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EBSD examination of Ti-6Al-4V samples produced with additive technology

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Abstract. Rapid Prototyping (RP) is a special technology which has many types included Direct Metal Laser Sintering (DMLS). The process starts by applying a very thin layer of material onto the construction platform, then fusing the powder at the exact points specified by the CAD model. After that, the platform is lowered and another layer of the substance is laid restarting these steps till the desire model is ready. Nowadays Additive Manufacturing (AM) expression is used instead of RP, because it is characterizing much better the process. This paper focuses on the microstructure, and EBSD examination of Ti-6Al-4V (Grade 5) samples produced with DMLS technology. Our main aim was to compare the properties of AM produced samples to the properties of traditional Grade 5 titanium alloy.

1. Introduction

Rapid Prototyping (RP) is a term used to describe fabrication processes responsible for creating representations and 3D models from digital information. This means that RP techniques are mostly used to materialize ideas and improve initiatives that are not finished yet, spending less money and time than traditional manufacturing procedures. RP is used for building final products as prototypes or can be found in different fields of art and hobbies. Nowadays the continuous improvement of this technology surprisingly increases the range of usage. Specialist have realized that instead of "Rapid Prototyping" a much more adequate name would be better in the scenario, so The American Society for Testing and Materials (ASTM) adopted the expression "Additive Manufacturing". This refers to the process of fabrications of parts using an additive approach [1, 2]. Of course we can find other synonyms such as: additive fabrication, additive process, etc. [3].

At the beginning of the 20th century scientists investigated new technologies to replace subtractive manufacturing processes and improved casting methods. During these researches prototypes were produced by human hand, but parts were not precise and repeatable with same geometry. These mistakes could be solve using machine-controlled technologies [4]. Despite of the fact, that AM just starts to spread around 1980, it is based on two technologies from the 19th century. The artist, Francois Willéme made 3D models taking photos of an object from 24 different angels. This is called photo-sculpture [5]. The other basic is from Joshep E. Blanther who prepared 3D maps placing layers onto layers [6]. In 1956 Jhon Munz successfully made 3D models using photosensitive raw material [7]. The very first real model related to Charles W. Hull, who used computer to build layer-by-layer parts from polymers in 1986 [8]. 2005 brings a great innovation, when an amateur team made available 3D printing worldwide for everyone using Scott Crump's thread-melting technology [9].

AM technology requires the raw material to be in the form of a liquid, powder or sheet, and it is usually ceramic, metal or polymer [10]. According to these there are numerous variations on AM processes separated into seven main categories.

- VAT Photopolymerization,
- Material Jetting
- Binder Jetting,
- Material Extrusion,
- Sheet Lamination,
- Direct Energy Deposition (DED),
- Powder Bed Fusion (PBF) [11].

As previously mentioned, DMLS is included in the Powder Bed Fusion category. Figure 1. shows how the method works schematically [12].

Raw material must be in a special form, called bended powder and nowadays has a wide range of choice such as, powder like stainless steels, titanium alloys, aluminum alloys, copper-based alloys, metal

