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A Review about the Technologies of the Additive Manufacturing

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Abstract
This paper present a short overview regarding the Additive Manufacturing (AM) (also named Rapid Prototyping) technologies developed during last years. The principles of the most important technologies such as, Stereolitography (SLA), Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Fused Deposition Modeling (FDM), Electron Beam Melting (EBM), and Laminated Object Manufacturing (LOM) are described in this paper. It was realized a comparison between the methods regarding the cost, materials and the complexity of the parts which are difficult to achieve by classical methods. It was presented a part regarding the structure of powder seen at scanning electron microscope (SEM) obtained by atomization and the surface morphology of the specimens fabricated from the powder obtained using argon and air. Also it was presented some samples made by SLM and by EBM. About the cost, the researchers said that the equipment and services of additive manufacturing in 2020 will reach at 11 billion euros. AM can produce prototype parts with similar properties or better than conventional means.

Keywords
additive manufacturing, selective laser sintering, selective laser melting, fused deposition, modeling electron beam melting

1. Introduction

Nowadays the additive manufacturing is one of the most used technique for obtaining prototypes and models which can be applied in vison concept evaluation or functional testing in various stages of the product development process [1, 2].

Additive manufacturing is a technique for making 3D pieces by adding the layer by layer of a material following the geometry of the digital model. The standard format for most 3D printers is .stl, through which digital models are transferred directly from computer. The stl file describes the surface geometry of the three-dimensional object. The additive fabrication offers the advantage of creating pieces with complex geometric shapes in a very short time with less human intervention. The function principle of the rapid prototyping could be observed in the Figure 1.

The large number of patents in this field in recent years demonstrates the intrigue in this area and the problems that it faces. For example: Ying She and James Beals in 2015 patend "Powder metal with attached ceramic nanoparticles", and in 2017 "Method of coating metallic powder particles with silicon", which has significant improved the properties of the powder. Powder properties are very important because can influence the porosity and the appearance of cracks in the parts. [3, 4]

Additive Manufacturing technology, developed in national laboratories, universities is now being adopted by industry and start to grow in importance due to reduced costs and manufacturing times. Has developed extremely rapidly over the past decades in automotive and aerospace industries, also has brought essential improvements in medical field, such as implants and human tissues [5, 6].

2. Main Additive Manufacturing Technologies

2.1. Stereolithography (SLA)

It was the first technology to make 3D pieces, taking the data directly from the CAD model, being designed by Charles Hull in 1982. The principle is based on the solidification on of photopolymerizable liquids in contact with light of a certain color. Like other processes, it starts from a CAD model, but also design support structures for fixing the workpiece in the construction platform in order not to distort or break parts of the workpiece. The material is placed in a vat and the beam selectively solidifies the desired surface by building the 3D piece. After solidification of a layer, the piece is submerged in the polymer, with a thickness of about 0.02 - 0.2 mm so that the cycle is repeated until the piece is completely made.

The process can produce one part in two variants: point-to-point solidification or layer by layer solidification. Finally, support structures are removed manually [7, 8].

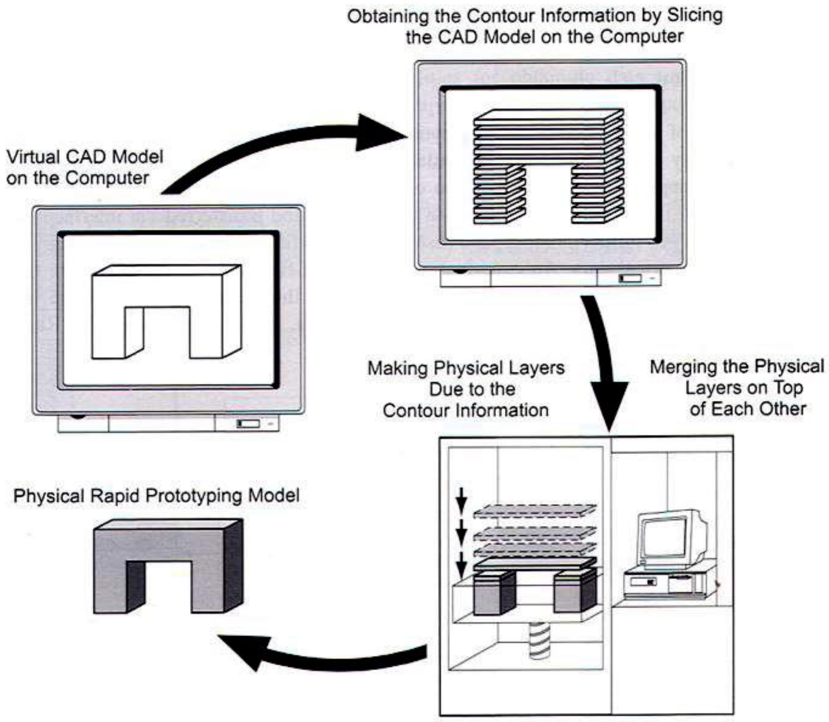

Fig. 1. Rapid prototyping principle [7]

