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DIRECT FABRICATION OF METAL COMPONENTS USING LASER FORMING TECHNIQUES

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Abstract: *This paper will focus on the direct fabrication of metal components by using laser forming techniques in a layer-by-layer fashion. Since then both the range of commercially available powder materials and also the properties of the resulting parts have indeed improved considerably, especially in the metals area. At the same time, the focus has changed from non-standard to conventional materials. This trend has been driven by the increasing interest in rapid manufacturing, i.e. direct manufacturing of end-use parts. Since such parts are typically intended to substitute existing products or components which are produced using conventional manufacturing processes such as investment casting, die casting, forging and machining, users often demand comparable materials (as similar as possible). This is in order to achieve acceptance for the new products, despite the still relatively low awareness and acceptance of laser-sintering, and also to minimize the effort for testing, certification etc.*
Key words: *Rapid Prototyping & Manufacturing, Selective laser melting, SLM principles.*

1. INTRODUCTION

Additive Manufacturing is the construction of finished products and prototypes using additive rather than subtractive methods. Additive Manufacturing systems join liquid, solid or powder materials layer by layer to create finished 3D objects, whilst subtractive manufacturing methods involve the removal of material until a desired shape is achieved and the assembling of the machined parts to complete the final product. The actual manufacturing process of a part is still a lot slower than the process involved in producing the same part by subtractive manufacturing techniques. The direct manufacturing of parts using Computer Aided Design (CAD) makes it an invaluable manufacturing technique because unimaginable design possibilities are introduced that have not been available to product designers before. The layer-by-layer building techniques also eliminate the need for special tooling and enable the production of highly complex designs. The integration of production planning and testing procedures into the product development phase also aids fast product design and development duration. Taking into account the short product development time, the vast design capabilities and the relatively slow manufacturing process, Additive Manufacturing lends itself towards the manufacturing of a small batch of complex customized products.

Additive Manufacturing techniques have the ability to manufacture unique products that meet customer requirements. In the past, Additive Manufacturing systems were used primarily for making prototypes but in recent years their application to the manufacturing industry has been explored and further developed.

Additive Manufacturing methods have emerged as an alternative to conventional subtractive manufacturing methods in industrial, consumer, medical, military and other such markets because products of greater complexity can be designed, manufactured and quickly released into the market in true

accordance with the needs of the customer. Additive Manufacturing can be split up into three categories, namely:
-Liquid-based processes
-Solid-based processes
-Powder-based processes

The oldest Additive Manufacturing process is Stereo-lithography, which is a liquid-based process that uses an ultraviolet laser to cure a particular resin layer-by-layer, thereby creating a solid 3D object. The patent for the first commercial Stereo-lithography machine was on the market in 1987. The most recent metallic powder-based systems are capable of processing metals such as stainless steel, tooling steels, titanium alloys, aluminium cobalt-chrome and others [1].

2. ADVANTAGES OF RP

RP implies that complex shapes are as easy to build as simple shapes, since the planning and manufacturing processes are automated. RP machines are actually "three dimensional printers" that allow designers to quickly create tangible prototypes of their designs, rather than just two-dimensional pictures. The some of the main benefits of RP are [2]:

1-RP allows Designers to make products faster and less expensively.
2-Rapidly Prototyped parts show great time, cost and material savings.
3-Quick product testing is possible.
4-Expeditious design improvements.
5-Fast error elimination from design.
6-Optimize part design to meet customer requirements, with little restrictions by manufacturing.
7-Minimize time consuming discussions and evaluations of manufacturing possibilities.
8-Minimize time and cost for design, manufacturing and verification of tooling.
9-Reduce the labor content of manufacturing.
10- Reduction in material cost waste disposal cost, material transportation cost, inventory cost.

Figure 1 shows the procedure of produce the product the part in all the RP manufacturing processing.

