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DIRECT LASER MICRO MANUFACTURING: THE MANUDIRECT MACHINE

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Abstract: *The industrial machine realized in the MANUDIRECT project, is a direct micromanufacturing platform which allows virtual engineering concepts and designs to be translated into real products in one step, without prototyping stages. The platform is a combination of software and hardware innovations: virtual integrated engineering and materials design tools, nanophased materials obtained by the patented ball milling method, slicing SW, in-line geometrical and shape layer monitoring systems, temperature control SW, multiple powder grades feeder, localized micro powder fluxes and laser heating systems. The process was evaluated on a number of case study components, selected by industrial partners, using metal-ceramic composite for mechanical components and machining tools, stainless steel for bio-medical devices and Ni-based systems for aeronautics and power generation, W based systems for hi-tech devices.*

Key words: *rapid micro-manufacturing, micro laser sintering, nano-phased systems, gradient material, high resolution*

1. INTRODUCTION

Laser sintering is currently seen as a method for prototyping or limited component production. At the beginning of the MANUDIRECT project (September 2006) no rapid prototyping (RP) and rapid manufacturing (RM) of metal and metal-ceramic technologies were available worldwide for production of micro structured prototypes, on the scale of 50 microns resolution.

Laser sintering produces solids by fusing together successively deposited layers of suitable powdered materials with a high-powered scanning laser beam [Matteazzi et al., 1997]. The shape of the resultant object is accurately controlled by programming the path of the focused beam with data derived from a dimensional description such as a CAD file.

Although able to shape a wide variety of metals, ceramic and plastics, laser sintering is currently limited to the production of prototypes and short-run components. The objective of MANUDIRECT project was to extend the materials and process technology, to deliver a platform for the cost-effective volume manufacture of components directly from powders, with spatial resolution better than 50 µm.

The project has reached its final stage (will be concluded next February 2011) and has already reached its main object: realization of an industrial platform for micro-laser sintering. This result comes out after development of a series of tasks: development of integrated engineering and materials design tools; formulation of nanopowders with appropriate mechanical, physical and chemical or bioactive properties; provision of a multi-grade powder feeder for gradient-structured layering; implementation of laser source and focusing systems; design and fabrication of in-line geometrical and shape layer monitoring systems; integration of all hardware and software components into a micromanufacturing platform.

The platform is currently manufacturing metal parts, according to case-study components selected by the industrial partners as test-pieces. Process optimisation is running to fulfill the requirements of the final applications.

2. INNOVATIONS IN VIRTUAL DESIGN

The virtual design phase, preceding the manufacturing of the components, aims at choosing combinations of materials and manufacturing techniques that will result in optimum component performance. This phase is realized through the use of a software system infrastructure, that allows new materials and process models to be incorporated as required. This software system is based on a set of tools, developed within the project: material property modelling; a web-based database system; a set of design and manufacturing methodologies (Fig. 1). The two key properties of this software system are that it exhibits the flexibility to allow new material and process models to be incorporated as required and it is capable of handling nano-phase materials (i.e. use the mathematical models developed to predict key properties of nano-phase materials).

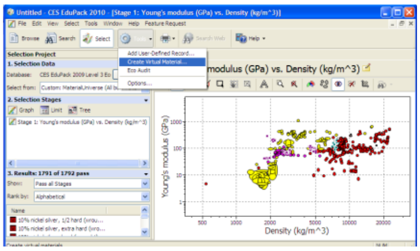

Fig. 1. CES selector Virtual material/composite synthesizer

In the second virtual step, the complex-shaped products design is changed into a series of instructions for the manufacturing machine through the Power Slice Software.

3. THE MANUDIRECT MACHINE

The core of the Manudirect direct laser sintering micro manufacturing platform (Fig. 2) is the sintering chamber, containing the laser and optical head. The powder feeders are hosted on the top chamber of the machine. The system can be equipped up to six powder feeders that allow the machine to realize a part with six different materials, in a single production batch, or a part with 3 materials having two different powders sizes. The laser sintering system is supplied with an automatic and user friendly interface and is able to build the parts starting from a CAD file, without operator intervention. According to the material or materials combination selection, the sintering process strategies are defined by the system, to achieve the best results in terms of shape resolutions and final mechanical properties. The laser sintering process works in a controlled argon atmosphere and the powder load and unload operations can be done during the production, without interrupting the process activities. All the sintering process parameters as laser beam power and focalization area dimensions, sintering temperature, axles control, powder feeding, process speed, part temperature and sintering chamber atmosphere are controlled in real time.