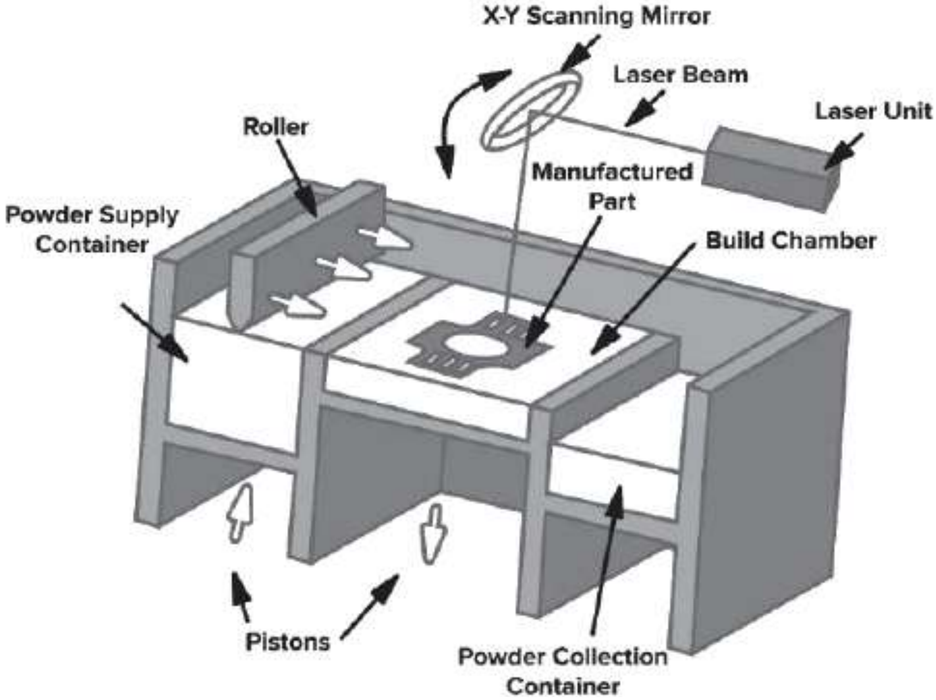

Figure 1. Schematic illustration of DMLS process

matrix composites [13]. In medical researches special composite materials are improved that can be used as implants and prosthesis [14].Another advantage of DMLS technology is the complexity of produced parts [15], which can be built in one production process, reducing post-processes and wasting less material [16]. The parts also have improves mechanical properties due to overlapping of laser paths, which create melt pools that solidify with characteristic fine microstructure [17].

The number of researches about AM grew ten times between 2011 and 2012, while the world market observed and increased from US$ 1.7 billion in 2011 to US$ 2.2 billion in 2012. It is clear that AM technologies are shaping the future of product development and manufacturing [18]. Current study's main aim is to examine the microstructure of DMLS produced Ti-6Al-4V titanium alloy samples.

2. Material

During tests we examined two variant materials to compare the microstructure of them. The difference was the way of production, one of them was a traditionally made titanium alloy, and the other one was produced with DMLS technology.

2.1. Chemical composition of Ti-6Al-4V material

The commercial available Ti-6Al-4V alloy does not have exact percentage of elements rather has intervals. Table 1. shows the table of chemical composition intervals for traditionally produced Ti-6Al-4V alloys.

Table 1. Chemical composition intervals of traditionally produced Ti-6Al-4V

Elements	Percentage (%)
Titanium (Ti)	88,1 – 91
Aluminum (Al)	5,5 – 6,5
Vanadium (V)	3,5 – 4,5
Iron	< 0,25
Oxygen	< 0,13
Carbon	< 0,08
Nitrogen	<0,03
Hydrogen	< 0,125

3. Metallography

For metallography study first of all the samples must be fixed in resin to make the grinding, polishing and etching effective. For etching we used Keller's reagent (190 ml H_2O, 5 ml HNO_3, 3 ml HCL, 2 ml HF), which is optimal for titanium alloys. Figure 2. shows the microstructure of a traditionally produced and an additive manufactured Ti-6Al-4V sample.
After the investigation using light microscope we used S50 30 kV scanning electron microscope (SEM) for more precise information and examine the chemical composition – especially focusing onto the main alloys - of DMLS produced samples comparing to Table 1.

