

# Experimental Investigation of the Effects of the Roller Burnishing Parameters on the Surface Roughness and Micro-hardness of Ti6Al4V Alloy

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## Abstract

In this research, the effects of three important input parameters of roller burnishing process, namely burnishing speed, feed rate and the number of passes on the surface integrity (surface roughness and surface micro-hardness) of Ti-6Al-4V alloy are investigated. The design of the experiment is carried out using a full factorial method. Measurement of process outputs is carried out with precise methods and the results are recorded and examined. The results showed that the parameters studied have a very significant effect on the surface roughness and micro-hardness of Ti6Al4V alloy. The feed rate is the most effective parameter on the surface roughness and the burnishing speed is the most effective parameter on the surface micro-hardness. Generally concluded, the roller burnishing process improves the final surface quality and increases surface micro-hardness. It also concluded that increasing the number of the burnishing passes from 1 to 2 would excel both of the output parameters while increasing of this parameter further has no significant effect or; in certain cases; an inverse effect on the surface roughness and surface micro-hardness.

## Keywords

Roller Burnishing, Surface Roughness, Surface Hardness, Burnishing Speed, Burnishing Feed Rate

## 1. Introduction

The burnishing process is a forming process, which is employed for the finishing of the workpieces. In this finishing method, high pressure is applied on the workpiece's surface using either hard rollers or hard balls. The applied pressure causes a plastic deformation on the material. As a result, the material flows from the hills to the cavities on the surface, resulting in the improvement of the surface quality [1]. A schematic illustration of the process presented in Figure 1 [2].

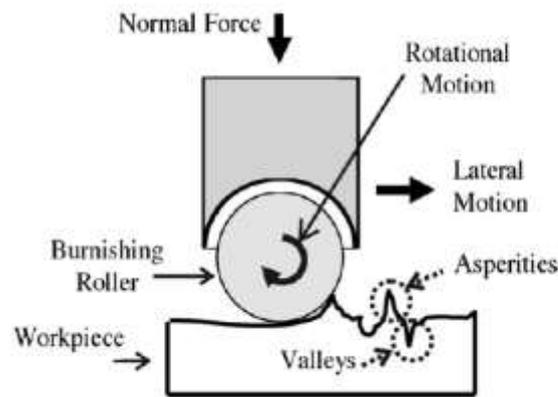


Figure1. A schematic illustration of the burnishing process [2]

The process is applicable to most of the internal and external surfaces, including curved or flat surfaces. Since the process increases the surface hardness and produces compressional residual stresses along with the reduction of the surface roughness, several research works have been conducted on this subject.

A considerable amount of literature has been published on the burnishing process, studying the different aspects of the process. El-Exir et al. [3] studied the effects of the burnishing rate, force application time, burnishing depth and primitive hardness of the workpiece on the final surface hardness, out of circularity and change in the diameter. Luo et al. [4] investigated the burnishing forced applied to the workpiece and compared the results with that in turning. El-Tayeb et al. [2] carried out experimental research on the effects of the burnishing rate, burnishing force and tool dimensions on the surface quality and tribological characteristics of Al 6061 alloy. Revankar et al. [5] excelled at the wear resistance and friction coefficient of the Ti6Al4V alloy using the ball burnishing process. Chomienne et al. [6] conducted their research on the influence of the ball burnishing process on the residual stresses of 15-5PH steel. Yen et al. [7] developed 2D and 3D FE models for roller burnishing. Klocke et al. [8] have studied the effect of the roller burnishing process on the surface quality of the turned surfaces. Sartkulvanich et al. [9] have studied the effect of the input parameters on the surface quality by FEM. Klocke et al. [10] have performed the roller burnishing process on the engine components and have studied their fatigue resistance.

There is rather a rich literature on the burnishing process, most of which have been working experimentally on the optimization of some parameters including the surface roughness, the surface hardness, the tool life, etc. In the present research, the effect of the input parameters' interactions on the surface microhardness and surface roughness is experimentally studied on Ti-6Al-4V. The research is conducted on the internal roller burnishing process, which has not been addressed by previous researches.

### Materials and methods

The material used in this study is Ti-6Al-4V, which is one of the most widely used titanium alloys. The aluminum stabilizes the  $\alpha$  phase in the microstructure, while vanadium stabilizes the  $\beta$  phase, resulting in a two-phase microstructure. The strength of the material is high and it is resistant to corrosion. Furthermore, the biocompatibility of the material has increased its application in medical devices. The mechanical properties of the material in the room temperature are presented in Table1.

