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Citation: [AIP Conference Proceedings](#) **1960**, 140007 (2018); doi: 10.1063/1.5034999

View online: <https://doi.org/10.1063/1.5034999>

View Table of Contents: <http://aip.scitation.org/toc/apc/1960/1>

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Impact of chemical polishing on surface roughness and dimensional quality of Electron Beam Melting process (EBM) parts

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Abstract. Additive manufacturing is growing faster and faster. This leads us to study the functionalization of the parts that are produced by these processes. Electron Beam melting (EBM) is one of these technologies. It is a powder based additive manufacturing (AM) method. With this process, it is possible to manufacture high-density metal parts with complex topology. One of the big problems with these technologies is the surface finish. To improve the quality of the surface, some finishing operations are needed. In this study, the focus is set on chemical polishing. The goal is to determine how the chemical etching impacts the dimensional accuracy and the surface roughness of EBM parts. To this end, an experimental campaign was carried out on the most widely used material in EBM, Ti6Al4V. Different exposure times were tested. The impact of these times on surface quality was evaluated. To help predicting the excess thickness to be provided, the dimensional impact of chemical polishing on EBM parts was estimated. 15 parts were measured before and after chemical machining. The improvement of surface quality was also evaluated after each treatment.

INTRODUCTION

Electron Beam melting (EBM) is a powder based additive manufacturing (AM) method. This process permits to produce high-density metal parts with complex topology. This process is more and more used in aerospace and biomedical industries [1, 2]. Among the powder bed additive manufacturing methods, EBM distinguishes itself by a good dimensional accuracy, and low residual stresses [3]. However, some defects remain such as the need of support structure and the high surface roughness [4].

To improve surface finish of metal powder bed processes, some finishing operations are needed such as traditional machining [5, 6], shot-peening [7, 8, 9], tribofinishing / vibratory finishing [10], laser polishing [11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22], chemical polishing and electrolytic polishing [5]. In this study, the focus is set on chemical polishing.

The literature review showed few references on the optimization of the surface roughness of AM process by chemical polishing. In a recent article, Łyczkowska *et al.* [23] have evaluated a chemical polishing approach of LBM lattice structures made of a titanium alloy (Ti6Al7Nb). Polishing times varying between 60s and 900s have been studied. Examination of the surfaces after treatment demonstrates the removal of the partially fused particles adhering to the surfaces as well as a relatively uniform pickling of the other zones. Pyka *et al.* have addressed in [24] the chemical polishing of Ti6Al4V LBM structures. Their results suggest that the concentration of reagent in the etching solution is preponderant over the other parameters (especially test time) for the reduction of the surface roughness. A study by design of experiment allowed them to develop satisfactory ranges of parameters that also predict the effects

of a treatment on the roughness and the quantity of removed material.

The goal is to determine how the chemical etching improves the dimensional accuracy and the surface roughness of EBM parts. To this end, an experimental campaign was carried out on the most widely used material in EBM, Ti6Al4V [25, 26, 27, 28, 29, 30, 31, 32]. Different exposure times were tested. The impact of these times on surface quality were evaluated. To help predicting the excess thickness to be provided, the dimensional impact of chemical polishing on EBM parts was estimated. 15 parts produced in 5 different batches were measured before and after chemical machining. The improvement of surface quality was also evaluated after each treatment.

EXPERIMENTAL PROCEDURE

Sample manufacturing

Samples were used to evaluate the impact of chemical etching on dimensions and roughness. All the parts were produced by an ARCAM Q20+ machine. For these parts, a set of standard parameters optimized for $90\mu m$ layers was used. 4 different geometries of sample were built (see Fig. 1). Only 15 parts underwent chemical machining to improve the surface quality.

