Influence on surface characteristics of electron beam melting process (EBM) by varying the process parameters

Adrien Dolimont, Sebastien Michotte, Edouard Rivière-Lorphèvre, François Ducobu, Solange Vivès, Stéphane Godet, Tom Henkes, and Enrico Filippi

Citation: AIP Conference Proceedings **1896**, 040010 (2017);
View online: https://doi.org/10.1063/1.5008036
View Table of Contents: http://aip.scitation.org/toc/apc/1896/1
Published by the American Institute of Physics

Influence on surface characteristics of Electron Beam Melting process (EBM) by varying the process parameters

Adrien Dolimont[1,a)], Sebastien Michotte[2], Edouard Rivière-Lorphèvre[1], François Ducobu[1], Solange Vivès[3], Stéphane Godet[3], Tom Henkes[4] and Enrico Filippi[1]

[1]*Machine Design and Production Engineering Lab - Faculty of Engineering - University of Mons, Place du parc 20, 7000 Mons, Belgium*

[2]*SIRRIS, collective centre for and by the technological industry, 26 Rue Auguste Piccard, 6041 Gosselies, Belgium*

[3]*4MAT, Université Libre de bruxelles, 50 av. F.D. Roosevelt (CP 165/63), 1050 Bruxelles, Belgium*

[4]*SAFRAN AERO BOOSTERS, Route de Liers 121, 4041 Herstal (Milmort), Belgium*

[a)]Corresponding author: adrien.dolimont@umons.ac.be

Abstract.

The use of additive manufacturing processes keeps growing in aerospace and biomedical industry. Among the numerous existing technologies, the Electron Beam Melting process has advantages (good dimensional accuracy, fully dense parts) and disadvantages (powder handling, support structure, high surface roughness). Analyzes of the surface characteristics are interesting to get a better understanding of the EBM operations. But that kind of analyzes is not often found in the literature. The main goal of this study is to determine if it is possible to improve the surface roughness by modifying some parameters of the process (scan speed function, number of contours, order of contours, etc.) on samples with different thicknesses. The experimental work on the surface roughness leads to a statistical analysis of 586 measures of EBM simple geometry parts.

INTRODUCTION

The development of additive manufacturing techniques such as EBM [1, 2] permits to build fully dense metallic near net shape parts from powder. This technology permits to build complex parts without an increase in price. One of its main drawbacks is the surface roughness of the part. The development of new products in mechanical applications such as contact application (solid-solid (prosthesis), fluid-solid (turbo machine), Ra from 1.6 to 0.1 μm) leads to study the surfaces of the manufacturing process. The roughness is high (Arithmetic roughness (Ra) is around 25 μm according [3]) and therefore it is necessary to finish the part in such applications.

To guide post-processing steps for finishing EBM parts [4] it is important to determine the dimensional accuracy of the process [5] and the surface roughness. In this paper, we focus on the surface roughness optimization. The main goal of this study is to determine if it is possible to improve the surface roughness by modifying some parameters of the process (scan speed function, number of contours, order of contours, etc.) on samples with different thicknesses .

The literature review showed few references on the optimization of the surface roughness of Electron Beam Melting parts. For the analyses of the surface roughness, a simplified energy density equation has been used by some authors as a simple variable for correlating input process parameters to the surface roughness [6, 7]. Those authors used different methods to evaluate roughness (optical [6] and touche probe [7]) . However, the only study analyzing in details this influence does not obtain satisfactory results on roughness prediction (Low R^2 value between experiments and model) [7].

To fill this gap, the goal of this study is to determine if is it possible to improve the surface roughness by modifying the process parameters. The parameters of inner and outer contours (beam speed, focus offset, current, etc.) have been modified and the roughness was defined for each sample. The results were compared to the standard

Proceedings of the 20th International ESAFORM Conference on Material Forming
AIP Conf. Proc. 1896, 040010-1–040010-6; https://doi.org/10.1063/1.5008036
Published by AIP Publishing. 978-0-7354-1580-5/$30.00

Table 1. Standard parameters for 50 μm layer recommended by ARCAM

Parameters	Values
Number of contours	2
Order of contours	outer to inner
Speed of outer contours	340 mm/s
Focus offset of outer contours	3 mA
Current of outer contours	4 mA
Multibeam of outer contours	40 spots

parameters recommended by ARCAM (see Tab. 1).