Table1. the mechanical properties of Ti-6Al-4V

Tensile strength $\sigma_b$ (MPa)	Yield strength $\sigma_{0.2}$ (MPa)	Elongation $\delta$ (%)	Reduction of Area z (%)
986	876	19	42

In this research, the effects of the 3 input parameters (i.e. burnishing speed, feed-rate, and the number of passes) on the surface integrity and microstructure are studied. The full factorial method is selected as the design method of the experiment. The parameters are selected at three levels. The values for each of the input parameters are selected with respect to the tool and process limitations. These values are presented in Table 2.

Table2. the experiments' variables and their values

Parameter	Level A	Level B	Level C
Burnishing speed (rpm)	300	500	800
Feed rate (mm/rev)	0.05	0.15	0.3
Number of passes	1	2	3

As a result, 27 experiments are carried out.

The specimen is fabricated from a titanium rod. Each of the specimens is precisely fabricated using a CNC lathe machine. The drawing of the specimen is presented in figure 2.

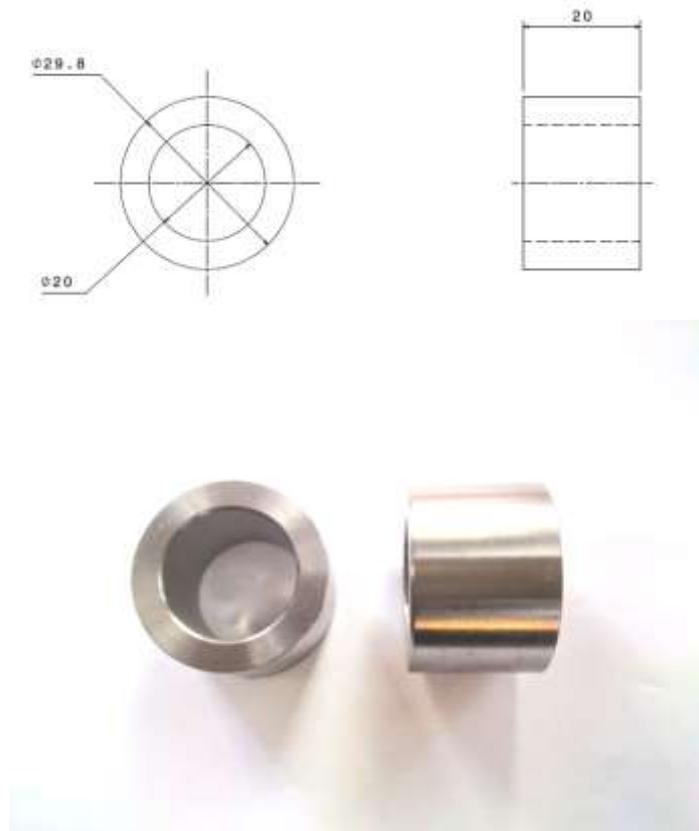


Figure2. The designed and fabricated specimen

The internal bore diameter of the specimen is selected 20 mm as the tool nominal diameter is 20 mm. The specimen's internal diameter is produced by drilling and boring processes. The outer

diameter is turned in order to have good concentricity with the internal bore, and the errors resulted from the eccentricities between the tool and workpiece could be minimized.

The initial surface roughness plays an important role in the final surface finish. This value has to lay between 5-50  $\mu\text{m}$  (according to the tool catalog). This value is 6.9  $\mu\text{m}$  in all of the specimens.

The roller burnishing tool is a DX grade roller burnishing tool produced by the YAMASA company. The tool is shown in Figure 3.



Figure3. The roller burnishing tool

The burnishing depth is set to 0.02 mm for each burnishing pass. The tool is capable of burnishing the holes with a maximum depth of 50 mm, while the length of the specimens is 20 mm. The experimental setup is depicted in Figure 4.



Figure4. The experimental setup

After the roller burnishing tests, the surface roughness of all of the specimens is measured using a surface roughness tester Mahr M300 C. The surface roughness is measured 3 times for each of the specimens and the average value is reported. Because of the bore diameter of the specimens, there is no need for cutting or sectioning of the specimens in order to measure the surface roughness.

The micro-hardness of the specimens is also measured for each of the specimens. Because of the curved surface of the internal bore, the micro-hardness could not be carried out without the destruction of the specimens. The specimens are sectioned for micro-hardness measurement. The outer surface is also face milled in order to produce a positioning surface for the specimens. One of the specimens is depicted in Figure 5.



Figure5. Specimen prepared for the micro-hardness test

The micro-hardness is measured in 3 different points along the cross-section of the specimens near the burnished surface, and the average values are reported.

### 3. Results and discussion

The ANOVA method is employed for data analysis. The results of all of the 27 experiments are entered to the Minitab software and the results are achieved in terms of the effect of the independent variables on the surface roughness and micro-hardness. The results are outlined in the following sections.

