ABOUT 3D PRINTING OF METALLIC MATERIALS

Prof. PhD Cătălin Iancu,
"Constantin Brâncuşi" University of Târgu-Jiu, ROMANIA

ABSTRACT: *In this paperwork is presented a documentary research on the latest developments in 3D printing technology regarding the use of metallic materials. It's well known that most of the 3D printing techniques that commercially exist today are in fact 2D printing, adding layer after layer in the Z dimension, using mostly polymers, along with the new volumetric 3D printing technology, that can creates the 3D object inside the volume of a photo-polymerizable resin that is solidified at the same time, in very short time. For industry is very important that 3D printing technology can shift and use directly metallic materials for special purposes.*

KEY WORDS: *3D printing, additive manufacturing, metallic materials, direct metal printing*

1. Introduction

In a previous study from 2010 [1], has been presented the situation regarding original file format used for 3D printing, commonly supported by most software and hardware for 3D printing, and furthermore has been stated that "3D printing and 3D printers have become financially accessible to small and medium sized business, thereby taking prototyping out of the heavy industry and into the office environment. The technology of rapid prototyping also finds use from industrial design to dental and medical industries" [1], a statement significant to the object of this paperwork.
The most common 3D printing technologies, regarding the complexity of the model, are using the so called "Additive layer Manufacturing" (AM) that can take hours or in some cases even days to obtain the final item, because this technologies are in fact 2D printing, adding layer after layer on a perpendicular dimension, as stated in [2].
"In other words, all 3D printing that commercially exists today is actually 2D printing, repeated layer after layer in the Z dimension" [3].

Also in [2] was presented a documentary research regarding a new development of 3D printing technology, named "volumetric 3D printing", first introduced in the end of 2017, developed in 2018, and with new applications in 2019. Some researchers even concluded that "volumetric 3D printing" could mean the end of additive layer manufacturing [4].
The vast majority of 3D printing techniques that commercially exist today are using mostly polymers, along with the new volumetric 3D printing technology, that can creates the 3D object inside the volume of a photo-polymerizable resin that is solidified at the same time. Although not new, the use of metallic materials in 3D printing presents a great interest for industry, and in this paper will be presented a short look on this topic.

2. Short history and actual state of use of metallic materials in 3D printing

In [5] there is a highly documented presentation of metallic materials used for 3D printing, with 118 bibliographic references.
In this referred paperwork is stated that "three-dimensional (3D) printing of metallic materials involves the layerwise consolidation of feedstock materials in the form of powder, wire, or sheet using various energy sources to form complex shapes".
In [5] it is stated too that "the past two decades have witnessed significant advances in the field, in terms of both technologies and materials for metal 3D printing".

The researchers have concluded that the 3D technology and transfer data from CAD package to 3D printers have a series of limitations and therefore new formats and even new technologies will replace it [6].
Ones of these new technologies is relies on transition from polymers to metallic materials in 3D printing.
3D printing technology is a relatively recent, but manufacturing parts using a layer-based approach dates long ago. The "age of modern 3D printing" can be considered to have started in 1987, with the first commercially produced 3D printer (SLA-1, built by 3D Systems), the technology of constructing metal parts using additive approaches dates back for more than almost 100 years [7]. The earliest known "cut and stack" approaches to layered part construction was by J.E. Blanther, who patented a process for cutting and stacking sheets of wax plates to create a die set for pressing paper sheets. [7], [8]
The first use of a modern 3D printer to create a metal part was laser sintering of a copper-solder mixture by Bourell in 1990 and the first direct metal part created using 3D printing, about approximately 7 cm in diameter, is presented in figure 1[9]

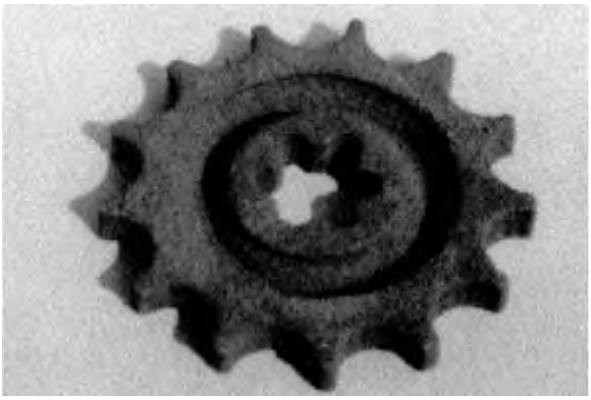

Figure 1. First metal part created using 3D printing [9]

In the late 90's and in the first decade of XXI century many industrial applications of these new materials used for 3D printing have emerged. It can be mentioned some leading actors in this field, like University of Austin, Texas, KU Leuven, Belgium, Fraunhofer Institute, Germany, 3D Systems, USA.
Regarding the methods used for 3D printing of metallic materials there are two classes: direct metal printing and indirect methods, involving sintering and infiltration.
The *direct metal printing* methods can generally be categorized as laser-based, electron-beam-based, arc-based, and ultrasonic welding-based [5].
This paperwork is focused on metallic materials used for 3D printing, while the specific methods will be discussed in a later paper.