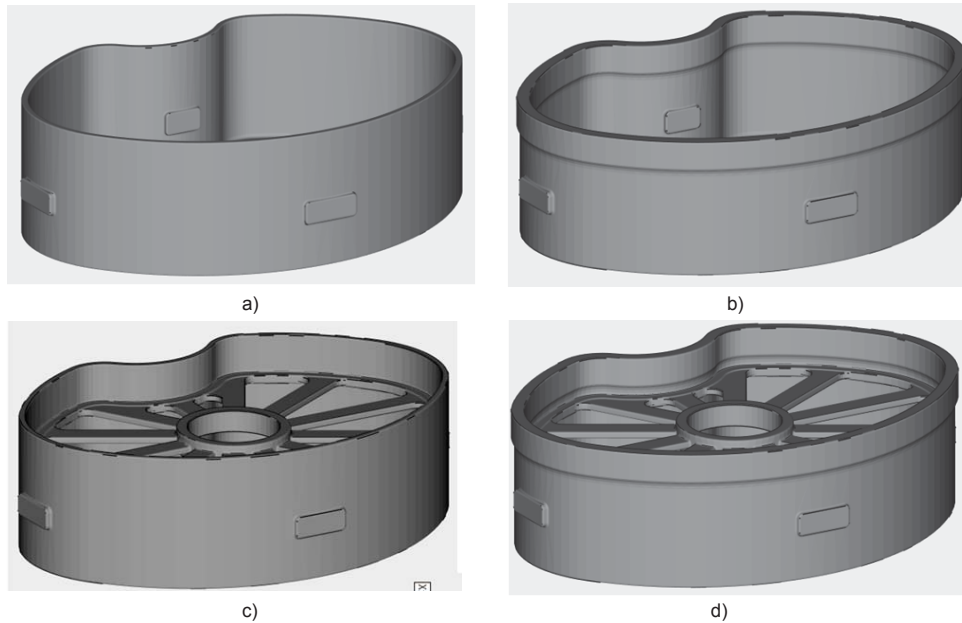


FIGURE 1. Sample profile to define the sample geometry in order to evaluate the chemical etching on EBM parts

In order to minimize the number of batches needed to reach the entire number of parts, the build envelope is filled as much as possible. Due to the part dimensions and EBM process constraints, the following solution was defined as the baseline (see Fig. 2). The supports of the parts follow the standard Arcam recommendations and standard features (i.e. type, density, teeth,...). Especially, the recommended length of 20mm for floating supports is the reason for the vertical spacing between levels. They support the bottom faces of sectors, letting the welding lips "clean", as it will be the case for the oil tank elements. The stiffener structures are supported to avoid any deformation during the process that could lead to a "out-of-layer" issue.

The basic profile used to define the 4 geometries is shown in Fig. 3. All dimensions shown in this figure are identical from one geometry to another. The dimensions of the samples are in Fig. 3. Flat surfaces were placed on the

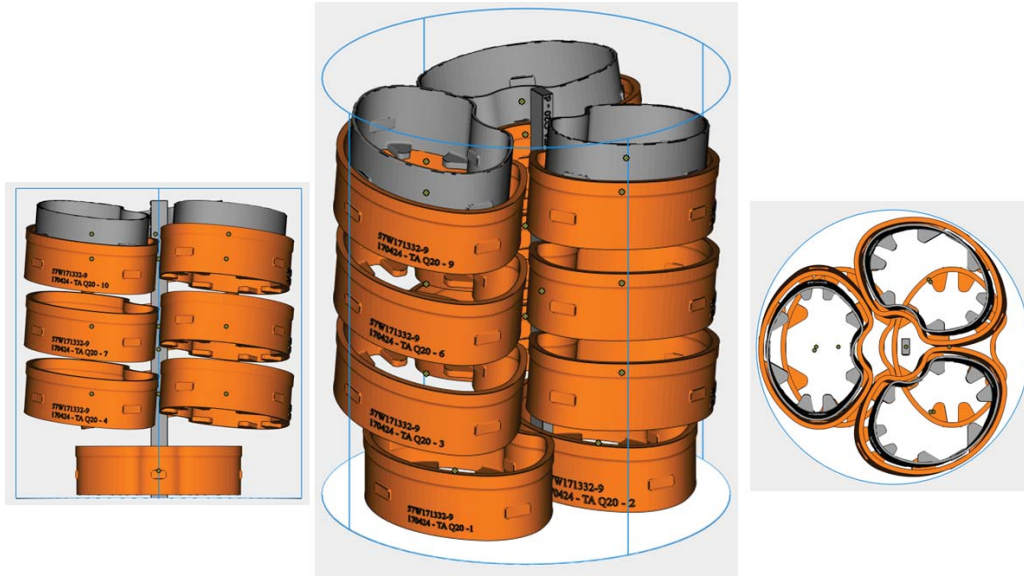


FIGURE 2. Samples' position on the build plate

sample to measure thickness and length (see Fig. 3, number 1 to 8). This profile (see Fig. 3) is extruded on 80mm (see Fig. 2 for final geometries).