EXPERIMENTAL PROCEDURE

Sample manufacturing

In this study, 3 batches of parts were fabricated (named job 1, job 2 and job 3) by an ARCAM A2 machine. Traditionally, the process starts with preheating the powder. Then the contours and finally the inner region are melted (hatch melting). During the fabrication the temperature of the processed surface is maintained at 850°C by scanning the surface with the electron beam.

The material properties are linked to the thermal history during fusion and solidification. If the path, the speed, the number of contour etc. are modified, the energy density is modified too. In EBM the density of energy is computed as :

$$E = \frac{60keV \times I}{d \times v \times t}$$

Where E is the energy density, I is the current, d is the diameter of the electron beam, v is the speed and t is the layer thickness.

For each batch, a set of standard parameters optimized for 50 μm layers (see Tab. 1) was used for at least one part in the batch to constitute a reference.

For the other parts some parameters were tuned such as scan speed function, number of contours, order of contours, etc. By this way the energy density is modified. To compare the energy density the proportional energy is define as :

$$E_j = k \frac{\frac{I_j}{v_j \times FO_j}}{E_0}$$

Where E_j is the proportional energy of part j, I_j is the current of part j, FO_j is the Focus offset of part j, v_j is the speed of part j and k a parameter in $J.mm/S$.

E_0 is the proportional energy of the standard parameter and it is given by :

$$E_0 = k \frac{I_0}{v_0 \times FO_0}$$

In the experiments conducted in this study the density energy varies from 0.3 to 3.9 times the standard value.

The geometry of the sample was a parallelepiped rectangle with different thicknesses built along the Z building direction (see Fig. 1). The height of the part allows to respect the ISO 4288 standard of roughness measurement [8].

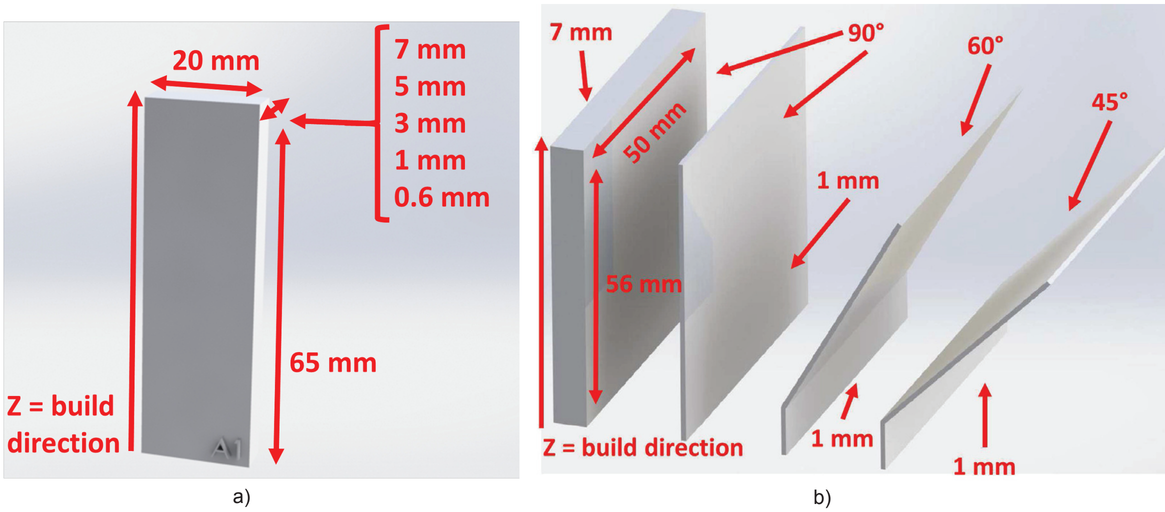


Figure 1. EBM Samples geometry (Job 1 (a), Job 2 and 3 (b)) for surface roughness analysis

In this case, according to the value announced by ARCAM for the arithmetic roughness Ra ($25\mu m$), the measuring length is $40mm$.

The material used in this study is the most widely used material for the EBM Process. It is Ti6Al4V.

In the first batch (Job 1), 28 different combinations of printing parameters (3 FO (Focus Offset), 2 numbers of contours (2 or 100), 2 outer currents, order of contours, 2 multibeam configurations (10 or 40) and 4 speeds contours) are tested and for each parameter 5 parts with different thicknesses were built (7 *mm*, 5 *mm*, 3 *mm*, 1 *mm* and 0.6 *mm*). The modified parameters have only an impact on the outer contours. The batch is built with recycled powder.