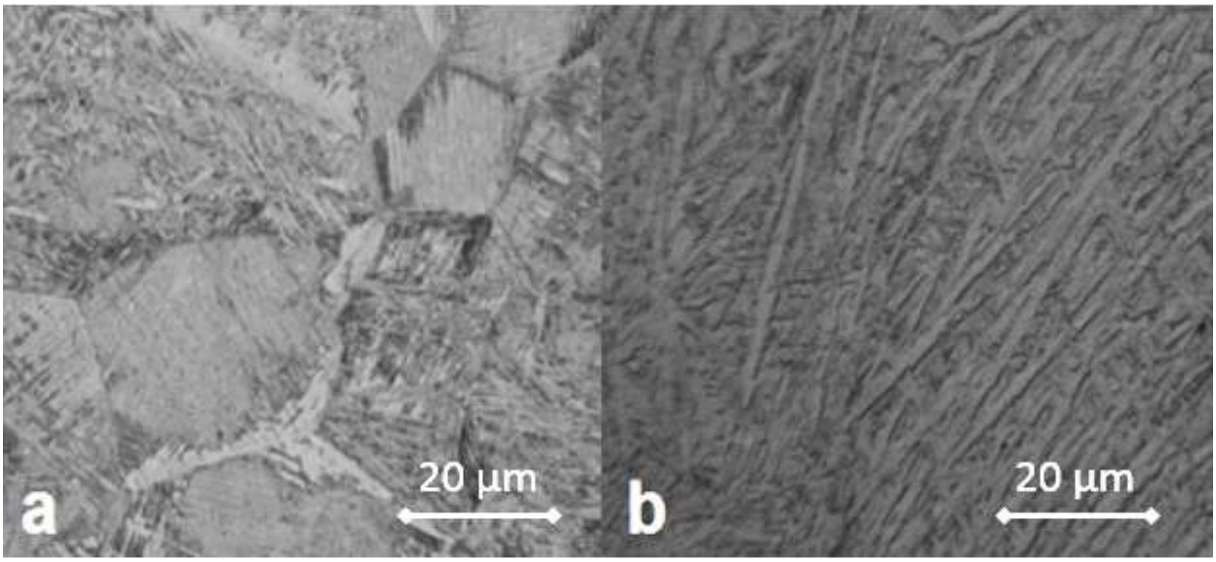

Figure 2. (a) Microstructure of traditionally produced titanium alloy,
(b) Microstructure of DMLS produced titanium alloy

Table. 2. Percentage of main elements of DMLS produced Ti-6Al-4V

Component	Element interval of traditional Ti-6Al-4V	Element percentage of DMLS Ti-6Al-4V
Titanium (Ti)	88,1 – 91	86,86
Aluminum (Al)	5,5 – 6,4	10,58
Vanadium (V)	3,5 – 4,5	2,56

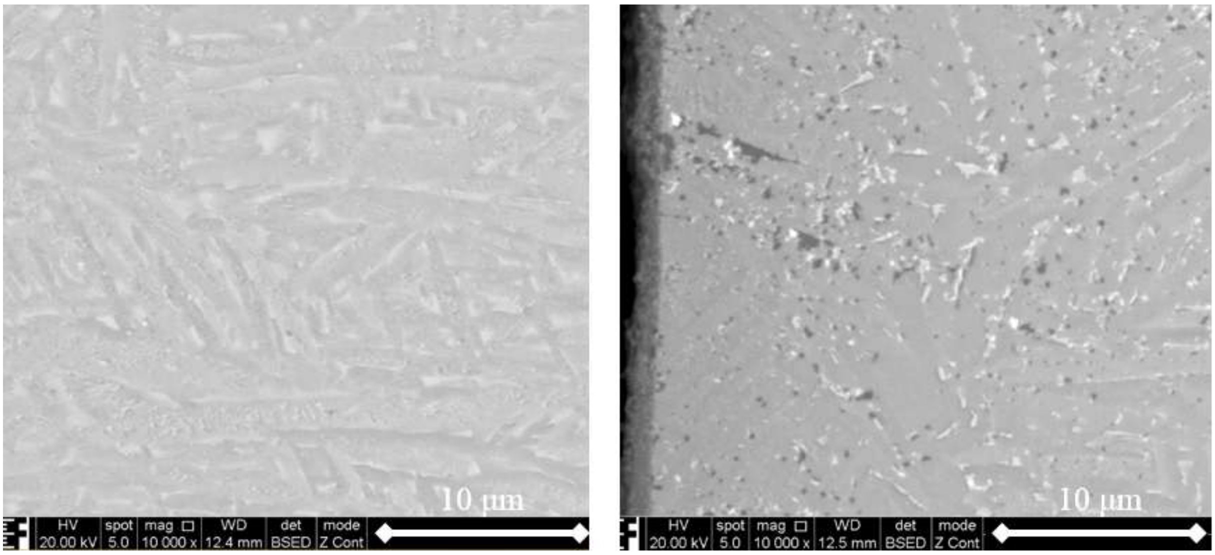

Figure 3. (left) SEM picture of traditionally produced titanium alloy, (right) SEM picture of DMLS produced titanium alloy

3.1. EBSD

Electron Back Scattering Diffraction (EBSD) is a special function of SEM and usually used to examine grain orientation and crystal structure of different materials. A short introduction of EBSD can be found in [19] reference. Our main aim was to obtain information even if DMLS produced titanium alloy has orientation or not. Furthermore we examined the traditionally produced sample's microstructure and compared the results with each other. Figure 4. shows information about traditionally processed Ti-6Al-4V.