2.2. Selective Laser Sintering (SLS)

It was patented in 1980 by Carl Deckard. The process is similar to stereolithography being replaced only the polymer by powder. The powder is stored in power hopper on both sides of the building room. The powder is pushed out of the hopper with a piston and a roll scatters it in a uniform layer over the construction area. A CO2 laser supplying an infrared beam draws every section of the CAD model on the surface powder. The atmosphere in which it is working is a controlled one with nitrogen. In this process the powder used is compacted into a sintered piece. Post-processing is done manually, eliminating the excess powder.

The use of metallic powders has some particularities, such as coating with a resin or polymer, resulting in a new powder (75-80)% metal and (20-25)% resin or polymer [6, 7, 8].

2.3. Selective Laser Melting (SLM)

It was patented in 1995 by W. Meiners and D. Fockele, similarly to laser selective sintering but using as a power source a laser beam with a power greater than 400 to 1000 watts. Compared SLM with classical manufacturing techniques like deformation or casting. SLM provides a lot of possibilities of short time production and high flexibility [9]. The raw material can be stainless steel powder, alloy steel, tool steel, and titanium powder. The process is similar to laser selective sintering but the powder is melted. The atmosphere in which it is working is a controlled one (argon or nitrogen) to prevent explosions or oxidation. An important role is the choice of supports that secure the entire construction of the machine plate. An important area is the medical one in which personalized orthopedic implants are made from biocompatible materials [7].

2.4. Fused Deposition Modeling (FDM)

FDM is the most used 3D printing technology. This process was developed by Advanced Ceramics Research and then improved by Stratasys in 1980. The materials from which the thread can be made are: special wax, nylon, polyamide or ABS plastic.

The process is carried out by depositing a continuous thermoplastic polymer or wax through a heated nozzle. The filament is inserted into the extrusion head and into the nozzle. The temperature is slightly above the point of flow so that the material solidifies quickly as it exits the nozzle. Until the part is complete a layer by layer is deposited moving down the build platform. Supports are not part of the part but are required to support the part's material. Generating supports is done automatically by the software. The manufacturing process is used in various areas: marketing, medicine, automotive, aerospace.

The advantage is that the materials are economical. Disadvantages would be the low quality of the parts and the small size [7, 8].

2.5. Electron Beam Melting (EBM)

The technology was developed at the University of Chalmers in Sweden in the 90's. The Electron Beam Melting (EBM) use a high energy electron beam melts metallic powders. The electron melting process, whose power reaches 4 kW, turns the kinetic energy into heat producing the melting of the metallic powder. And this process follows the same steps: the 3D model and layer by layer execution just as the process takes place in a vacuum chamber. Vacuum chamber provides an environment that protects melted metal from oxidation and provides better physical-mechanical characteristics.

There are two stages: the first time is a preheating of the powder layer and then the selective melting of the powder by adjusting the power. After completing the layer, the platform get down and a new layer is deposited, the process repeating until the piece is finished. The process does not require the construction of supports.

EBM process produce complex parts for which other technologies would be expensive to made. Disadvantages are that gamma rays are produced during operation and that only materials with good conductivity can be used [6, 8].

2.6. Laminated Object Manufacturing (LOM)

The process was developed by Helisys. The production of the parts consists of the successive deposition of sheets of paper or plastic (with one of the adhesive faces) glued to a rolled heated at about 70 degrees. A small power laser cuts the outer and inner contour. A new layer is glued to the previously cut layer and cut as before. The system consists of two rolls that store and supply the material. The platform of the machine is lowered so a new layer is deposited, the process repeating until the last section is cut. Like raw material are used: paper, plastic, ceramic and composites [7, 8].

3. Analysis and Discussion

Research has been made on the influence of various parameters on the characteristics of the samples obtained by SLM. Many authors have analyzed the Al-based powder while others have done research on the Ti powder, since it is widely used in the medical field.

R. Baitimerov et al [10] presented the density and the porosity in AlSi12 parts fabricated from three different powders processed by the same procedure have shown different behavior during SLM. The powders were brought from three different companies. The powders were obtained by atomization, A and B were obtained using argon and C using air. The powders were dried at 100 °C for 60 minutes to remove the moisture. To avoid oxidation was used argon and oxygen content in the building chamber was kept below 500 ppm. The power of the laser was fixed at 200 W. In Figure 2 can be seen the powder and the samples at scanning electron microscope (SEM) [10, 11].

