characterized by having excellent mechanical properties (strength, hardness etc.), 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.

Figure 1. Example of EOSINT M270 parts build for industry in INCDMTM

The chemistry of EOS CobaltChrome MP1 conforms to the composition UNS R31538 of high carbon CoCrMo alloy. Parts 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 cast CoCrMo implant alloys, as well as the requirements of ISO 5832-12 and ASTM F1537 for wrought CoCrMo implants alloys except remaining elongation. The remaining elongation can be increased to fulfil even this standard by hot isostatic pressing (HIP).

This material is ideal for many part-building applications (DirectPart) such as functional metal prototypes, small series products, individualised products or spare parts. Standard processing parameters use full melting of the entire geometry with 20 µm layer thickness, but it is also possible to use the Skin & Core building style to increase the build speed. Using standard parameters the mechanical properties are fairly uniform in all directions. Parts made from EOS CobaltChrome MP1 can be machined, spark-eroded, welded, micro shot-peened, polished and coated if required. Unexposed powder can be reused.
Typical applications:
- prototype, one-off or small-series biomedical implants, e.g. spinal, knee, hip bone, toe and dental.
- parts requiring high mechanical properties in elevated temperatures (500 - 1000 °C) and with good corrosion resistance, e.g. turbines and other parts for engines, cutting parts, etc.
- parts having very small features such as thin walls, pins, etc., which require particularly high strength and/or stiffness.

EOS CobaltChrome SP1 for EOSINT M 270

EOS CobaltChrome SP1 is a cobalt-chromemolybdenum-based superalloy powder which has been especially developed to fulfil the requirements of dental restorations which have to be veneered with dental ceramic material and has been optimized especially for processing on EOSINT M 270 systems. Other materials are also available for EOSINT M systems, and further materials are continuously being developed.
EOS CobaltChrome SP1 is a Co, Cr, Mo and W based alloy in fine powder form. Its composition corresponds for type 4 CoCr dental material in EN ISO 16744 standard. It also fulfills the chemical and thermal requirements of EN ISO 9693 for CoCr PFM (porcelain fused metal) of dental materials (Ni content: < 0.1 %, no Cd or Be) and requirements of EN ISO 7504 and EN ISO 10993 regarding the biocompatibility and cytoxity of the dental materials.
This material is ideal for producing dental restorations. Standard processing parameters use full melting of the entire geometry with 20 µm layer thickness.
Standard processing parameters use full melting of the entire geometry with 20 µm layer thickness, but it is also possible to use the Skin & Core building style to increase the build speed.
Typical application:
- dental restorations (crowns, bridges etc.)

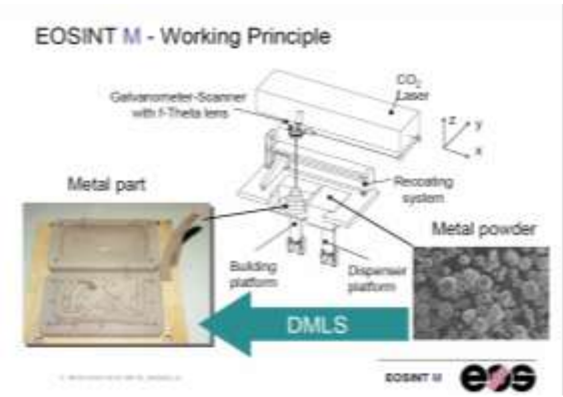

Figure 2. Eosint M working principles

EOSINT M – Advantages

– Net-shape metal parts created directly in one step; no binder removal, generally no post-machining;
– Very high geometric flexibility (e.g. free-forms, deep slots and curved cooling channels);
– Fully automatic operation, high productivity and low personnel costs; low level of training and experience necessary;
– Low material consumption; optimal usage of material, unsintered powder can be reused;
– Compatibility with other processes; parts can be milled, drilled, welded, etc.