3. Metallic materials in 3D printing

As stated before, the 3D printing of metallic materials is based on the layer-by-layer consolidation of various materials in the form of powder, wire, or sheet using various energy sources, like laser beam, electron beam, electric arc or ultrasonic welding to obtain complex parts.
The researchers have been processed through metal 3D printing a large range of metallic materials. This range is from pure metals (gold, copper, niobium, tantalum, titanium), alloy powders (aluminum-based, cobalt-based, copper-based, iron-based, nickel-based, and titanium-based), and powder mixtures (copper-based, iron-based, and graded compositions such as Ni-Al, Ti-Ni, Ti-Mo, and Ti-V) [5], [9].
There are many published studies that have shown the potential for development of metal-based AM, but also there are many issues that limit the adoption of this technology across industries, mainly the need for high qualification of process and components.
Also there are problems regarding "tendency for defect formation as well as microstructural heterogeneity" [10]. Another problem is porosity that appears due to processing, increasing along with part thickness [11].
Considering these aspects, there are some metallic materials that can exceed these limitation, according to Markforged Company, founded in 2013 and based in Massachusetts, listed as the #2 fastest-growing hardware company in the US in the 2019 by Deloitte, that have the largest online fleet of industrial 3D printers in the world [12].
According to Markforged Company "the most useful metal 3D printing materials offer

manufacturers the greatest value-add compared to traditional manufacturing methods" , "this means the availability of metal 3D printing materials in additive manufacturing must depend almost entirely on how easily the powderized form can be fused together. Aluminum powder, for example, is more difficult to meld together than steels that are much more easily bonded, and is therefore a lot less common of a metal 3D printed material [13].
Further, will be presented the most used metallic materials for 3D printing, according to Markforged Company.

3.1. Stainless steel

Stainless steel is a material that has a high strength and excellent corrosion resistance. Stainless steel can be used across a vast range of manufacturing industries. Some of 3D printed stainless steels include the extremely corrosion resistant 316L type and the heat treatable 17-4 PH Stainless Steel, up to 36-44 HRC [13].
Among specific parts made of 17-4 PH Stainless Steel, can be mentioned end-of-arm tools, lightweight brackets, custom wrenches.
In figure 2 are presented 17-4 PH Stainless Steel grippers, 3D printed.

Figure 2. 17-4 PH Stainless Steel grippers, 3D printed [13]

Another important application of 3D printed stainless steel parts is universal orthopedic implant insert/removal tools, as shown in figure 3:

Figure 3. 17-4 PH Stainless Steel orthopedic tools, 3D printed [14]

3.2. Tool steel

This class of steels is used for a variety of manufacturing tooling, regarding their high hardness, and excellent high heat and abrasion resistance. Generally tool steels are difficult and expensive to machine, making them an ideal candidates to be 3D printed. The most used forms are powders and filaments include A2, D2, and H13 Tool Steel, heat treatable up to 50 HRC. [13].
In figure 4 are presented 3D printed parts used for injection molds and extrusion dies:

Figure 4. 3D printed parts made of H13 Tool Steel [13]

3.3. Titanium alloy

Titanium is very strong, incredibly lightweight, and heat and chemical resistant material. Normally, titanium and its alloys are extremely hard to machine (contributing to its high cost), making it a great candidate for 3D printing. The most common 3D printed titanium is an alloy, Titanium 64 (Ti-6Al-4V), used in situations when a very high strength to weight ratio is needed, such as aircraft industry.

3.4. Inconel 625

A nickel-based superalloy, Inconel 625 is a strong, stiff, and corrosion and heat-resistant material, which is often used in places like turbines and rockets. In figure 5 are presented parts made of Inconel 625, 3D printed.

Figure 5. 3D printed Inconel 625 crucible clips [13]

4. CONCLUSIONS

At this point "the current list of metal 3D printing materials is relatively short and focused on higher grade materials that are most financially beneficial to fabricate" [13].
However, as metal 3D printing develops, is expected to see more and cheaper metal 3D printing powders and filaments, available across different metal printing platforms.
In this paper were presented the most used metallic materials for 3D printing, including stainless steel, tool steel, titanium alloy and nickel alloy.
Applications of metal 3D printing are currently concentrated in the aerospace, parts for injection molds and extrusion dies and biomedical sectors [5], [13], [14].
Development efforts made by researchers today are concentrated on several important issues: machine cost and build speed, which impacts the effect of machine cost on part cost, feedstock cost, surface finish, qualification and certification, and part size (can be mentioned BAAM-big area additive manufacturing technology, up to 2-3m parts) [5].

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