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CUTTING FORCES ANALYSIS IN ADDITIVE MANUFACTURED TITANIUM ALLOY WITH DIFFERENT ANGULAR LAYER DEPOSITION

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Abstract. *Additive manufacturing is a process of high growth and, consequently, many challenges. Among the various challenges of additive manufacturing, post-processing of parts is one of the most important. Moreover, generally, the materials undergo micro-milling processes to finalize the process. The overall goal of this research is studying the cutting efforts in the micro-milling of a titanium alloy material produced by the additive manufacture. For this, three different workpieces with the same size and with different angulation of their deposition layers were fabricated. The results had shown that the deposition of the layers promotes anisotropy during the data collection process in micro milling.*

Keywords: *Micro-milling, Deposited layers, Anisotropy.*

1. INTRODUCTION

The growth in industrial demands for the continuity of complexity and miniature for titanium alloys has been on the advance in recent years, principally because titanium alloys have excellent properties like high-temperature strength, hardness, and chemical wear resistance. In general, micro-machining processes in titanium alloys are related to aerospace, military, design, electronics, and health-related areas (HASSANIN et al., 2016; JOSHI, 2006; LIAN et al., 2018). Additionally, because micro-milling is an extremely versatile process, its application should include a promising future within the manufacturing processes (AURICH et al., 2017). As manufacturing processes evolve, and additive manufacturing advance, this study aims to analyze the mechanical efforts involved during the micro-milling process. Thus, the influence of the anisotropy of the deposited layers from the additive manufacture of the titanium alloy in the micro-milling process.

Products manufactured by additive manufacturing (AM) are formed in layers from some metal complex (THOMPSON et al., 2015). The use of AM can have an impact on the physical well-being and health of the individual, as well as preventing the environment from being used and wasted by reducing energy consumption, and increasing opportunities for improvement in the supply chain (BAUMERS et al., 2016). However, there are still many challenges for additive manufacturing to become an independent process. The central problems encountered in additive manufacture are related to surface finish, shape, and determination of alternative orientations (ZHANG et al., 2017). Considering the products manufactured by the additive manufacture do not have a satisfactory surface quality to meet consumption standards yet, some finishing processes were required for the part. According to TAMINGER and HAFLEY (2003), all parts produced by the additive manufacturer to date have required post-processing to ensure the contour and finishing conditions.

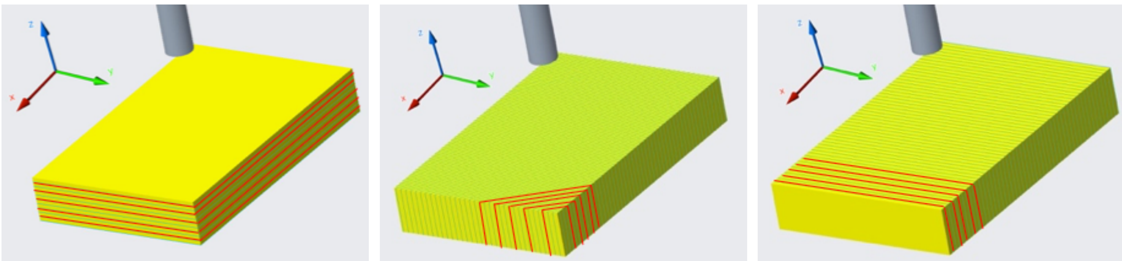
Several authors have studied the processes behind the additive manufacturing parts to solve their challenges. SEIFI et al. (2015) studied the dependence of fracture toughness and fatigue crack propagation behavior of a titanium alloy produced by EBM. For the authors, both fracture toughness and fatigue can increase mechanical stress compared to the same cast materials. Also, they examined the effects of sample orientations to determine the existence of some anisotropy in the material. While studies in additive manufacturing are still quite recent, DZUGAN et al. (2018) carried out a characterization of the local properties of Ti-6Al-4V samples for the establishment of the ASTM evolution standard. For this, the authors studied the effects of the layers and the small-scale orientation of fracture behavior of this titanium alloy. Besides that, LEWANDOWSKI and SEIFI (2016) have reviewed the influence of crack growth and, consequently, fracture toughness. For them, an in-depth review is critical to document ASTM and to generate a forecast of the efforts in materials that come from additive manufacturing. All of this is because there are significant differences in microstructure, texture, residual stress, and defects.