THE MECHANICAL AND OPTICAL UNIT PRINCIPLES OF THE SLS MACHINE

Mechanical Unit

The mechanical unit contains the following components:

1. Recoater
2. Dial gauge with bracket
3. Building platform
4. Feeler gauges (graduation 0.05 mm)
5. Measuring strip

A. Adjusting motor for adjusting the Y-axis
B. Adjusting motor for adjusting the X-axis

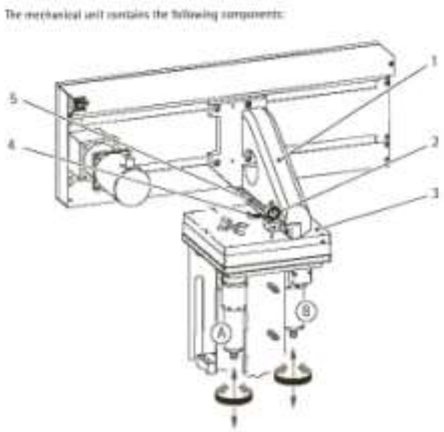

Figure 3. EOSINT M – mechanical unit

Optical Unit

The optical unit contains the following components:

1. Scanner with protective covers
2. Adjusting knob BEAM EXPANDER ADJUSTEMENT
3. Beam expander optics
4. Collimator with holder and protective cover
5. Laser fibre optic

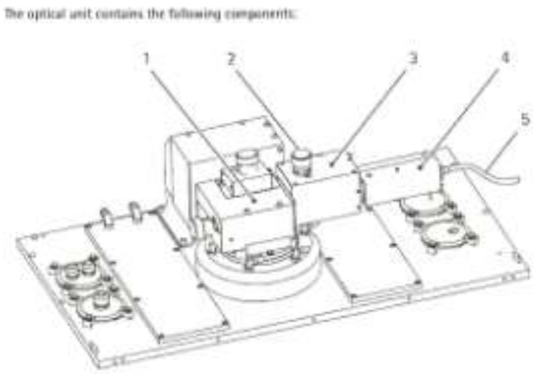

Figure 4. EOSINT M – optical unit

MECHANICAL AND BIOCOMPATIBILITY PROPERTIES

This is only a short list, because constantly are developed new powders with increased mechanical, physical and thermal properties.

Table 1. Categories of metal powders that can be used

Material name	Material type
DirectMetal 20	Bronze-based mixture
DirectSteel H20	Steel-based mixture
EOS MaragingSteel MS1	18 Mar 300 / 1.2709
EOS StainlessSteel 17-4	Stainless steel 17-4 / 1.4542
EOS CobaltChrome MP1	CoCrMo superalloy
EOS Titanium Ti64*	Ti6Al4V light alloy
EOS Titanium TiCP*	Pure titanium

Figure 4. A complex example of the great quality, fidelity of shapes in maxilofacial implantolgy

Titanium alloys offer a unique combination of properties for many biomedical applications.

Summary of important biomedical properties:

- Excellent corrosion resistance, biocompatibility and bioadhesion;
- Titanium and its alloys are used for many biomedical and dental applications (implants, screws, crowns...).

Property	Stainless steel	Titanium alloys	CrCo alloys	Nb/Ta
Corrosion resistance	o	++	+	++
Biocompatibility	o	++	+	++
Bioadhesion	o	++		
Price	++	+	+	-

Figure 5. Summary of important biomedical properties

Titanium alloys offer a unique combination of properties for many engineering applications.

Summary of important engineering properties:

— Light weight material with high specific strength (strength per weight)
— Ti6Al4V with high strength also at elevated temperatures
— The combination of mechanical properties and the corrosion resistance is the basis for applications in Formula 1 and aerospace.

Various grades of Titanium (alloys) are commonly used in industrial applications.

Table 2: Summary of the most important Ti materials

Material name	Composition	Typical applications
CP Ti grade 1	Ti; O <0.18%; N <0.03%	Medical and dental
CP Ti grade 2	Ti; O <0.25%, N <0.03%	Medical and dental, chemical industry
CP Ti grade 3	Ti; O <0.35%, N < 0.05%	Medical and dental
CP Ti grade 4	Ti; O < 0.40%, N < 0.05%	Medical and dental
Ti6Al4V (grade 5)	Ti; Al 6%; V 4%; O <0.20%, N < 0.05%	Aerospace, motor sport, sports goods, medical and dental
Ti6Al4V ELI	Ti; Al 6%; V 4%; O <0.15%, N < 0.05%	Medical and dental

CP = commercially pure, ELI = extra-low interstitials

Uses of CAD and Rapid Prototyping in medicine

Combined with traditional CT scanning techniques rapid technologies (prototyping and tooling) can be used as instruments for better (three-dimensional) visualization, simulation of procedures and treatment of patients.