The second batch (Job 2) is a combination of 6 different printing parameters (2 FO, 2 numbers of contours (2 or 100), and 3 speeds contours) with different thicknesses (7 *mm* and 1 *mm*) and different inclinations (90°, 60° and 45°). The modified parameters have only an impact on the outer contours. In this batch new powder is used.

The last batch (Job 3) is a combination of different printing parameters (3 CO (contours offset), 3 FO and 4 speeds contours) also with different thicknesses (7 *mm* and 1 *mm*) and different inclinations (90°, 60° and 45°). The modified parameters have only an impact on the inner contours. In this batch the powder used is the same powder as in job 2.

Experimental Setup and method

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 [8] is followed for each measurement. The arithmetic roughness Ra and the total roughness Rt values are recorded for each measured samples. 3 measures are conducted on each face of the sample.

The samples are statistically analyzed and an algorithm is followed (see Fig. 2). According to [10], the first step is the determination of the normality of the samples by a Shapiro-Wilk Test. If the samples are not normal, a non parametric Wilcoxon test is performed otherwise, the variance are compared by a Fisher Test. If the variances are equal a Student Test is used to compare the samples. Otherwise, a Welch test is performed. For more information about those tests see [10]. The goal of these tests is to determine if the samples with standard and modified parameters are significantly different.

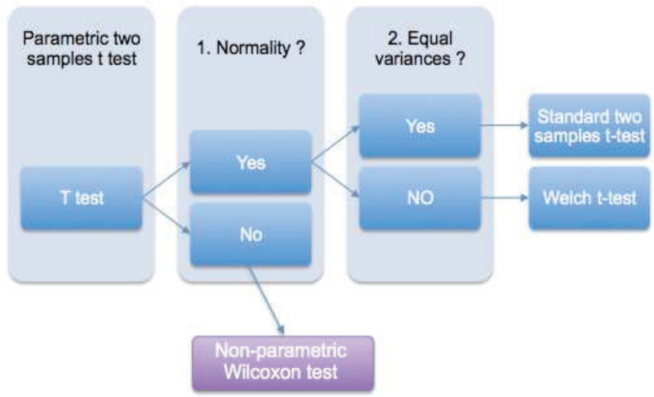
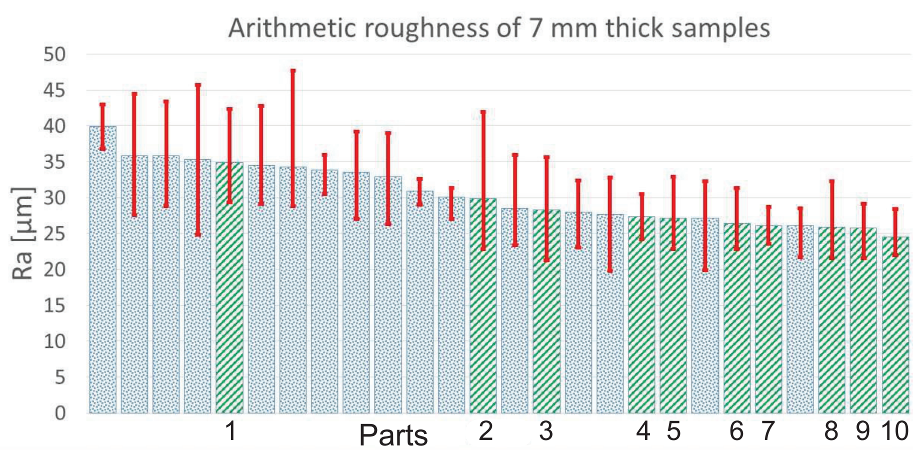


Figure 2. Average comparison of the samples [9]

RESULTS AND DISCUSSIONS

In this study, more than 24 differents build parameters have been modified with different thicknesses (outer contour FO, number of contours, outer current, order of contours, multibeam configuration, outer speed contours, contours offset, inner contour FO, inner speed contours, etc.). The statistical tests showed that there was no significant difference between standard parameter parts (reference) and modified parameters parts. To support these results, the different Ra and Rt values were plotted (see Fig. 3 and 4).