Accordingly, to analyze the behavior of the micro-milling process in three different workpieces of titanium alloy produced from EBM with three different deposited layers (zero, 45 and 90 degrees). This research intends to collect some force data and discuss the results. Moreover, micro-end-milling tool and workpiece from additive manufacture were used to represent a micro-milling process

2. METHODOLOGY

2.1 Used Materials

For the accomplishment of this work, pieces of Ti-6Al-4V were chosen. The microstructural characteristics of this alloy present great versatility with an excellent relation between the mechanical properties. Frequently, titanium alloys have excellent mechanical properties, castability, plastic workability, heat treatability, and weldability (GALARRAGA et al., 2016). The technology used to produce test specimens from the additive manufacture was EBM (Electron Beam Melting). EBM is a fast metal prototyping technology that is being widely used in the production of materials with complexity in their forms aimed, mainly, at the manufacture of implants for hospital patients (PARTHASARATHY et al., 2010). For confirm the same microstructural characteristics, three workpieces of the same Ti-6Al-4V powder material were fabricated at three deposition positions of the different layers, at zero degrees, 45 degrees, and 90 degrees. Figure 1 (a), (b) and (c), respectively.

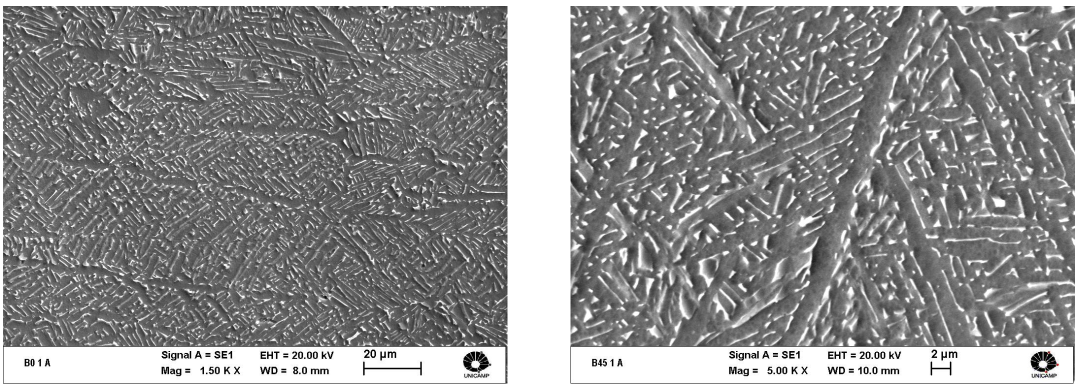


(a) (b) (c)

Figure 1. Illustration of deposition of layers of additive manufacture.

Figure 1shows both the representation of a cutting tool highlighted in gray color and lines in blue color. These lines represent the deposition layers of titanium in the process of additive manufacture. Layers of thickness of 0.05 mm were deposited. For the deposition, a Q10 model was used, with Focus of 3,073 mA, Beam Current of 41 mA, Backing Pressure of 7.9 e-1 mBar, Chamber Pressure of 3.9 e-3 mBar, Column Pressure of 1, 9 e-6 mBar, Bottom Temperature of 360ºC and Power Supply of 60 KV.

An MEV analysis was performed to examine the material characteristics of this researcher. However, the MEV was performed to analyze some pores or cracks, as a function of the solidification of the material, in the structure. The presence of pores or cracks in the workpiece can cause the material to change its mechanical strength during the micro-milling process. Figure 2 (a) and (b) show of example made it with MEV performed at a magnification of 1.5k and 5.0k, respectively. Besides this, the MEV was performed to compare the structure of Ti-6Al-4V used in the experimental procedure.