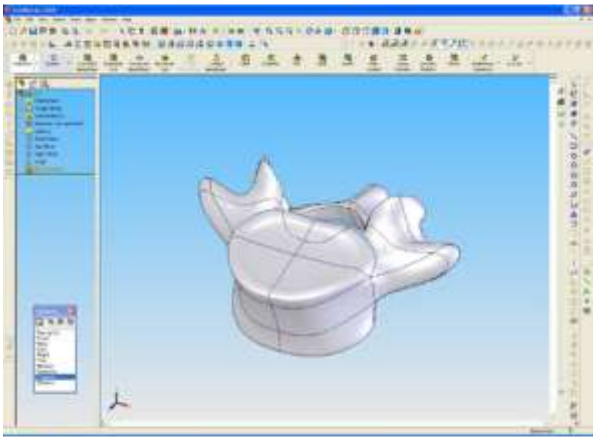

Figure 6. Parametric model in 3D CAD - SolidWorks

The CAD models, virtual model of a human body or a part of it can be used to study the problematic area before the actual operation starts. This is especially important in cases where functionality of the body part has to be re-established (orthopaedic surgery). Besides the continuous flow and other FEA methods that are used to calculate required mechanical and physical properties of the implant, the virtual models can also be used to study the surgical procedures, like directions of implantation, required preoperational treatments and preparations, etc.

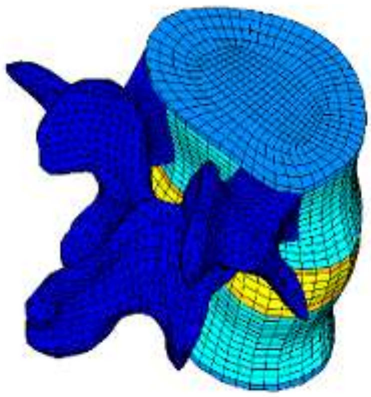

Figure 7. CAD model on human vertebrae used for FEM analysis

The easiest way to reconstruct the structure of a patient's bones is to use those CT images that already exist from previous treatments of the patient. A set of CT images can be converted into a three-dimensional, digital model using one of the available conversion software, such as: Mimics (Materialise), RapidForm (Inus Technology), 3D doctor (Able Software), Amira (Marcury Computer), or others. The input to this software is usually in the form of DICOM files and output is predominantly STL (Standard Tessellation Language), which can be directly used in most RP technologies to produce real models (Figure 1).

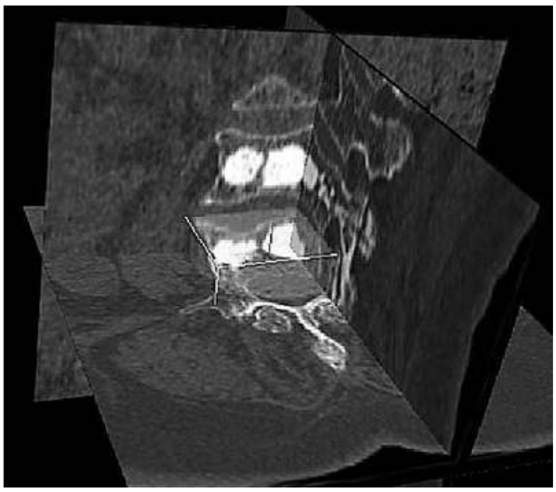

Figure 8. CT scan used for analysis

Three dimensional reconstruction of DICOM images in a form of STL file can be further manipulated by several CAD software. The usual 3D modelers based on parametric, volume modeling techniques are not very well suited to the task. Newer versions of these software packages (SolidWorks 2008, Delcam, etc.) enable manipulation of triangulated surface files, but using dedicated software, known from Reverse Engineering fields, such as Magics (Materialise), RapidForm, PolyWorks (InnovMetric), or others is much more effective in terms of time and effort. Using these software and STL models of scanned body parts, missing tissue can be modelled and saved as new STL files. These can be further processed or used for the production of real implant models by means of RP or RM technologies. CAD modelling of the implant was performed using several reverse engineering software packages.

