Effect of HIPping (Hot Isostatic Pressing) on Electron Beam Melting Ti6Al4V parts after machining

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Abstract. The fast growing of Additive Manufacturing (AM) leads us to study the functionality of parts built by these processes. Recently, the Electron Beam Melting process and the Direct Melting Laser Sintering process are used to produce parts in the biomedical and aeronautical fields. The Ti6Al4V is largely used in these fields. This paper present an experimental study of machining Ti6Al4V alloy produced by Electron Beam Melting (EBM) before and after HIPping (Hot Isostatic Pressing). The results shows that the hipping has no significant influence on specific cutting pressure.

INTRODUCTION

During the last decade Additive Manufacturing (AM) technologies have continued to expand [1]. Initially the AM technology were devoted to rapid prototyping applications (product visualization, non-functional parts,...) but recent developments were made to allow production of real parts with the required mechanical properties. Highly competitive industries such as biomedical, aerospace or rapid tooling parts widely use AM to produce parts [2]. The development of new products in various fields used also AM technologies. The main advantages of AM technologies are linked to the production of complex shapes closer to the final product (so less raw material is used and less waste is produced during finishing operation) as compared to traditional techniques. AM also unlocks the design limitations and allows the production of parts virtually impossible to manufacture with traditional production techniques. The Electron Beam Melting (EBM) technology, developed at Chalmers University of technology in the late 1990s and commercialized by the Swedish company Arcam AB in the early 2000s [3], is one of these advanced AM technologies. This process is a layer-by-layer process which allows to build fully dense metallic parts from powder particles. This is divided into 5 steps (Figure 1):

1. Definition of a CAD model (.stl file);
2. Pre-treatment to orient the part in the batch of fabrication and supports placement (to improve heat transfer);
3. Slicing the part in a 2D-file (the electron beam works in 2D);
4. Manufacturing with the ARCAM printer;
5. Post-treatment of the part (sand blasting, supports removing, etc.).

The most widely used material for the EBM Process is Ti6Al4 ([5], [6], [7], [8], [9], [10], [11], [12]). This is the material used in this study with standard processing parameters.

In this study, the focus is set on the step 5 (post-treatment of EBM Parts). A Hot Isostatic Pressing (see [13] for details) was done to decrease the porosity (the samples were processed by using hot isostatic pressing (HIP) equipment under the pressure of 100 MPa for 2 h at the temperature of 920 °C and then cooled in the furnace to the room temperature). The samples were machined and the cutting forces were measured.

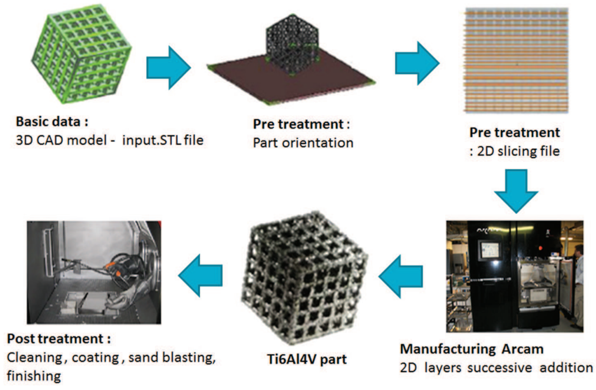

FIGURE 1. Manufacturing Cycle for EBM Process [4]

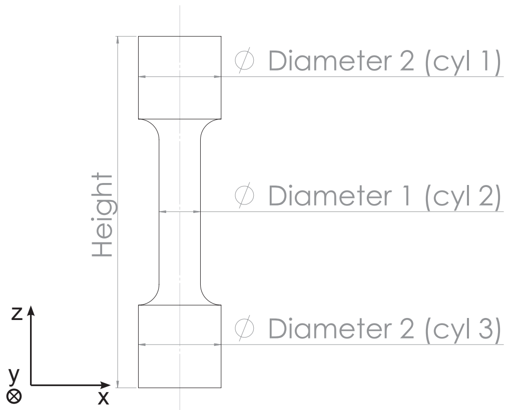

FIGURE 2. Geometry of tensile samples : EPS1

EXPERIMENTAL PROCEDURE

Sample manufacturing

These samples, here named EPS, were designed for tensile testing (their axis is along the Z building direction see Fig. 2). For these parts, a set of standard parameters optimized for 70 μm layers was used. As explained in the introduction, the process starts with preheating the powder then the contours melting and finally the inner region were melted (hatch melting). During fabrication, the temperature of the processed surface is maintained at $850°C$ by scanning the surface with the electron beam.