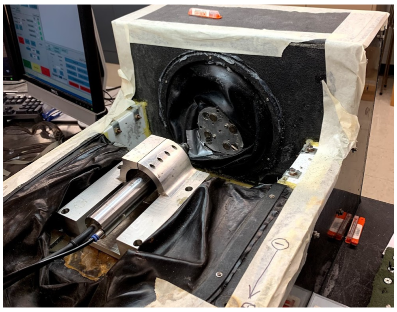


(a) (b)

Figure 2. MEV of Ti-6Al-4V

2.2. Experimental procedure

A Microlution 310-S, with 3 axes for micro-milling, maximum spindle speed of 50000 rpm, maximum acceleration of 5g, 0.001mm of positioning accuracy and 0.00002mm of resolution, was used in this research. Figure 3 (a) shows the micro-milling machine used it. For the micro-mill, a Micro100 milling cutter of AlTiN, model BMS-020-2 was chosen. The diameter of the tool chosen was 508um, with flute length of 762um and overall length of 38.1mm. The micro mill model also has 2 Flute, center cutting, 30° helix angle, 10° rake angle and 30° relief angle. The micro tool tolerances of shank diameter, cutter diameter and the total indicated runout max were 2,54 – 7,62um, 12,7um and 12,7um respectively (MICRO100, 2019). Figure 3 (b) shows a representation of the tool used for this research.


(a)


(b)

Figure 3. Micro-milling machine, and microtool.

While one of the objectives of this research was to analyze the influence of the deposition layers of the additive manufacture, it was determined that the only two parameters that would be analyzed would be the axial and radial depth of cut. Accordingly, the axial depth of 100um and 200um were chosen. For the radial depth of cut, values of 5um, 10um, 15um, and 20um, respectively, were specified. Besides, the workpiece surface was pre-machined before each experiment, and all such variations of axial and radial depth of cut were repeated for each angulation of the deposition layers seen in Figure 1. One micro milling tool was used to accomplish the experiments. Tests were performed with a speed of 16000rpm, a feed rate of 150mm/min and 35mm of machined length during each test. All assays were repeated three times, with a total of 72 experiments performed. The room temperature of the laboratory during the experiments was constrained in 21 Celsius degrees.

The cutting force were measured using a Kistler 9317B piezoelectric triaxial dynamometric load cell, where only the forces of the micro-milling plane X and Y were collected. Two Kistler 5015A charge amplifiers were used to acquire Fx and Fy forces, which were recorded to a PC with an acquisition program.

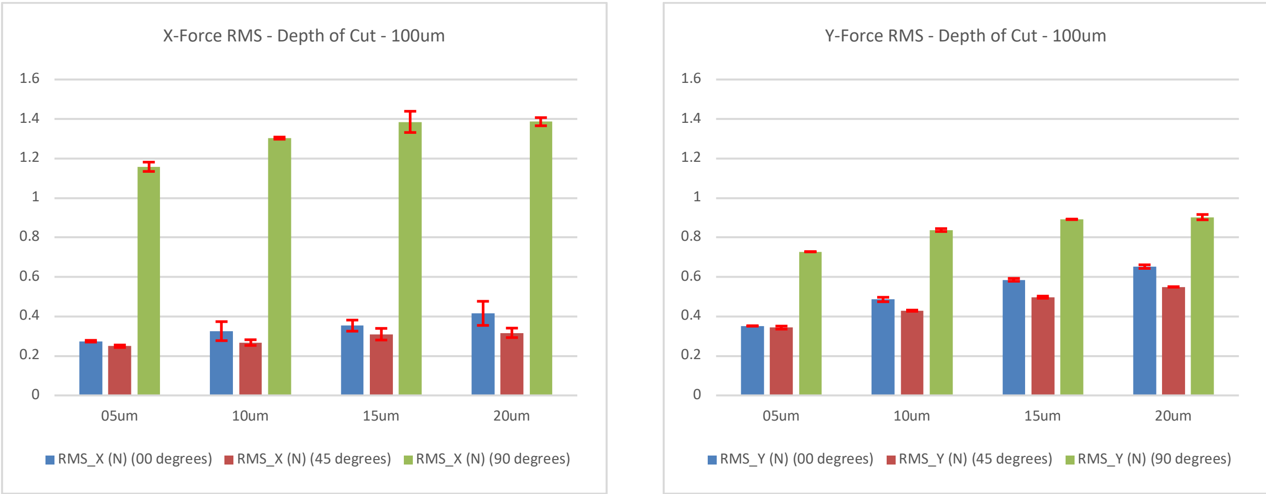
Data from micro-milling experiments was collected for all three different angular layers of Ti-6Al-4V AM. Therefore, a Root Mean Square (RMS) was calculated for each analyzed force in “x” and “y”. Since all experiments had been replicated three times, the average and standard deviation/sigma for each force component were calculated. It was noteworthy that the direction of y was the feed rate direction.