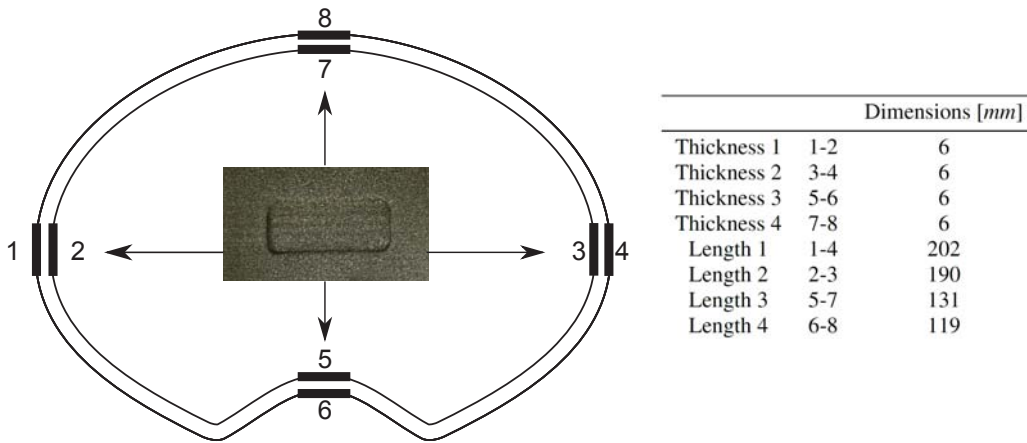


FIGURE 3. Sample profile and dimensions to define the sample geometry in order to evaluate the chemical etching on EBM parts

In this study, all the parts were measured before and after chemical machining. The characteristics of the chemical bath are:

- HNO₃ : 330 g/l
- HF : 17 g/l
- Ti : 5 g/l

All the pieces underwent a first treatment of 14 minutes. At the end of this treatment the dimensions and roughness were measured. Then, they underwent a second surface treatment of 55 minutes to see if it was still possible to improve the roughness.

The powder used in this study was also Ti-6Al-4V spherical plasma atomized powder provided by Arcam, with a size distribution going typically from 45 to 106 μm and centered around 70 μm . This powder is recycled with fresh additions of ELI (grade 23) powder.

Experimental Setup and method

For each batch of fabrication, the dimensions were determined using a coordinate measuring machine (Wenzel LH 54 precision : $U_x, U_y (\mu\text{m}) = 3 + 10.L/3$ and $U_z (\mu\text{m}) = 3.5 + 10.L/3$). This technique uses a spherical probe to touch directly the part to define fundamental entities (plane, cylinder, etc.). The touch probe used for the measurements has a 2.5 mm diameter.

For these samples all the basic geometries were defined by planes (see Fig. 3). To define the planes : 6 points are touched uniformly along the planes (1, 2, 3, 4, 5, 6, 7 and 8 on Fig. 3). The measures were repeated 3 times for all the samples.

The surface quality is defined by a surface roughness meter SURFCOM 1400D-3DF. The diameter of the probe used is 2 μm . The ISO 4288 standard [33] is followed for each measurement. The arithmetic roughness R_a and the total roughness R_t values are recorded for each measured samples. 3 measures are conducted on the sample.

RESULTS AND DISCUSSIONS

In this study, 15 different parts were measured for the dimensional accuracy. This way, it allows to see if the process is repeatable.