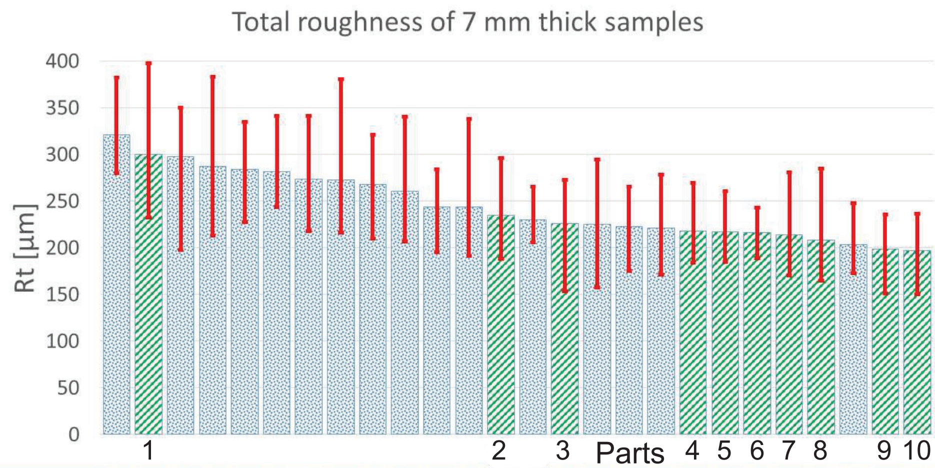


outer	speed	0	--	0	0	0	0	0	0	--	0	0	0	0	+	0	0	0	0	0	--	0	0	0	0	0	0
	current	0	0	0	0	0	0	++	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F.O.	0	0	0	0	0	++	0	0	0	++	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	number of contours	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	++	0	0	0	0	0	0	0	0	0
	multibeam	0	0	-	No	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
inner	speed	0	0	0	0	0	0	0	++	0	0	0	0	0	0	0	+	0	0	0	0	0	0	0	0	0	0
	current	0	0	0	0	0	0	0	++	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F.O.	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	-	0	0	0
	number of contours	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0
	contour offset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0	0	0	--	0	0	0
Double fusion		X																									
order of contours												X															
Job		1	1	1	2	1	1	1	3	1	2	1	3	2	2	2	3	2	3	2	2	2	3	3	2	2	2

Figure 3. Arithmetic roughness of parts with different parameters. The correspondent parameters are consigned just below (Standard parameter are noted by 0. If the value is larger, there is a + and if the value is lower, there is a -. (Standard parameter = hatched bars)

The influence of input parameters permits to conclude that the modification of input parameters, which affects the most the energy density equation, does not lead to an improvement of the surface roughness, whatever the thickness of the samples and the chosen parameters may be. The proportional energy varies from 0.3 to 3.9 times the standard value for the energy density. In spite of this, the maximum and minimum values for Ra are close (see Fig. 3).

The three sets of parts, Job 1, 2 and 3, revealed that the standard parameters are the best compromises in the Ra and the Rt, whatever the thickness of the parts and their inclination with respect to the horizontal. Fig. 3 and 4 show that the standard parameters give the best results for Ra and Rt. The measures showed that Ra is between 24 μm and 40 μm and that Rt is typically around 250 μm. That corresponds to values announced by ARCAM [3] and is similar to what was observed by [7].



outer	speed	0	0	0	0	0	--	0	0	--	0	0	+	0	0	0	0	--	0	0	0	0	0	0	0	0	0
	current	0	0	0	++	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F.O.	0	0	0	0	0	0	0	0	0	++	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	number of contours	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	++	0	0	0	0	0	0	0	0	0	0
	multibeam	0	0	No	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
inner	speed	0	0	0	0	++	0	0	0	0	0	++	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0
	current	0	0	0	0	++	0	0	0	0	0	++	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F.O.	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	-	0	0	0	0	0	0	0	0
	number of contours	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0	0	0
	contour offset	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	--	0	0	0	0	0	-	0	0
Double fusion		X																									
order of contours									X																		
Job		1	1	2	1	2	1	1	1	1	1	3	2	2	3	2	2	2	3	2	2	2	2	3	3	2	3

Figure 4. Total roughness of parts with different parameters. The correspondent parameters are consigned just below (Standard parameter are noted by 0. If the value is larger, there is a + and if the value is lower, there is a -. (Standard parameter = hatched bars)

The study of the roughness of inclined parts shows that the underside has a lower roughness than the upper side. This observation was made in the majority of cases.