Another interesting idea is to use a combination of CT and RMN images.

TECHNICAL AND ECONOMICAL ASPECTS; FUTURE TRENDS

EOS has successfully produced parts in Inconel alloys on EOSINT M 270.

Description

— Material type

•nickel-based superalloy, commonly used for high-temperature engineering applications such as aerospace turbine parts

— Alternatives

•can in many cases be substituted by EOS CobaltChrome MP1

— Commercialization status

•so far only in R&D

Figure 9. Example of the complexity of the design

EOS has successfully produced parts in gold on EOSINT M 270.

Description

— Material type

•precious metal, used in various purities / alloys for jewellery, electronics and dental restorations

— Alternatives

•currently no comparable commercial material available for EOSINT M

— Commercialization status

•so far only in R&D

Figure 10. Example of geometrical complexity

Various grades of Titanium (alloys) commonly used in industrial applications

Under the direct supervision of EOS specialist, Dipl. Eng. Deniz Demirtas, we build an impressive amount of difficult parts for neurosurgery and orthopaedic implants. The results were impressive.

Table 3. Mechanical properties of conventional barstock

Material name	Tensile strength (*) [MPa]	Elongation at break (*) [%]
CP Ti grade 1	240	24
CP Ti grade 2	345	20
CP Ti grade 3	450	18
CP Ti grade 4	550	15
Ti6Al4V (grade 5)	895	10

CP = commercially pure, ELI = extra-low interstitials
(*) Source: Euro-Titan Handels AG, Solingen, Germany

EOS Titanium - light alloy materials for prototyping and series production

Characteristics and applications
— Several versions will be available
- EOS Titanium Ti64 (Ti6Al4V)
- EOS Titanium Ti64 ELI (higher purity)
- EOS Titanium TiCP (commercially pure)

— Key characteristics
- lightweight
- high strength

•biocompatibility
— Typical applications
•aerospace and engineering applications
•biomedical implants

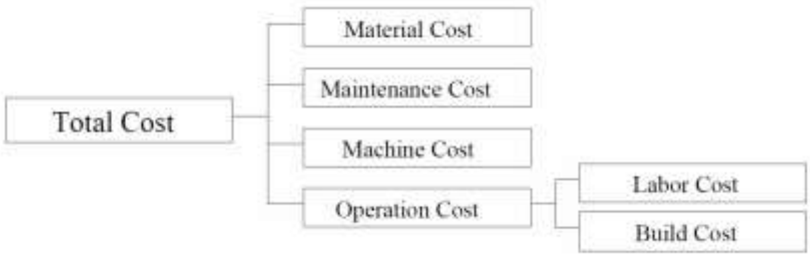

Figure 11. Parametric cost model

EOS Titanium Ti64 parts fulfil relevant industrial standards and relevant requirements.

Physical and chemical properties:

— Physical properties
•laser-sintered density: approx. 100 %
•only single pores
— Chemical properties
•laser-sintered parts fulfil requirements of ASTM F1472 (for Ti6Al4V) and ASTM F136 (for Ti6Al4V ELI) regarding maximum concentration of impurities
• oxygen < 2000ppm or 1500ppm
• nitrogen < 700ppm
— Bioadhesion
•cell growth tested with good results

EOS Titanium Ti64 produces parts with excellent mechanical properties.

Property	Value	
Ultimate tensile strength	approx. 1100 MPa	approx. 159 ksi
Yield strength (Rp 0.2 %)	approx. 1000 MPa	approx. 145 ksi
Young's Modulus	approx. 120 GPa	approx. 17 msi
Elongation at break	approx. 8%	
Hardness	approx. 450 HV ≈ 45 HRC ≈ 425 HB	

Figure 11. Mechanical properties

Figure 12. Different types of spinal implants from EOS

EOS Titanium Ti64 produces fully dense parts with dendritic, martensitic grain structure.