#### 3.1 The effect of independent parameters on surface quality

##### 3.1.1 The effect of the speed

The effect of the burnishing speed on the surface roughness is illustrated in Figure 6. The average of the data is 0.93  $\mu\text{m}$ , which is indicated by a horizontal line in Figure 6. As can be seen, the surface roughness is decreased as the speed is increased, however, it is increased by a further increase in the burnishing speed.

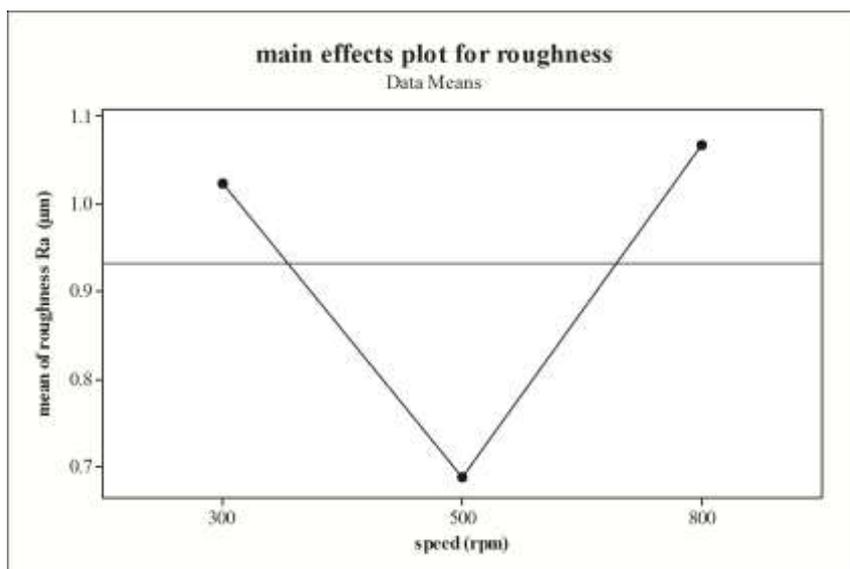


Figure6. The effect of the speed on the surface roughness

The main cause of the poor surface quality at lower speeds is the adhesion between the tool and the specimen, which is the result of the longer contact time between the roller and the specimen's surface. Increasing the speed reduces the contact time and adhesion and consequently reduces the surface roughness.

### 3.1.2 The effect of the feed rate

The effect of the feed rate is also studied on surface quality. The variance analysis of the data reveals that the feed rate significantly affects the surface quality. The results are depicted in Figure 7 shows that the increase in the feed rate reduces the surface quality.

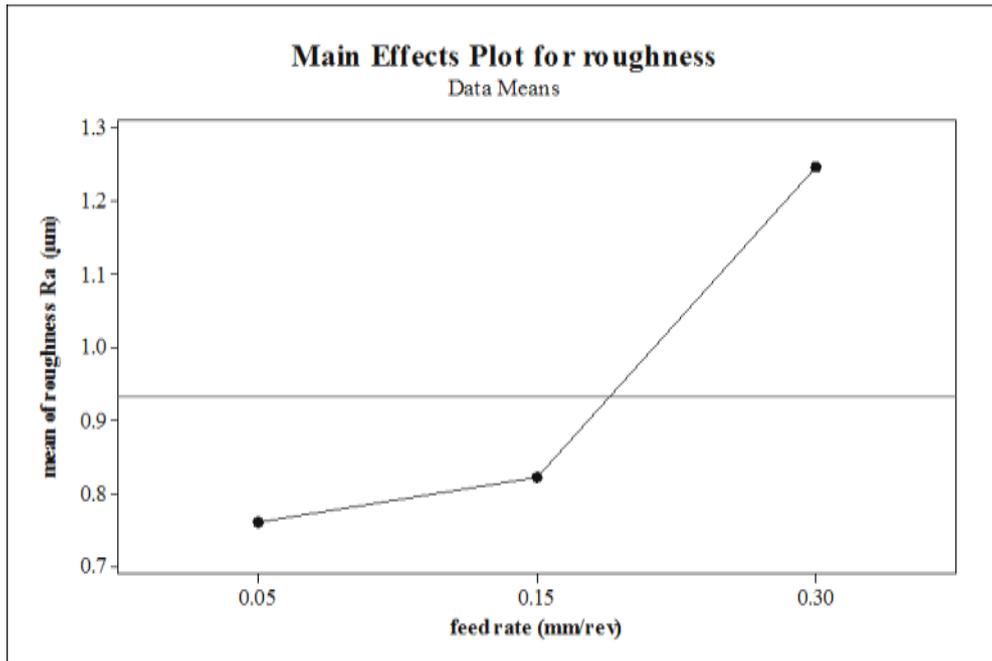


Figure7. the effect of the feed rate on the surface finish

The reason for such an increase in the surface quality is that as the feed rate is increased, the exerted force is increased as well [5].