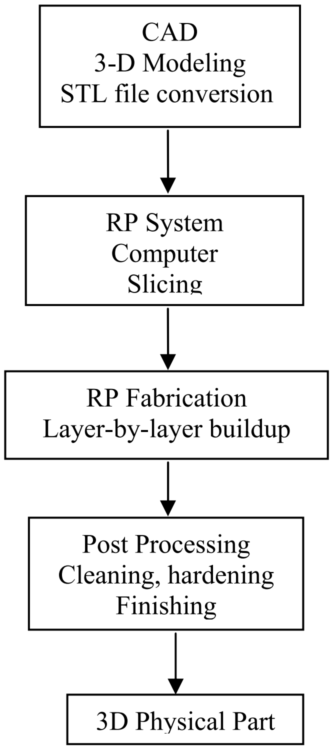


Fig. 1. RP process chain

3. SELECTIVE LASER MELTING

Selective laser melting is a new generative manufacturing technology used for the rapid manufacturing of metal parts with almost unlimited shape complexity. Through the use of standard metal powder in combination with layer-by-layer manufacturing this innovative process opens new possibilities in different industrial fields.

The melting process during Selective Laser Melting yields parts with a density close to 100% and standard materials like Tool steel, Titanium, Nickel and Cobalt alloys can be processed. Mechanical properties of parts, like tensile strength and hardness, match the material specifications [3].

Figure (2) repeating the operation up to the full height of the component can be produced in very short delays.

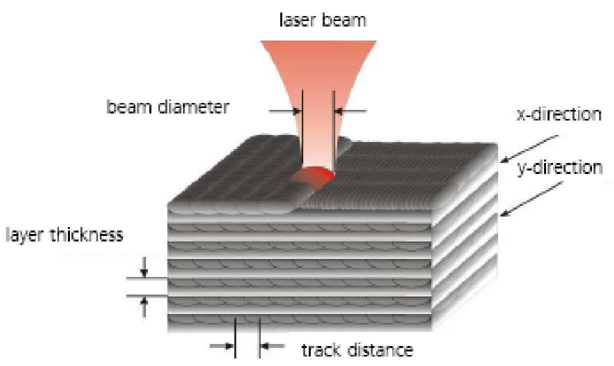


Fig. 2. The operation of SLM [3]

4. BASIC PRINCIPLE OF SLM PROCESS

Such as all the so called rapid prototyping processes, a 3-CAD file converted to the "stl" extension is sliced in layers of a definite thickness

The scanning pattern "Sorted" is a raster pattern with x-direction and y-direction. This forms layer to layer, starting from the first layer. An overview of the scanning patterns is given in Figure 3 [4].

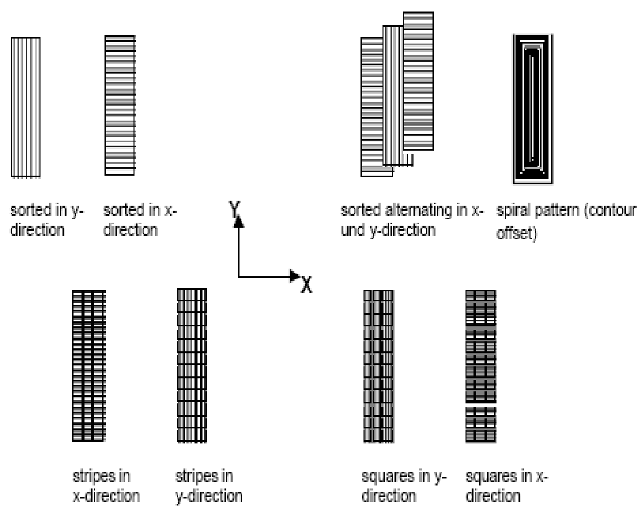


Fig. 3. Scanning patterns used in SLM

Figure(4) shows the selective laser melting system. The pulsed laser head attached to an x-y table is scanned onto the powder bed. Figure (5) shows the hatching method. One hatching cycle consists of: outline scanning; outline and x direction scanning; outline built completely; scanning; outline and y direction scanning. This pattern is repeated until the component is built completely [5].