These 20 samples were produced dimensions with proportions kept according to ASTM E466 standard [14]. Other sample were manufactured and the dimensions were modified to evaluate (in another study) the impact on the properties caused by a variation of the samples dimensions. As far as the sample are machined to reach tolerances imposed by the standard, a machining allowance was added to the nominal dimensions (see [15] for details on determination of machining allowance on EBM parts). Dimensions for the target values of EPS are 103.250 *mm* for the height, 9.656 *mm* for Diameter 1 and 21.070 *mm* for the Diameter 2.

The powder used in this study was Ti-6Al-4V ELI Grade 23 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 powder.

Half of the samples (10 samples) have undergone hipping treatment (Hot Isostatic Pressing) in order to de-

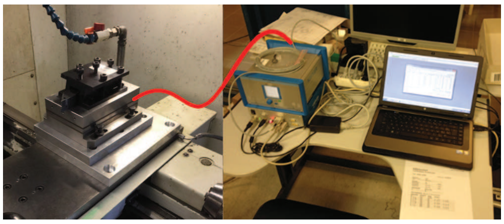

FIGURE 3. Acquisition chain

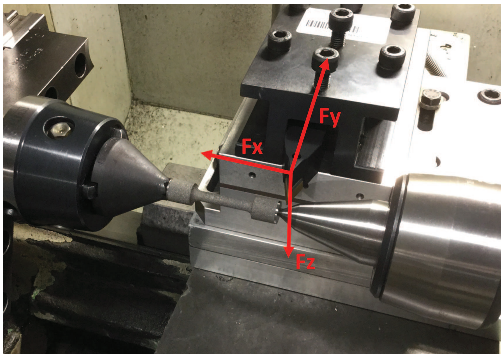

FIGURE 4. 3 directions of measure

crease the porosity from 99.6 % to 99.8%. In this study, half of the sample EPS were machined (5 HIP and 5 NO HIP).

Experimental Setup

In this section, the experimental setup used for the cutting force measurement is presented. The experimentation consists in a recording of the cutting force in turning. The machining center used for the experimentation is a Weiller E35. The spindle has a maximum speed of 3000 RPM and a spindle power of 11 kW.

The acquisition chain (Fig. 3) is composed of a dynamometer (Kistler 9257B) which measures cutting forces in 3 directions (X,Y,Z) (Fig. 4). In the present case, F_x is the axial force, F_y is the radial force and F_z corresponds to the tangential force (cutting force F_c). The signals are then amplified by a conditioning amplifier (Kistler 5070A). Then, they are processed by the system DAQ Kistler 5697A2 and saved on the PC by the software Dynoware.

The tool used for the experimentation is a cutting insert (VBMT 160404-FM2 (CP500)) and a tool holder (SVVBN 2020K16) provided by SECO TOOLS.

The cutting conditions were determined from the SECO TOOLS recommendations. The cutting speed was V_c = 50 m/min for this alloy. The cutting speed is kept constant. The feed rate was f_1 = 0.08 mm/rev for Cyl1 and Cyl3 and f_2 = 0.12 mm/rev for Cyl2.

The machining is done in a single pass (Diameter 1 and 2 after machining are respectively 8.65 mm and 19 mm) with lubrication (Quakercool 7100 HD). Because of the tolerance of the EBM process (see [15]), the depth of cut varied for each sample.So it is necessary to calculate the value for each sample.

The specific pressure (K_c) is determined by measuring the cutting forces with the measured cutting forces (Fz). The RMS (root mean square) value is calculated as follows:

$$Fz_{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} Fz_i^2}$$

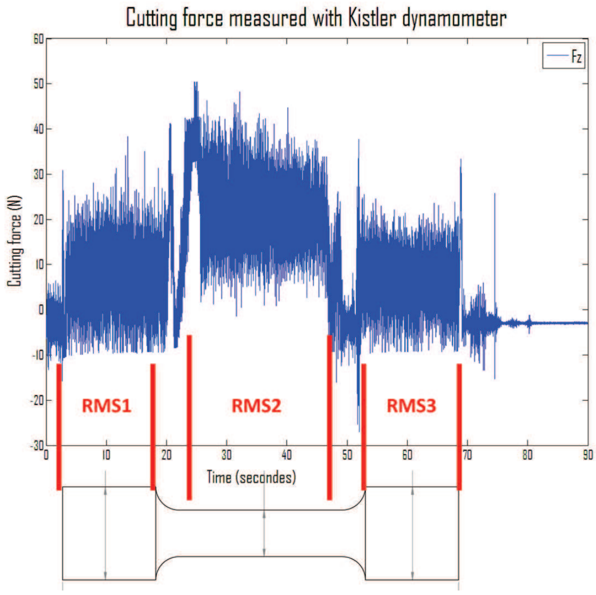

FIGURE 5. Definition of RMS1, RMS2 and RMS3

With the RMS value, it is then possible to calculate the specific pressure:

$$K_c = \frac{Fz_{RMS}}{A}$$

where A is the chip section defined as :

$$A = a_p \cdot f$$

In this study, the depth of cut (a_p) vary for each parts and depends on the initial dimension of the specimen, so it varies within the tolerances of EBM process. The real dimensions of EBM parts are measured for each diameter (see Fig. 2) before and after machining with a Coordinate Measuring Machine (CMM). The a_p is calculated with the real diameter before machining (D_{be}) and the diameter after machining (D_{af}).

$$a_p = \frac{D_{be} - D_{af}}{2}$$

The value of a_p vary from about 1 mm for Cyl1 and Cyl3 to 0.5 mm for Cyl2 (see. Fig. 2).

3 RMS (RMS1, RMS2 and RMS3) values were calculated (see Fig. 5). The a_p value vary for each diameter (Cyl1, Cyl2 and Cyl3) so the RMS value differs also with the diameter. The figure 5 shows the repartition of measurements along the sample.

After machining, tensile tests were conducted on 3 hipped samples and 3 no-hipped samples to compare the influence of hipping on EBM parts.

RESULTS AND DISCUSSIONS

The presented values are dimensionless with the mean value of hipped samples as a reference. The reference for the calculation of dimensionless value is the mean value of hipped samples.

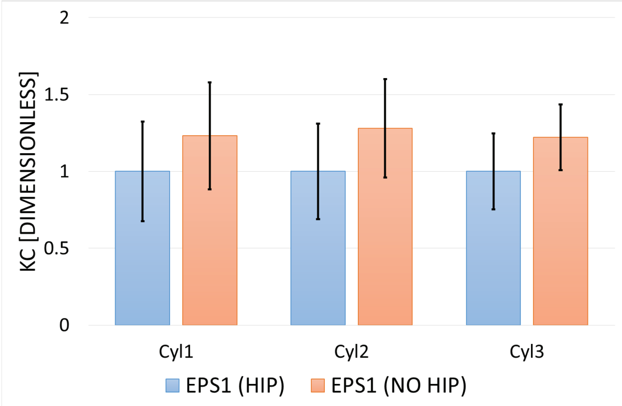

FIGURE 6. K_c Dimensionless values for Cyl1, Cyl2 and Cyl3 for EPS1 Samples (HIP in blue and NO HIP in red) with a 3 σ error bar.

TABLE 1. A summary of the mean values for Young modulus (E), Yield stress (R_m) and elongation at ruptur ($A\%$) for hipped and no-hipped sample. ϵ is the dispersion of the measured values

	E	ϵ	Rm	ϵ	A%	ϵ
EPS1 HIP	1	0.098	1	0.004	1	0.448
EPS1 NO HIP	0.934	0.209	1.048	0.013	0.431	0.104

Figure 6 presents K_c values for hipped and no-hipped parts. This Figure shows that the cutting forces on hipped samples tend to rise but the difference stays under the experimental uncertainty. The hipping has therefore no significant influence on the specific cutting pressure.

The Table 1 presents the results of tensile tests on hipped and no-hipped samples. The results show that the Young modulus is quite similar. The R_m value for hipped part in lower than the no-hipped part. This is probably due to diminution of the porosity and the small increase in the size of α-lamellar

CONCLUSIONS

This paper presents preliminary results in machining EBM Ti6Al4V parts. The followed methodology is highlighted. 10 samples were machined (5 hip and 5 no hip) and 6 samples were used to do tensile tests (3 HIP and 3 NO HIP). At this point, there is no strong influence of the HIP process on machining properties themselfs, although it has an strong impact on mechanical properties that the hipping as no significant influence on cutting specific pressure.

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