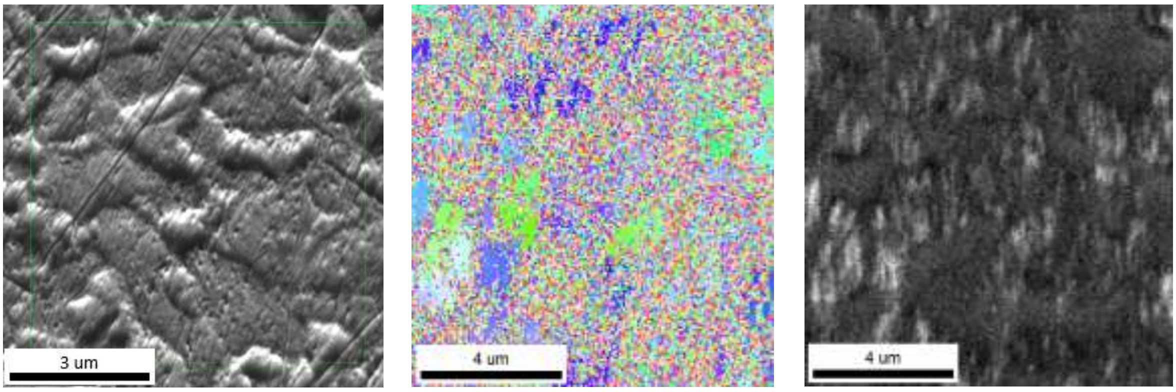

Figure 4. Traditional samples: (left) Test area, (middle) IPF picture with grains, (right) image quality picture

Figure 5. shows the same information about DMLS produced Ti-6Al-4V alloy.

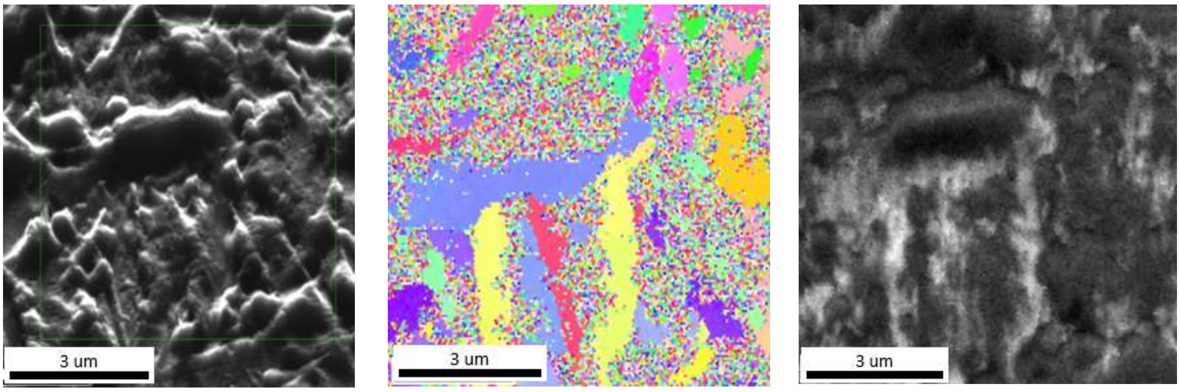

Figure 5. DMLS samples: (left) Test area, (middle) IPF picture with grains, (right) image quality picture

4. Conclusion

DMLS technology shows a great innovation to the economy during the past century, and now it has been gaining space in manufacturing processes. It is very important to continue this improvement in the future, and this is possible because of the standards created by ISO since 2009. DMLS technology is still a new method, so all the tests were performed to show the efficiency of it. It is possible to realize that the grains are much more visible in case of traditionally produced sample, but both have quite the same structure. As chemical composition, additive manufactured sample's elements are nearly in the interval. As the results of EBSD tests grains were shown with nearly equal size and orientation is also possible to examine.

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