Laser power intensity, scan rate, hatch distance, layer thickness, and number of layers were varied influence on the amount of residual stresses and variation of the thermal gradient by using different laser scan lengths, Figure (6) shows most of these parameters having influence on the part quality and time to completion.

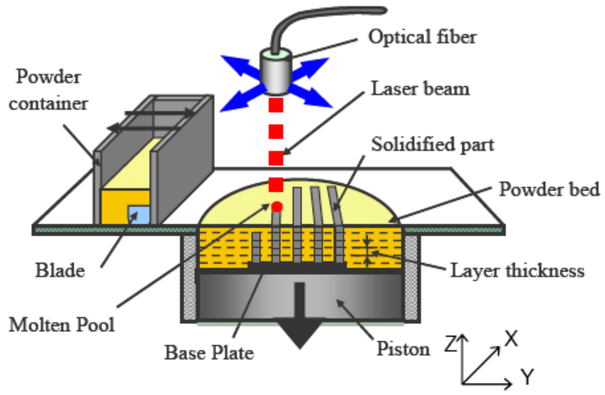


Fig. 4. Working principle of the system

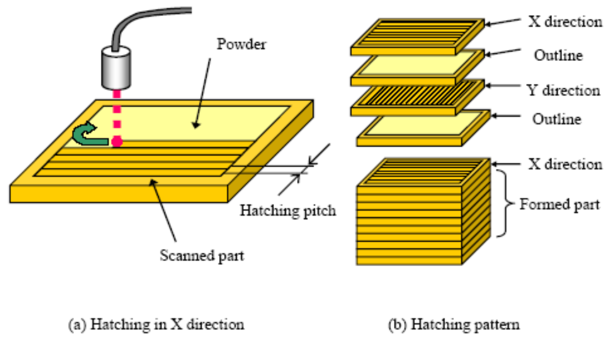


Fig. 5. Hatching method

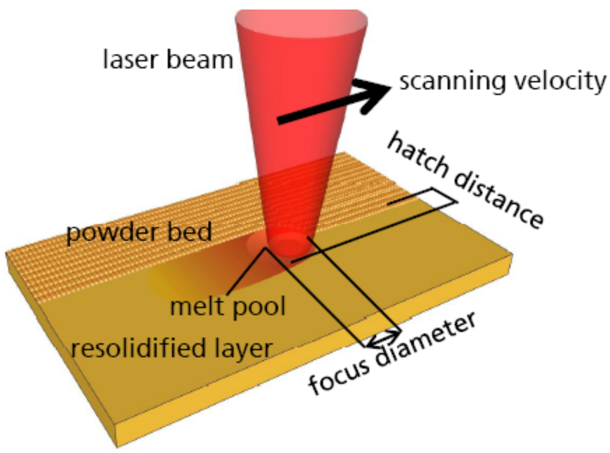
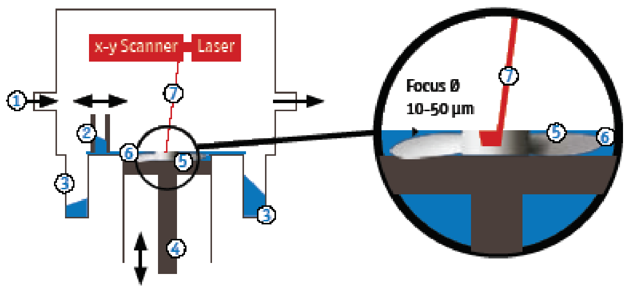


Fig. 6. Influence parameters in SLM process [6]

The process is carried out in a closed chamber and argon is flushed continuously in order to minimize oxygen and nitrogen pick-up [7].

The metal powder being melted locally by an intensive laser beam, which traces the layer geometry. The building platform is lowered by a defined layer height, coated with the metal powder, and melted again [2].

The workpiece is fabricated layer by layer in this manner. The duration of the process, which takes place in closed inert gas atmosphere, is dependent on the amount of material used and the number of layers as shows in Figure 7 [8].