Metallurgy:
Typically martensitic structure with grains growing from layer to layer
•preferential Z orientation
•grain size >> layer thickness

EOS Titanium TiCP produces fully dense parts with very fine, uniform grain structure.

EOS Titanium TiCP produces parts with excellent mechanical properties.

Property	Value	
Ultimate tensile strength	approx. 567 MPa	approx. 82 ksi
Yield strength (Rp 0.2 %)	approx. 477 MPa	approx. 69 ksi
Young's Modulus	approx. 114 GPa	approx. 16 msi
Elongation at break	approx. 32 ± 5 %	

Figure 13. Mechanical properties

Main advantages of rapid prototyping technology

Finally, to name just a few of the key advantages of this technology:
- no tooling or part-specific tools required
- no tool path generation or design of EDM electrodes necessary
- metal parts created directly in one step
- simple, fully automatic operation
- complex geometries such as freeforms, deep slots and conformal cooling channels can be produced without additional effort
- unsintered powder can be reused, giving minimal waste.

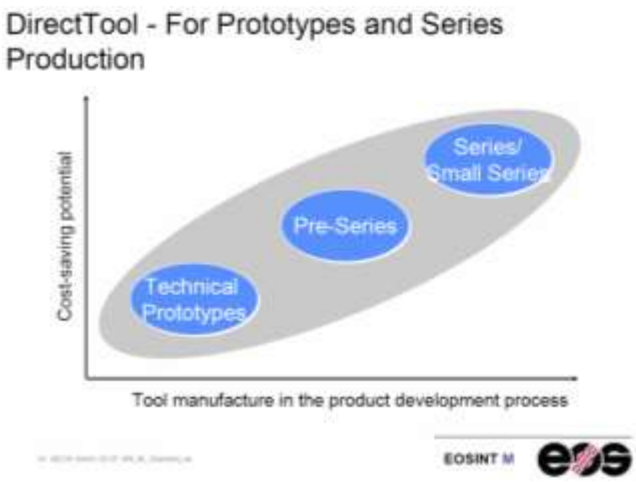

Figure 14. Comparable graph of conventional vs rapid prototyping manufacturing processes

APPLICABLE STANDARDS

The Laser-Sintering System for metal powder is in conformity with:

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

and 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 ISO 12100-2, Publication date: 2004-04 – Safety of machinery; Basic concepts, general principles for design; Part 2: Technical principles and specifications (ISO 12100-2:2003); German version EN ISO 12100-2:2003;
- EN 60204-1, Publication date: 1998-11 – Safety of machinery – Electrical equipment of machines, Part 1: General requirements (IEC 60204-1:1997 + Corrigendum 1998); German version EN 60204-1:1997;
- EN 60825-1, Publication date: 2003-10 – Safety of laser, Part 1: Equipment classification, requirements and user's guide (IEC 60825-1:1993 + A1:1997 + A2:2001); German version EN 60825-1:1994 + A1:2002 + A2:2001;
- EN 55011, Publication date: 2000-05 – Industrial, scientific and medical (ISM) radio-frequency equipment – Radio disturbance characteristics – Limits and methods of measurement (IEC/CISPR 11:1997, modified + A1:1999); German version EN 55011:1998 + A1:1999;
- EN 61000-6-2, Publication date: 2000-03 – Electromagnetism compatibility (EMC), Part 6-2: Generic standards – Immunity for industrial environments (IEC 61000-6-2:1999); German version EN 61000-6-2:1999;
- EN 12626, Publication date: 1997-07 – Safety of machinery – Laser processing machines – Safety requirements (ISO 11553:1996 modified); German version EN 12626:1997.

CONCLUSIONS

The functional and design capabilities of a metallic implant material are important with respect to the metal's ability to be formed, machined, and polished. An implant metal must be capable of being utilized with state-of-the-art metallurgical techniques. In addition, the implant device must remain functional during its expected performance life; it must not be degraded with time in the body through fatigue, fretting, corrosion, or impact loading. Titanium and its alloys meet all of these requirements.