The samples made from the powder A show a smooth aspect. The specimens made from the powder B present a surface with holes because of the low flowability. The samples made from powder C present large spherical objects bigger than 100 μm.

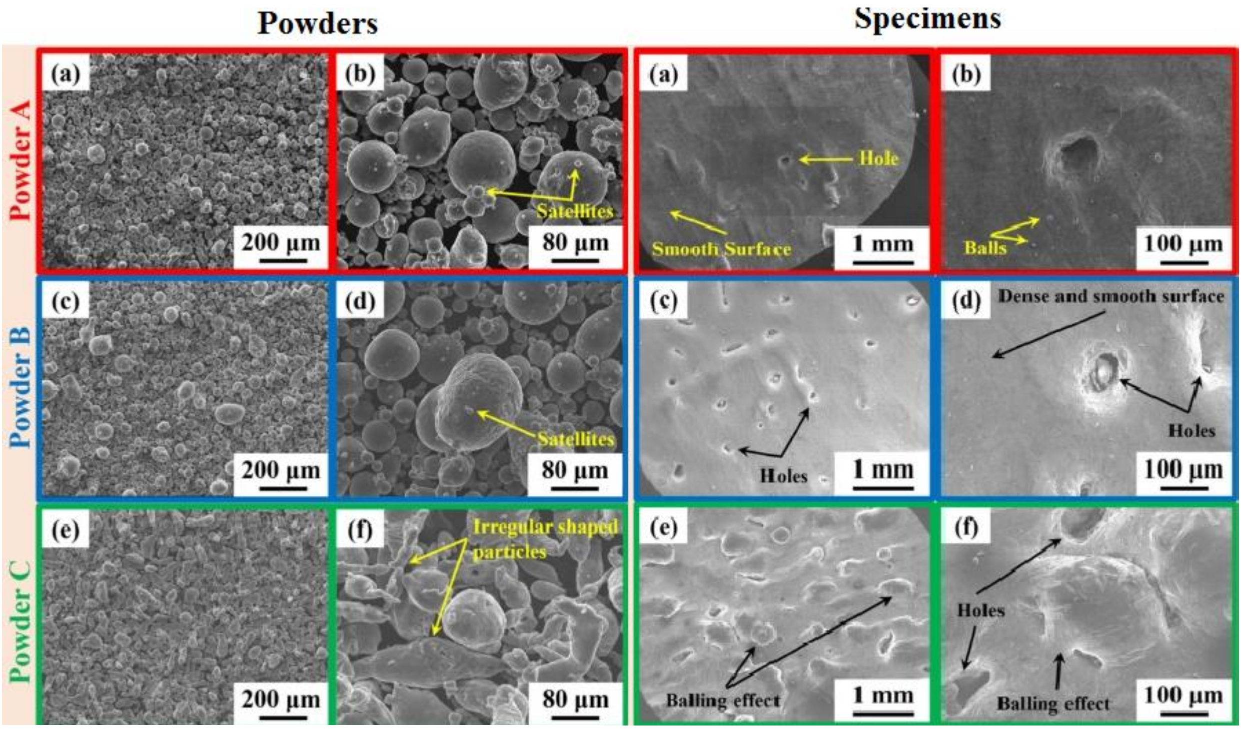

Fig. 2. SEM image of the three different powders: (a, b) powder A, (c, d) powder B and (e, f) powder C, and the specimens fabricated from the powder [10]

The specimens from powder A has the highest relative density than the specimens made from powder B and C. The relative density for powder A is 99.4±0.3 %, for B is 95.6±1.6 % and for C is 94.4±2.3 %. Also flowability and powder layer density are important on the SLM processability.

Michaela Fousová presented the comparison between samples made from TI6Al4V powders from different suppliers. The powders were obtained by atomization. The samples were obtained by SLM and EBM showing surface morphology, in Figure 3.