1- Inert gas (Argon)
2- Recoater (or wiper)
3- Powder container
4- Height adjustable work platform
5- SLM component
6- Powder bed
7- Minimum laser focus

Fig. 7. Basic principle of SLM process

Basic binding mechanisms involve solid state sintering, chemically induced binding, liquid phase sintering, partial melting and full melting.

Many subcategories can be distinguished based on the type of structural or binder powder composition: single component powder grains (single material or alloy), composite powder grains, mixtures of different powder grains, distinct binder material (sacrificial or permanent) etc. [9].

Liquefied by the laser beam it acts as a binder for the structural grains (Fig. 8).

5. SOME OF MATERIALS USED IN SLM [10]

1- Tailored (non-standard) materials Direct Metal 20 is a bronze-nickel-based, multi-component metal powder, and is the most recent version of a family of powder materials dating back to the very first tailored powder which was developed in 1994.

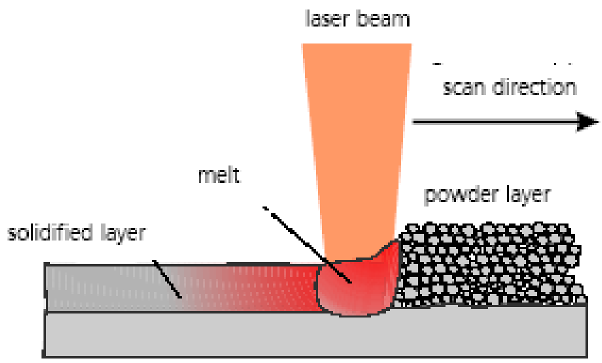


Fig. 8. Binder for the structural grains [6]

Thicker layers can be processed, as well as combinations of different layer thicknesses within the same part to optimize both surface quality and build speed.

This material was developed primarily for rapid tooling applications, and therefore optimized for high build speed together with excellent detail resolution and surface quality, easy polish ability and adequate mechanical properties.

2- Stainless steels are widely used in many industrial applications and are typically characterized by good mechanical properties and corrosion resistance at relatively low cost. Very acceptable ultimate tensile strength and remarkably high elongation corrosion resistance are required, for example medical instruments where high toughness and ductility is desired.

3- Super alloys are a class of metals characterized by very high strength and typically also very good performance at high temperatures. They are generally either nickel- or cobalt-based alloys. Nickel-based super alloys are mainly used in aerospace and similar applications, whereas cobalt-based super alloys are used both for aerospace and also biomedical applications such as implants.

4- Light alloys are widely used in industry. The most commonly used types are Aluminum - or titanium-based. Titanium-based alloys are commonly used in applications with demanding requirements, but parts are typically expensive to manufacture conventionally, because titanium is generally difficult to cast and to machine. This makes titanium alloys an ideal target for e-Manufacturing. This material is characterized by excellent biocompatibility and corrosion resistance, in addition to its good mechanical properties and low specific weight. It is mainly used for manufacturing biomedical implants.

In contrast, Aluminum alloys are typically easy and cheap to cast and to machine, enabling low-cost conventional manufacture. Typical applications include parts requiring a combination of high mechanical properties and low specific weight, e.g. structural and engine components for aerospace, motor racing applications and biomedical implants etc.

5- Other classes of metals in addition to the materials mentioned specifically above, many other materials have also been successfully processed by SLM, even if they have not yet been developed to commercial status. These include other stainless and tool steels, other light alloys, hard metals, refractory metals and precious metals (gold, silver etc.). Parts have also been successfully built in non-metallic materials such as ceramics and metal-matrix composites.

6. PRODUCTION BY SLM AND SOME DIFFICULTIES

Several samples made from Titanium and its alloys composite materials where manufactured to observe the ability to produce holes in the sample made in the 3D model in deferent sizes and shapes.

These samples were produced using different laser powers (70W, 100W, 160W, respectively) to see the impact of differences in the quality and time of production.