In Job 2 and 3, parts printed with the same parameters in the same batch can produce different results with a difference sometimes up to 5 μm for Ra (see the second and the sixth with standard parameters (hatched) on Fig. 3). This finding brings to two questions: does the position of the part in the batch play an important role on the surface roughness? And what about the repeatability of EBM process in the surface finish? These differences may be explained by the fact that the position of the part in the manufacturing batch has an influence on its heat exchanges. If 2 parst in the same place and with the same parameters are compared (see the third and the seventh with standard parameters (hatched) on Fig. 3), the difference for the Ra value decreases to about 3-4 μm. The maximum and minimum values of the samples show that this is not so significant.

Another interesting observation is that the use of new powder leads to an improvement of the surface roughness (see the first (job1) and the others (job 2 and 3) with standard parameters (shaded) on Fig. 3).

CONCLUSIONS

This paper presents results of surface characterization of EBM Ti6Al4V parts by a mechanical method (with touch probe). The followed methodology is highlighted and the ISO 4288 standard [8] is adopted for each measurement. 586 measures were conducted on EBM samples with different parameters. The use of a mechanical method leads to higher value than in an optical method [6].

The main conclusion of this study is that the modification of the various parameters influencing the energy density does not allow a significant improvement in the surface roughness of the parts, whatever the thickness or the inclination of the parts may be. The standard parameters are, according to this study, optimal for the arithmetic roughness Ra and for the total height of the roughness profile Rt. The measurements show an arithmetic roughness ranging from 24 μm to 40 μm and a typical total roughness ranging from 197 μm to 321 μm. This had not been demonstrated before this study.

The use of new powder leads to an improvement of the surface roughness. But if new powder is used for each batch of fabrication one of the best advantages of AM is lost : not much waste.

References

[1] F. Monfort-Windels, Sirris (Juillet 2013).

[2] K. Vutova, V. Vassileva, E. Koleva, E. Georgieva, G. Mladenov, D. Mollov, and M. Kardjiev, Journal of Materials Processing Technology **210**, 1089 – 1094 (2010).

[3] S. ARCAM, www.arcam.com consulted on 11/06/2015 ().

[4] A. Dolimont, S. Michotte, E. Rivière-Lorphèvre, F. Ducobu, C. De Formanoir, S. Godet, and E. Filippi, “Effect of hipping (hot isostatic pressing) on electron beam melting ti6al4v parts after machining,” (2016).

[5] A. Dolimont, S. Michotte, E. Rivière-Lorphèvre, E. Filippi, and S. Godet, International journal of Rapid Manufacturing **5**, 320–338 (2015).

[6] A. Safdar, “A study on electron beam melted ti-6al-4v,” Ph.D. thesis, Division of Solid Mechanics, Department of Construction Sciences, Faculty of Engineering, Lund University, Lund, Sweden. 2012.

[7] R. K. Ek, L.-E. Rannar, M. Backstom, and P. Carlsson, Rapid Prototyping Journal **22**, 495–503 (2016).

[8] *International standards ISO 4288 (1996) - Geometrical Product Specifications (GPS) – Surface texture: Profile method – Rules and procedures for the assessment of surface texture* (1996).

[9] Statistical tools for high-throughput data analysis - test de student : Est-il toujours correct de comparer des moyennes ? http://www.sthda.com/french/wiki/test-de-student-est-il-toujours-correct-de-comparer-des-moyennes ().

[10] D. C. Montgomery and G. C. Runger, *Applied statistics and probability for engineers* (John Wiley and Sons, Inc, 1999).

[11] W. He, W. Jia, H. Lin, H. Tang, X. Kang, and H. Yu, Rare Metal Materials and Engineering **40**, 2072–2075 (2011).

[12] J. Karlsson, A. Snis, H. Engqvist, and J. Lausmaa, Journal of Materials Processing Technology (2013).

[13] M. Koike, P. Greer, K. Owen, G. Lilly, L. E. Murr, S. M. Gaytan, E. Martinez, and T. Okabe, Materials 2011 1776–1792October (2011).

[14] T. R. Mahale, “Electron beam melting of advanced materials and structures.” Ph.D. thesis, Faculty of North Carolina State Universitty 2009.

[15] L. Murr, E. Esquivel, S. Quinones, S. Gaytan, M. Lopez, E. Martinez, F. Medina, D. Hernandez, E. Martinez, J. Martinez, S. Stafford, D. Brown, T. Hoppe, W. Meyers, U. Lindhe, and R. Wicker, Materials characterization **60**, 96–105 (2009).

[16] A. Neira-Arce, “Thermal modeling and simulation of electron beam melting for rapid prototyping on ti6al4v alloys,” Ph.D. thesis, North Carolina State University, Raleigh, NC 2012.