Many different kinds of parts have been built in EOS Titanium Ti64.

Figure 15. Examples of parts built in EOS superalloy CoCr MP1 on INCDMTM

The principles of design, selection of biomaterials and manufacturing criteria for orthopedics implants are, basically, the same as for any other product that must be dinamically stressed. However, even the replacement of human tissues with materials similar in shape and density seems tempting, in fact this is much difficult task to undertake. That is because the living tissue has some extraordinary caracteristics including the capacity of remodeling both micro structural and macrostructural under the different directions loads.

Figure 16. Examples of parts built in EOS superalloy CoCr MP1 on INCDMTM for industry

Orthopedics will emerge as the single most promising source of future investor returns in healthcare, given the confluence of demographics, technology and global expansion. While other healthcare sectors such as cardiovascular devices, cancer or biotech may have been more lucrative in the past, what the American Association of Orthopedic Surgeons (AAOS) calls the "Decade of Orthopedics" provides the best opportunity for future investor profits in healthcare.

Figure 17. Examples of parts built in EOS superalloy CoCr MP1 on INCDMTM for orthopedy, neurosurgery and maxilofacial implants

A number of elements will create this opportunity for the next ten years:

- Increased life expectancies, which is a powerful demand driver that uniquely favors orthopedic devices.
- Technological innovation, which will change the entire complexion of the industry.
- Attractive industry economics and profitability.
- Combined, these elements will cause the industry to grow more than twofold, from $30 billion per year to $65 billion in the coming decade, resulting in as much as $40 billion of potential investor profits.

This combination of factors supports sustained, attractive industry valuations.
We must understand that science and innovations are keys to SUCCESS.

ACKNOWLEDGMENTS

The implementation of this revolutionary technology was possible through the research contract between INCDMTM - NATIONAL INSTITUTE OF RESEARCH AND DEVELOPMENT FOR MECATRONICS AND MEASUREMENT TECHNIQUE and NASR - National Authority for Scientific Research, through the NPRDI-II The National Plan for Research, Development and Innovation for the period 2007-2013, under the high authority of the Government of Romania.

GOVERNMENT OF ROMANIA
ANCS
Autoritatea Nationala pentru Cercetare Stiintifica

REFERENCES

[1] Bannon, B. P., and Mild, E. E., **„Titanium Alloys for Biomaterial Application: An Overview,"** Titanium Alloys in Surgical Implants, ASTM STP 796, H. A. Luckey and Fred Kubli, Jr., Eds., Americcan Society for Testing and Materials, 1983, pp. 7-15

[2] MCP HEK Tooling GmbH, Selective Laser Melting Technology, www.mcp-group.de

[3] Installation Conditions – EOSINT M 270, ED.01.08, 9212-0041, EOS GmbH – Electro Optical Systems

[4] Ciobota N.D., Titanium and Titanium Alloys for Biomedical and Industry Applications, National Institute of Research and Development for Mechatronics and Measurement Technique, Bucuresti, International Conference 6th Workshop on European Scientific and Industrial Collaboration on promoting Advanced Technologies In Manufacturing WESIC'08, Bucharest 25-26 September 2008

[5] http://en.wikipedia.org/wiki/Titanium_alloy

[6] http://www.healthpointcapital.com/about_us/

[7] Euro-Titan Handels AG, Solingen, Germany

[8] Igor Drstvensek, Natasa Ihan Hren, Tadej Strojnik, Tomaz Brajlih, Bogdan Valentan,Vojko Pogacar, Tjasa Zupancis Hartner., **„ Applications of Rapid Prototyping in Cranio-Maxilofacial Surgery Procedures,"** International Journal of Biology and Biomedical Engineering, Issue 1, Volume2, 2008, pp. 29-38

[9] Material data sheets – EOSINT M 2x0, EOS GmbH – Electro Optical Systems, Robert-Stirling-Ring 1, D-82152 Krailling / München

[10] Handzettel, EOS GmbH, 02-07, MS, M_ Standard_en

[11] http://www.eos.info

[12] http://www.pddnet.com/news-eosint-m-270-system-purchased-for-titanium-in-n-america-052209/