All parts were made in the Rapid Prototyping laboratory of the Technical University of Cluj-Napoca, on the MCP Realizes 250 machine manufactured by MCP HEK Tooling GmbH Company in Germany. This machine is equipped with a Ytterbium Fibber laser system with a λ=1076.5nm wavelength and a maximum power of 200W. The thickness of the powder layer can vary between 0.03mm to 0.1mm. Laser spot diameter with which the parts were made was 0.15 and 0.2mm.

Figure 9 produced by MCP Company in Germany. This system uses selective laser melting technology.

Fig. 9. SLM machine

From the practical experience of production of these samples one may observe that the Laser power intensity used to produce samples and type of material used at the productive batch effect on the time of the process and quality of the products, such as when produce of pure titanium sample, as show in Figure (10) are the specifics and time requirement for the production of samples typical and the quality of the samples manufactured is typical too.

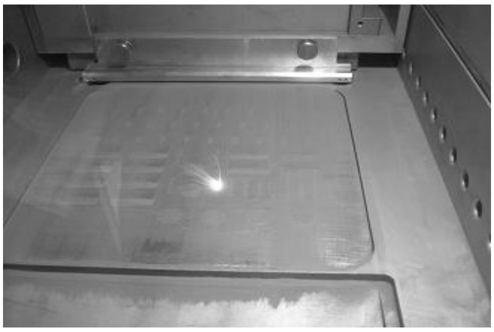


Fig. 10. Chamber of SLM produce pure Titanium

However, for some of the laser powers used it was difficult to remove the sample from the working plate, leading some times to the bend of sample during the removal from the working plate at the degree of 160 watts for pure Titanium samples shown in figure 11.

Fig. 11. The bend of sample during the removal

Difficulty occurred when producing samples made from higher complexity compounds (metals + ceramics). In some case, the manufacturing process failed. The quality of the samples was poorer than for the samples produced from pure metals powder, Figure (12) shows the bending of a sample due to the thermal stresses.

It is also difficult to remove the samples made of complex compounds from the working plate due to the risk of breaking the sample as shown in figure 13, in such case, it is necessary to change the type of support.