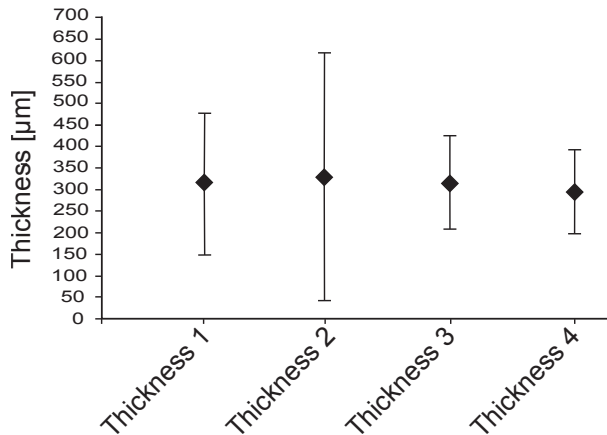


FIGURE 4. Sample geometry to evaluate the chemical etching on EBM parts with a 3 σ error bar

Figure 4 shows the thickness removed on EBM parts. This figure shows that the treatment acts uniformly over the entire part. The average thickness removed on the various thicknesses is of the order of 300 μm . It is interesting to see that the results are repeated from one experience to another. There is therefore a possible control of the machining thickness on the whole part.

Regarding roughness, the average values obtained before chemical etching are of the order of 27.68 μm ($\sigma = 4.23$) for the arithmetic roughness and 212.77 μm ($\sigma = 22.23$) for the total roughness. After a chemical machining of 14 minutes under the previously defined conditions, the arithmetic roughness decreases to 16.02 μm ($\sigma = 2.04$) and the total roughness to 117.26 μm ($\sigma = 16.53$). This means that under these conditions, a reduction of about 58% for the arithmetic roughness and 55% for the total roughness is possible by removing only a layer of about 150 μm on the surface of the part.

Once the first treatment has been performed and the measurements made, the parts have undergone a second treatment in a similar bath. This additional processing was done for 55 minutes. It can be seen in Fig. 5 that after a second treatment it is still possible to improve the surface conditions. It has unfortunately not been possible to perform roughness measurements on these samples however, the Figure shows a clear improvement of the surface roughness as a function of processing time.

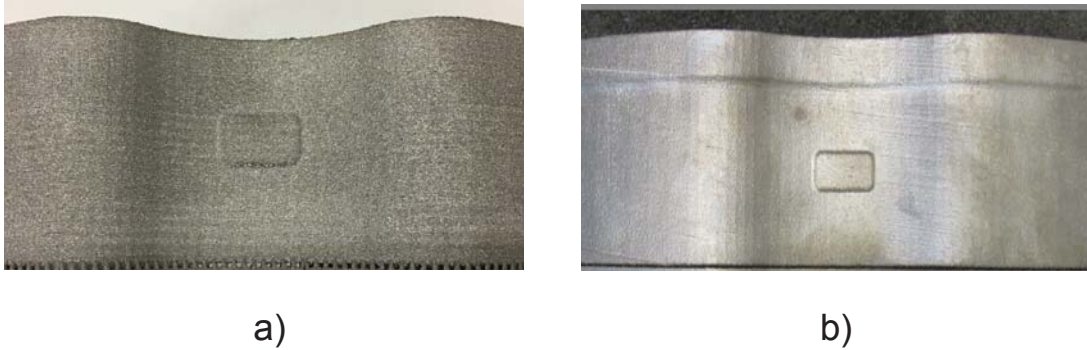


FIGURE 5. Improvement of the surface roughness as a function of the duration of the treatment: a) rough b) 14minutes + 55minutes of chemical etching

In Fig. 5, it is possible to see the facetization of the 3D-CAD model. This shows that a good quality finish is achieved.

CONCLUSIONS

This study aimed to study the impact of chemical machining on dimensional accuracy and surface roughness. Two treatment times were performed but the measurements were only performed after 14 minutes of bathing. This 14-minutes bath reduced the arithmetic roughness of about 58% and the total roughness of about 55% by removing only a layer of about $150\ \mu\text{m}$ on the surface of the part.

This layer of $150\ \mu\text{m}$ machined on the part is reproducible on all the samples. This means that it is possible to have a control of the final dimensions for a defined bath.

Extending the bathing time by 55 minutes clearly leads to a surface improvement. For technical reasons, it was not possible to carry out the various measurements at the end of this bath. Figure 5 clearly shows an improvement of the surface. This figure highlights the geometric simplification due to the generation of the STL file.

Several questions arise regarding the chemical machining. Does this process not eliminate the more "complex" elements of the geometry? Does not there exist a "threshold" of complexity? Further analysis is still needed to try to answer these questions. This study is a first step in understanding the phenomenon.

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