3. RESULTS

Among the accomplishment of the experiments, it is expected to find more significant results in the direction of the cutting speed. In this case, these forces refer to behaviors on the x-axis. The cutting forces relative to the y-axis refer to the feed rate of the tool.

All tests were performed with a cut's depth of 100um. These depths of cut were chosen because they represent twice the size between the deposition layer of additive manufacture. The results of the micro-milling process on the workpieces of 00-degrees and 45-degrees show that the force was much smaller than the workpiece with 90-degrees.

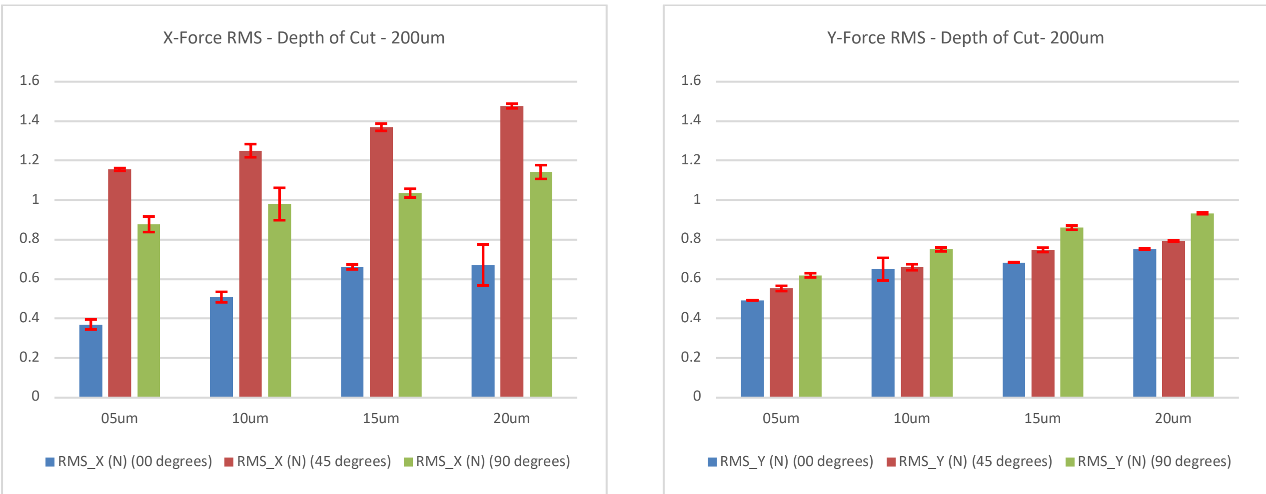
Moreover, where the x-forces of 00 and 45-degrees have a difference between four and a half times the force of 90 degrees, Figure 4 (a) shown these results. Besides, the calculated error of each experiment repetition remained very low for x strength tests at a cutoff depth of 100um, with a maximum value of 6.1% and an average of 2.3%. In Figure 4 (b) the force values of y were calculated for a cut depth of 100um. As the force of y was in the direction of the feed rate, and consequently, in the path of the variations of the AM layers, the forces result presented different values. In the Figure 4 (b), the workpiece with 00 and 45-degrees behaved respectively were similar to the efforts at x, but the y-forces in 90-degrees had twice the value in comparison with 00 and 45-degrees. Also, the 45-degree workpiece presented the lowest values for the 100um depth tests.



(a) (b)

Figure 4. Micro-milling forces Depth of Cut 100um.