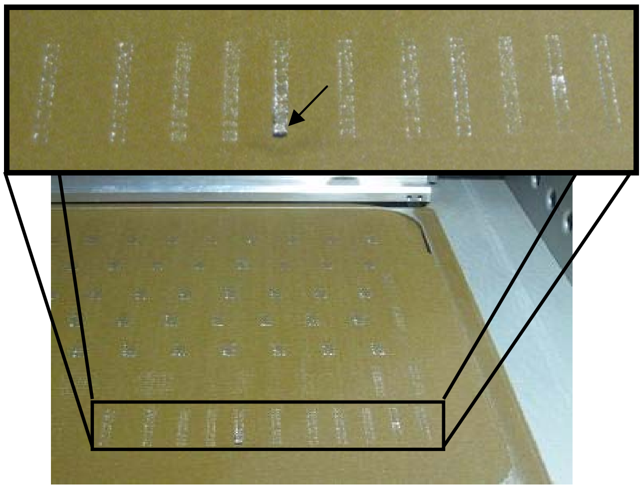


Fig. 12. Chamber of SLM produce complex compounds of Titanium

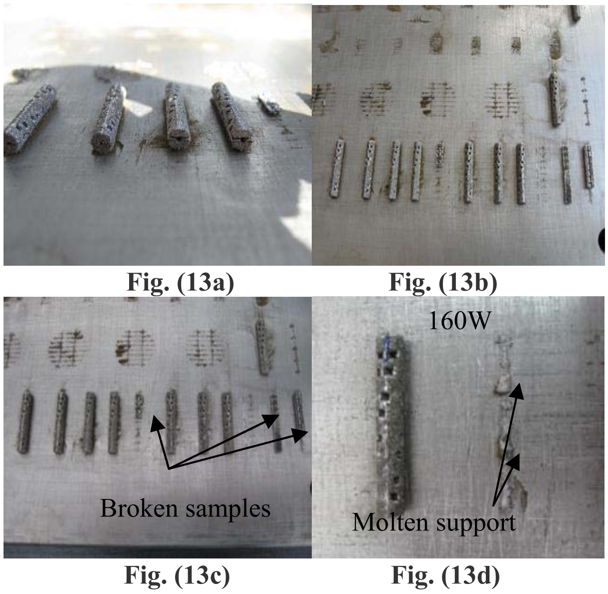


Fig. 13. Samples from Titanium component before remove from the base plate

When producing samples made from compounds of titanium, it was increasingly difficult to remove the parts from the supports at higher laser power. One may notice in figure 14 the deferent between the sample having circular holes (group B) and those having rectangular hole (group A) made using the same process parameters and the same compound.

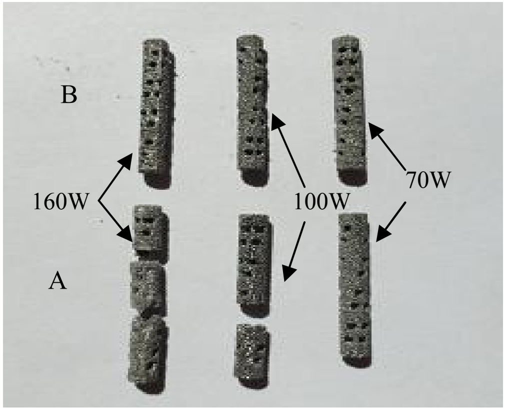


Fig. 14. Internal holes square and circle section

The small size of the internal holes increased the difficulty of manufacturing, especially at high laser power, as shown in Figure 15. We obtained the best manufacturing accuracy at 70W, and worst accuracy at 160W. We also found that the holes smaller than 0.4mm could not be properly manufactured on this machine.

Fig. 15. Internal holes and the best accuracy

7. A*CKNOWLEDGEMENTS*

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8. CONCLUSIONS

This paper has demonstrated the possibilities and limitations of different SLM processes as rapid manufacturing techniques for producing metal components.

The aim of this paper was to describe the capabilities and performances of the SLM process.

It was found that the process has a good accuracy for nominal dimensions over 0.4 mm; the dimensional error increases for values lower than 0.4 mm because the nominal size is gradually approaching to the laser spot diameter.

The complexity of the metals powder composition, especially when adding ceramic materials, influences the manufacturing process and the removal of the sample from the support. The shape of the internal holes also affects the quality of the samples.

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FABRICAREA DIRECTĂ DE COMPONENTE METALICE, UTILIZÂND TEHNICILE LASER DE DEFORMARE

Rezumat: Această lucrare se va axa pe fabricarea directă a componentelor metalice prin utilizarea tehnicii de formare cu ajutorul laserului strat cu strat. De atunci, atât în gama de materiale sub formă de pulberi, disponibile din punct de vedere comercial şi, de asemenea, îmbunătățirea considerabilă a proprietăților şi rezultatelor obținute asupra componentelor, în special în domeniul metalelor. În acelaşi timp concentrarea s-a schimbat dinspre materialele neconvenționale spre cele convenționale. Aceste tendințe au dus la creşterea interesului spre domeniul de prototipare rapidă, prin folosirea directă a pieselor fabricate. Deoarece aceste componente sunt de obicei destinate să înlocuiască produsele existente, care sunt produse obținute prin procedee de fabricație convenționale, cum ar fi turnarea, turnarea în matrițe, forjare şi de prelucrare, utilizatorii de multe ori cer materiale comparabile cu cele clasice (cu valori mai apropiate cu atat mai bine). Acest lucru este cu scopul de a obține acceptul pentru produse noi, în ciuda gradului scăzut de conştientizare şi acceptarea sinterizarii cu laser şi, de asemenea, pentru minimizarea efortului de testare, certificare, etc.

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