Fig. 2. Manudirect industrial platform

Ten systems of nanophased powders for direct manufacturing were developed using high energy ball milling technology [Becker et al., 2005]. Material development was based on experimental approach including intense design activity and selection of best material combinations for components. Developed nanopowders systems were first tested using different material characterization techniques then were preliminarily validated by laser sintering process on the industrial prototype machine. Developed materials were supplied also for the validation of developed predicting models and for validation of the platform components performances.
The platform is equipped with automatic measurement system to perform quality inspection/control of the realized part, in order to identify any deviation from the part CAD mechanical drawing. The part realized and scanned is verified on the entire volume with a Multifocus equipment able to reach resolution up to 10 µm. Multifocus measurement system can acquire the entire part 3D geometry in only one minute but with an accuracy of 10 microns. In parallel, another measurement tool, the Confocal system, is used to acquire only one or two part sections (a line width of 1 or 2 micron) with an accuracy on Z axis better than 1 micron. The Confocal measurement system is used to acquire only part section, because the time required for the inspection is very high, compared with the Multifocus one, but the combination of the two measurements guarantees a very high precision measurement system of the realized part.
The first industrial version of the platform has the following main characteristics:

- Manufacturing platform capable to produce fully dense materials;
- enhanced geometrical resolution (60 µm);
- extended range of materials available (metal/metal and metal/ceramic composites, stainless steel, Ni-based systems and W-based systems);
- Material Properties predicting system (CES selector);
- gradient structures;
- unique combination of process and real time analyses: geometrical measurement systems: Confocal (1 µm accuracy on z axis) and Multifocus (10 µm accuracy);
- system with a dual production scheme, high resolution- low productivity and high productivity-low resolution (laser beam size available during sintering process: 20-40-60-120 µm).

4. REAL PRODUCTS

At present stage the manufacturing of metal components, selected by end users as case studies, is running with encouraging results in terms of spatial resolution, accuracy and density. The first testing phase aimed to evaluate the capabilities of the laser-sintered nanomaterials and to test their suitability for use in their target application.
Trials were carried out using the AISI420 alloy and a simplified thin wall reference sample. This demonstrated that walls with a thickness between ~60 to 95 µm and a height of 4mm can be produced. In addition, this also showed that walls can be produced with reduced weld spatter and sintering beads attached. These very positive results show the potential of the Manudirect platform. The achievement of a 60 µm wall thickness is a large achievement in this field.
A set of samples with more complex geometries have been realized, as prototypes of the case studies selected by end users: a grid with four parallel walls, a hollow cylinder, a 12-edge ring, blade shapes (Fig. 3, anticlockwise).

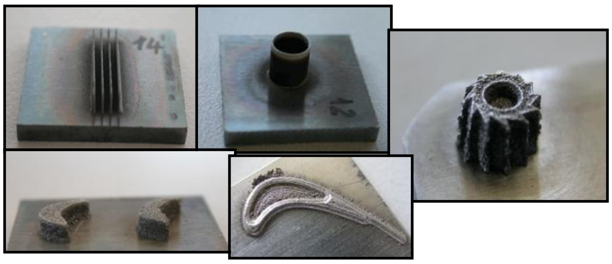

Fig. 3. Realized geometries

The samples were first made by AISI420 alloy, as reference material, then the grid and the cylinder were realized also in Tungsten base material, the blade was sintered also with Ni based superalloy. These results verified the good capability of the slicing software combined with the laser sintering process in the realization of components starting from complex virtual design. From the point of view of geometry resolution and accuracy, samples were analyzed with the on board automatic measurement system and, then, off line by means of optical and electron microscopes. Measurements revealed that geometry resolution is about 60 µm. Further analysis showed that hardness for AISI420 has reached values of 650-700 $HV_{0.1}$.
Currently machine allows to produce 3D 20x20x20 mm part and, by modifying the base plate dimension, of 50x50x50 mm part can be reached. Best results were achieved with tungsten base material both in terms of geometry resolution and in number of different shapes.

5. CONCLUSIONS

Realisation of this bottom-up fabrication method will allow virtual engineering concepts and designs to be translated into products in one step, without the need for prototyping stages. MANUDIRECT will thus have considerable economic impact in many industrial sectors, including microengineering, biomedical devices and even in the macro-scale manufacture of parts for automotive, aeronautical and other applications.

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