For the tests with the depth of cut of 200um, the layers of the additive manufacturing process began to influence more considerably the process of micro-milling than the depth cut of 100um. Figure 5 (a) shown the x-forces for a depth of cut of 200um, and the depth of cut is doubling the value. The workpieces with 00, 45 and 90 degrees, the forces in x are practically doubling, quintupling and reducing a little, respectively, in comparison with the same test with a depth of cut with 100um. The most interesting fact that occurred in this test was the layers deposited at a 45-degree angle showed a significant increase compared to the other forces. This significant increase as a function of the 45-degree angle of the AM layer was found in the tests of the shear y-forces. Figure 5 (b) shows that the 90-degree deposition angle was not the dominant influence on the strength increase at y as seen in Figure 4 (b). For both tests performed with a depth of cut with 200um, we found a maximum value of 10.3% and an average of 1,3%.

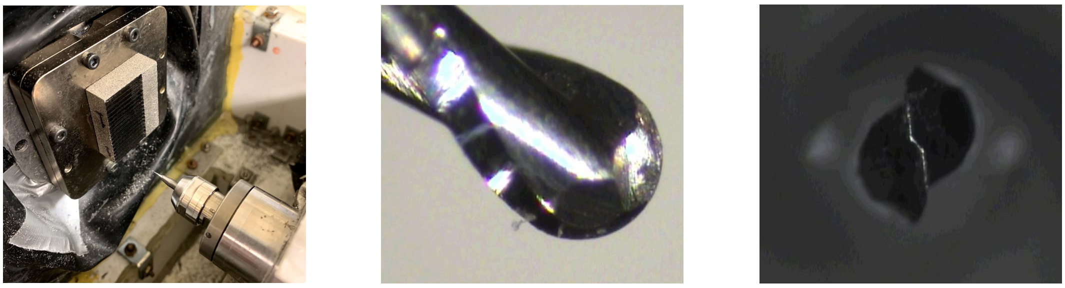


(a) (b)

Figure 5. Micro-milling forces Depth of Cut 200um.

All of the graphs analyzed above shown force values increase with radial depth of cut because as the Cut Width was increased, the stresses in Fx and Fy were increased too.

Figure 6 (a) shown one of the experiments began performed with the 45-degree workpiece. Subsequent, the entire workpiece was changed with the completion of micro-milling, the micro mill was analyzed to find any damage or wear on the tool. Figures 6 (b) and (c) shown the final state of the micro mill after all the experiments performed. Therefore, no damage and wear was found on the tool. Besides this, the results of the average of the sigma for any test performed was less than 10% for each case. Consequently, the micro-milling tool did not present any damage as can be seen in Figures 6 (b) and (c).



(a) (b) (c)

Figure 6. Micro-milling forces Depth of Cut 200um.

4. CONCLUSIONS

Although the layers are perpendicular to the workpiece with 90-degree deposition angle, for depth of cut of 100um (finishing process), the effects on the y-forces were much more significant than the 200um depth of cut for the same workpiece, which can cause significant vibration and surface roughness problems. Besides this, the deposition angles of 00 and 45-degrees presented lower values of mechanical stresses during the micro-milling finishing process. Generally, smaller force values result of forces were found in the micro-milling process with the 00-degrees of deposition layer. In processes of higher material removal (depth of cut of 200um), micro-milling of the workpiece with deposition angle of 45-degree should be avoided because high stresses in the x-direction (direction perpendicular to the feed rate) can cause the micro tool to vibrate and break during micro milling

5. ACKNOWLEDGMENTS

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ANÁLISE DOS ESFORÇOS DE CORTE NA LIGA DE TITÂNIO DA MANUFACTURADA ADITIVA COM DIFERENTES ANGULOS DE DEPOSIÇÃO EM SUAS CAMADAS

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Resumo. *A manufatura aditiva é um processo que vem crescendo bastante e, devido a isto, apresenta muitos desafios. Entre os vários desafios da manufatura aditiva, o pós-processamento de peças é um dos mais importantes. A fim de se garantir características dimensionais, esses materiais passam por processos de micro fresagem para finalizar o processo. O objetivo geral desta pesquisa é estudar os esforços de corte na micro-fresamento de um material de liga de titânio produzido pela manufatura aditiva. Para isso, três peças diferentes com o mesmo tamanho e com diferentes angulações de deposição em suas camadas foram analisadas. Os resultados mostraram que a deposição das camadas promove anisotropia durante o processo de coleta de dados no micro fresamento.*

Palavras-chave: *Micro-fresamento; Camadas de demosição; Anisotropia.*