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STUDY OF THE LATERAL PASS WIDTH FOR CONVENTIONAL AND ULTRASONIC VIBRATIONS-ASSISTED BALL BURNISHING ON TI-6AL-4V SPECIMENS

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ABSTRACT

Ball burnishing is a technological finishing process based on plastic deformation of the objective surface by means of a hard ball gliding over it. Along with its easiness of application, possible on the same machine where machining was performed [1], burnishing is a comprehensive process able to achieve surface roughness improvements, and compressive residual stresses up to deep layers of the material [2]. Burnishing results have proved to be depending of a proper selection of parameters, which must be correctly controlled during the process. That is the case of burnishing force or the number of passes [3]. Among these parameters, the lateral pass width has proved to be influential on the surface roughness results, due to the behavior that most materials show when being plastically deformed. In effect, the applied force makes the material to flow to the borders of the burnishing imprint, giving way to a pile-up effect. This paper deals with indentation experiments on Ti-6Al-4V to deepen in the burnishing process of this material. Single burnishing imprints are geometrically characterized combining different levels of force, number of passes, and comparing the conventional process with that assisted with vibrations. An optimal lateral pass width is thus determined, and technological recommendations are made for future applications of the process.

Keywords: ball-burnishing, lateral pass width, vibration-assistance, Ti-6Al-4V

1. INTRODUCTION

During the last decades, one of the main drivers of manufacturing technology innovation is the improvement of finishing process for high performance industrial parts. Surface integrity is an important matter to be controlled to optimize the tribological behavior and fittings of dynamic parts, and their hardness. These characteristic have influence on the lifecycle of those parts.

Ball burnishing is a plastic deformation process that enhances surface roughness and improves hardness by keeping untouched geometrical tolerances of manufactured parts [1]. This process allows to treat parts with no material loss, as burnishing is based on applying a force *F* which strains the material by deforming the peaks of its roughness profile, defined by h_2, through a ball of diameter *d* (figure 1).

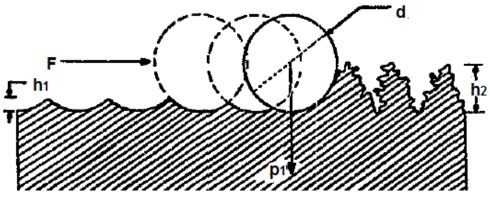

Figure 1. Burnishing schematically representation

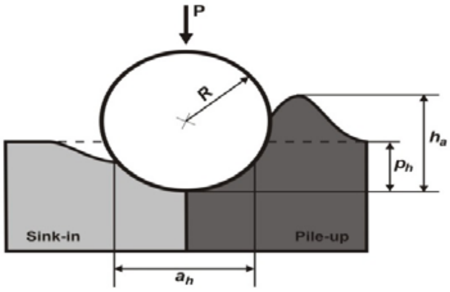

Figure 2. Contact of the burnishing ball with the material. The burnishing imprint is defined by: ah, imprint width; ph: imprint depth; ha: pile-up height; R: burnishing ball radius; P: burnishing force.

Assisting the process with vibrations improves the results in terms of surface roughness, hardness and residual stresses [4]. The physical mechanism which enables these positive results is called acoustoplasticity, which has been reported by other authors as a means of helping the displacement of materials dislocations, thus making easier the overall deformation process [5] As for burnishing parameters, lateral pass width has not been a central burnishing parameter in previous technological research, although, as shown in figure 2, it can be influential in final results, as intermediate pile-ups of the material might influence ulterior burnishing passes. Lateral pass width can therefore be defined as the linear distance between two adjacent burnishing passes. This paper aims to evaluate the influence of force, number of passes and the assistance of the process with vibrations with regards to indentation imprint geometry on Ti-6Al-4V parts. The B10PZ40k11 prototype developed and patented by Jerez-Mesa et al. [6] has been used. This tool is prepared to work under conventional and vibrations-assisted regimes. The nominal frequency of vibrations is 40 kHz. Throughout the paragraphs below, the following parameters will be considered: b: lateral pass width; N: number of burnishing passes; F: calibrated burnishing force.

2. MATERIALS AND METHODS

Burnishing results are highly dependent on the applied parameters, but also on initial conditions [7]. For this reason, Ti-6Al-4V specimens used for this research have been previously characterized in order to define their metallographic state and their mechanical properties (figure 3). The material came from an extruded cylinder raw part, cut in disks to achieve specimens easier to handle. Figures 4 (a-c) shows the metallographic images obtained for the used material, in both the laminating direction and the perpendicular one. Images show a homogenous material with α and β phases. The former is represented at the light areas, whereas the latter correspond to the dark ones. In figure 4 (a), grain boundaries can be identified, revealing a long shape which confirms that the raw material has been produced by a lamination process with an ulterior thermal treatment.

The next step was to measure the surface hardness. A Buehler 5114 durometer was used, with a Vickers indenter and 2 kg of load. The burnished specimen show an average hardness of 400,8 HV. His hardness leads to the need of applying higher forces than with other softer materials such as steel.

Figure 4. (a) Ti11, sentido laminación, x5 aumentos, (b) Ti11, sentido laminación, x10 aumentos, (c) Ti11, transversal a laminación, x5 aumentos

2.1. Indentation experiments

The burnishing tool with which this study was carried out was used to perform a series of linear indentations on the Ti-6Al-4V surface. The burnishing tool prototype was attached to a LAGUN MC 600 milling machine (figure 5), simulating a real burnishing process. The 10-mm diameter of the ball and a feed velocity of 600 mm/min were taken as fixed parameters, based on the results arising from previous investigations [7]. The case study has been organized as a factorial design of experiments where three parameters have been varied, as shown in table 1.