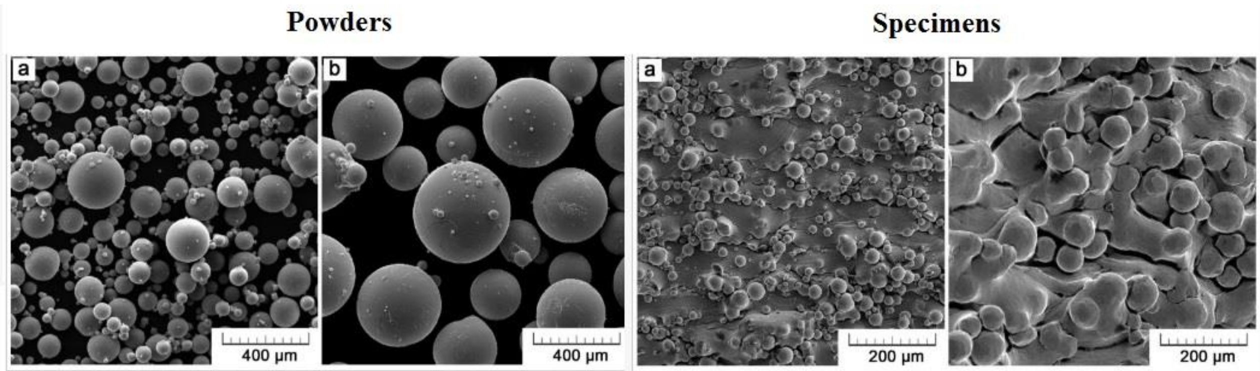

Fig. 3. SEM image of the two different powders
(a) Selective Laser Melting (SLM), (b) Electron Beam Melting (EBM) and the surface morphology of the specimens fabricated from the powder [11]

4. Costs

In traditional manufacturing, mass production is needed to offset the cost of tools and labor, on the other hand, with additive manufacturing is cheaper when the quantity is small.

Making complex parts via traditional manufacturing requires precision which means that price increase. With 3D printing is no added cost for complexity and build entire piece in one process. A possible cost allocation involved in the additive manufacturing processes, considering a single part geometry for production at 4500 h/year could be observed in the Figure 4 [12].

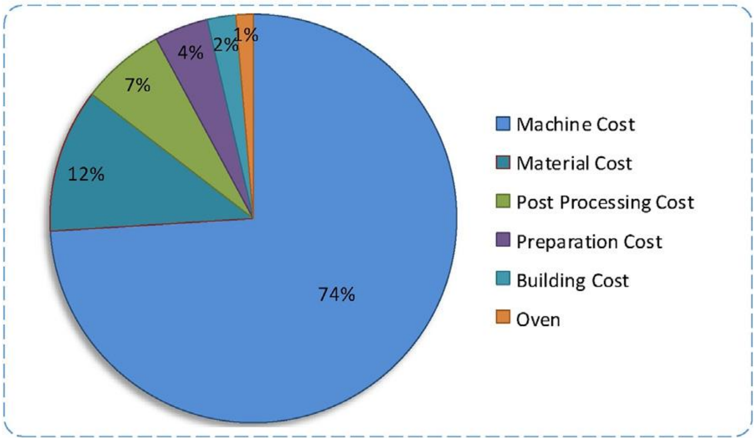

Fig. 4. Additive manufacturing cost structure [12]

According to Malte Schröder, in 2013 additive manufacturing had an increase of 34.9%, in 2015 the equipment and services of additive manufacturing was estimated at 3.7 billion euros, in 2016 at 7 billion euros, and in 2020 will reach at 11 billion euros, could be seen the Figure 5 [13].

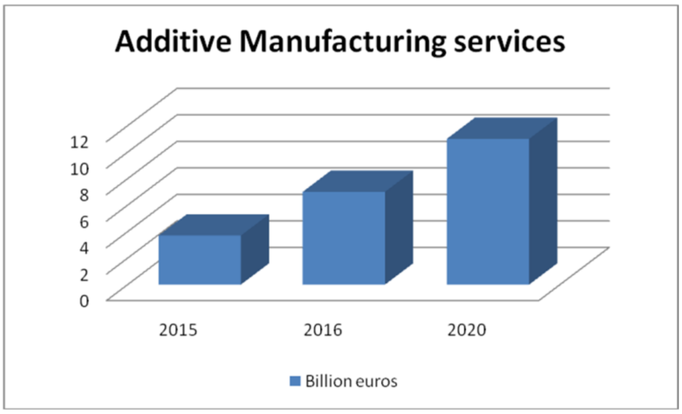

Fig. 5. The increase of Additive manufacturing [13]

5. Conclusion

The critical analysis presented by the authors, in this article, highlights the importance of additive manufacturing compared to classical subtraction technologies. Almost there is no branch of activity where the use of these technologies does not grow. The fact that prestigious R&D Institutes and Universities allocate important resources to research in this field suggests the full impact these technologies will have on the industry of the future, which indicates the actuality of this article.

In aerospace, additive manufacturing technologies have been welcomed for the lighter structures. AM technologies in the automotive industry are advantageous because produce parts difficult to find. In medicine can be produce complex parts and creating an accurate transplant.

At the present time AM technologies are used by professors, scientists and medical doctors. AM technologies had and have a great impact in various areas. Since the early 1990s, products obtained through rapid manufacturing can be used to verify the correctness of designs, today the products of these technologies can be functional with great properties. AM is in a continuous development by improving production factors such as quality, flexibility and productivity.

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