Figure 5. Left: external vibrations generator. Right: burnishing tool attached to milling machine.

The Ti-6Al-4V is a material known for the great difficulty it presents in terms of burnishing. Therefore, indentation marks on the surface are expected to be difficult to differentiate. Therefore, ensuring a low roughness surface is fundamental to ensure an ulterior analysis of the indentation imprint section topology. For that reason, the Ti-6Al-4V specimens have been polished before being indented.

Table 1. Factorial experiment designed to study indentations on Ti-6Al-4V specimens.

Exp	Force (N)	Number of passes	Vibration Amplitude (%)
1	300	1	0
2	300	3	100
3	300	5	0
4	300	1	100
5	300	3	0
6	300	5	100
7	450	1	0
8	450	3	100
9	450	5	0
10	450	1	100
11	450	3	0
12	450	5	100

3. RESULTS ANALYSIS

The titanium indented surface according to the defined experimental design was measured through an Alicona Infinite Focus optical profilometer. Figure 6 shows the transverse indentation section for 450 N and 5 passes, and the vibrations-assisted process. The central section of the figure clearly represents the deformation path left by the ball, whereas the extreme points show the pre-polished stable surface. The same profile was represented for each indentation imprint, measuring the depth and the width of the imprint, and the geometrical features of each path was measured with the Alicona software.

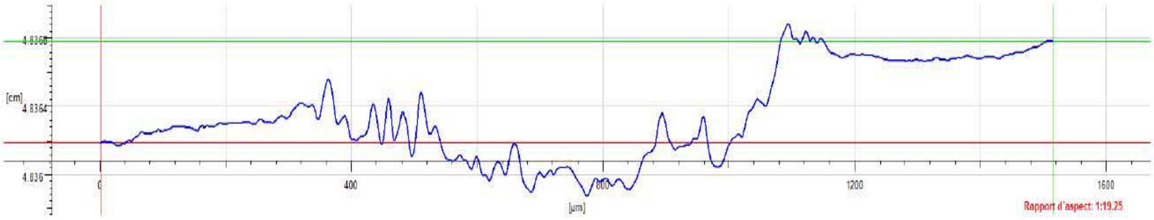

Figure 6. Indentation profile for F = 450 N, n = 5 and the ultrasonic-vibrations-assisted process.

Comparative results are shown in figure 7. In the first place, the imprint depth experiments an increase when the number of passes is also increased, regardless of the assistance of the process with vibrations. The same behavior can be observed when considering the burnishing force, observing a direct relationship with the burnishing imprint. Both effects had already been observed in previous studies [7]. On the other hand, the results related to the assistance of the process show that the introduction of vibrations provokes a remarkable decrease on the imprint depth. This result might be due to the fact that the main effect of vibrations is the hardening of the surface, which prevents the applied force to cause a higher penetration inside the material. Further research should be performed to confirm this intermediate result.

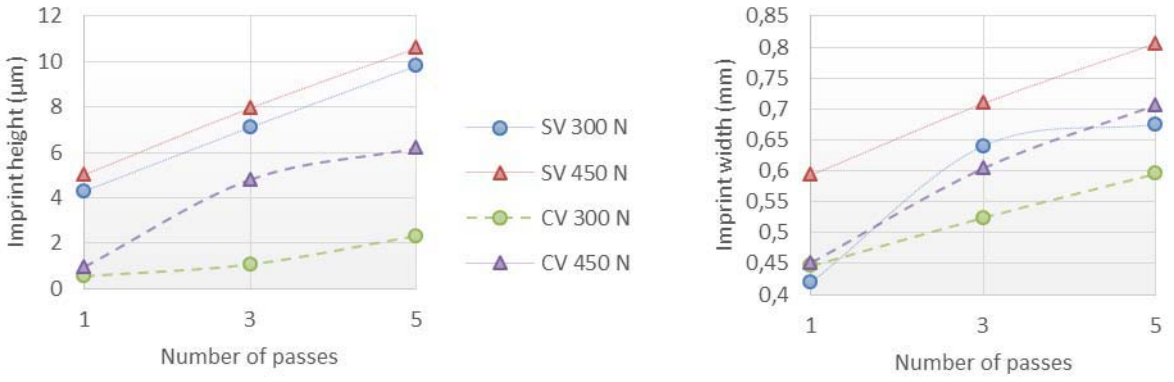

Figure 7. Indentation imprints geometry. Left: Imprint height. Right: Imprint width.
Continuous line: conventional burnishing. Discontinuous line: vibrations-assisted burnishing.
Circles: 300 N. Triangles: 450 N

As for the imprint width, which is the parameter which really defines the lateral pass width of the burnishing technological process, results are similar. Once again, assisting the process with vibrations causes a narrower mark on the material, even with the highest applied force. Therefore, a higher force and a higher number of passes are to be recommended if productivity wants to be maximized. Nevertheless, further research must be undertaken to confirm that the reason of this smaller imprint is self-hardening of the material due to the effect of vibrations, and in that case, finding an optimal solution which increases surface hardness without compromising the process productivity.

4. CONCLUSIONS

An experimental design to measure the indentation effects on Ti-6Al-4V has been undertaken, and the following conclusions can be drawn:

1. Burnishing imprints show higher dimensions when the burnishing force and the number of passes are increased, achieving the maximum width when treated with a 450 N force and applying 5 passes, with the conventional process. That means that those parameters are the best for the burnishing process in terms of productivity, for they allow performing passes with a higher lateral pass width.
2. The assistance of the process with vibrations generates smaller imprints on the Ti-6Al-4V, and therefore, might be detrimental to the process in terms of productivity. Nevertheless, this can be due to a higher self-hardening effect on the material, and might therefore be more positive in terms of absolute results after a burnishing process.

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