### 3.1.3 The effect of the number on the forming passes on the quality

The effect of the number of passes on the surface roughness is presented in Figure 8 Obviously, increasing the number of passes from one pass into two passes excels the surface quality significantly, while increasing it from two into three passes has increased the surface roughness slightly.

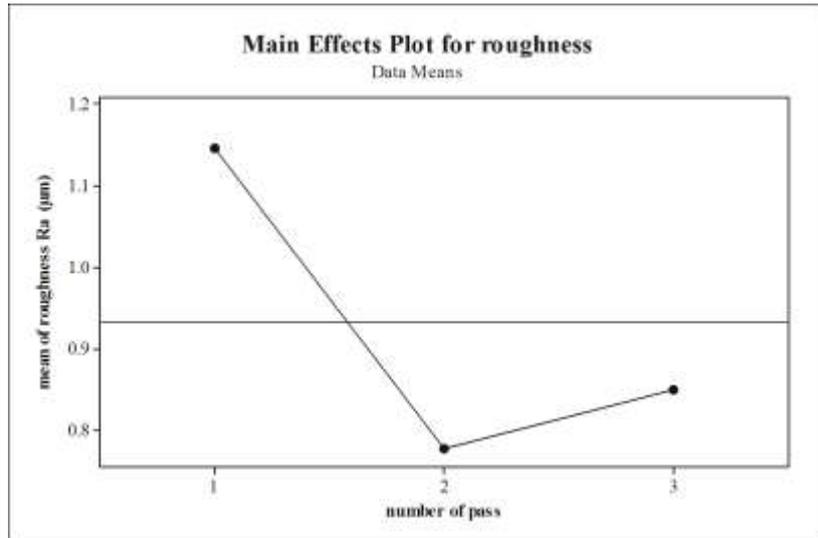


Figure8. the effect of the number of the passes on the surface quality

The reason for the improvement in surface quality is that by increasing the number of passes, more and more surface cavities are been filled and therefore, the surface quality is improved. However, increasing the number of passes from two into three is excessively increased the plastic deformation which causes the surface delamination and increases of the surface roughness.

### 3.2 The effects of independent parameters on the micro-hardness of the burnished surface

#### 3.2.1 The effect of the burnishing speed

The effect of the burnishing speed on the micro-hardness of the 27 specimens is studied. The micro-hardness of each of the 27 specimens is measured 3 times and the results are analyzed using the data variance analysis method. The results are depicted in Figure 9.

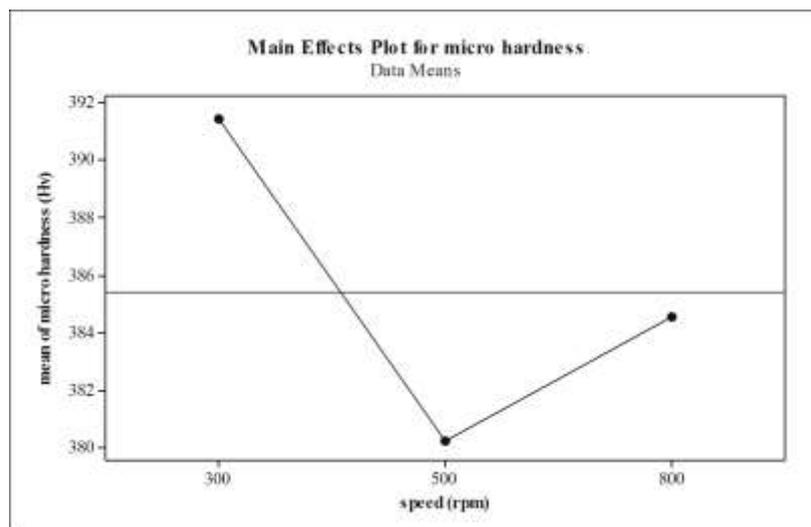


Figure9. The effect of the burnishing speed on the micro-hardness

The results show that the micro-hardness is decreased as a result of the increase in the burnishing speed. This is due to the increase of the workpiece temperature as a result of the increase in the

burnishing speed, which reduces the strength of the material. In higher speeds, the micro-hardness is increased again, which is the result of a higher strain rate which eventually increases the strength of the material.

### 3.2.2 The effect of the burnishing feed-rate on the micro-hardness

The effect of the feed-rate on the micro-hardness is also studied. The results are presented in Figure 10. As can be seen, the increase in the feed rate up to 0.3 mm/rev is increased the micro-hardness, while a further increase in the feed-rate causes the micro-hardness to decrease.

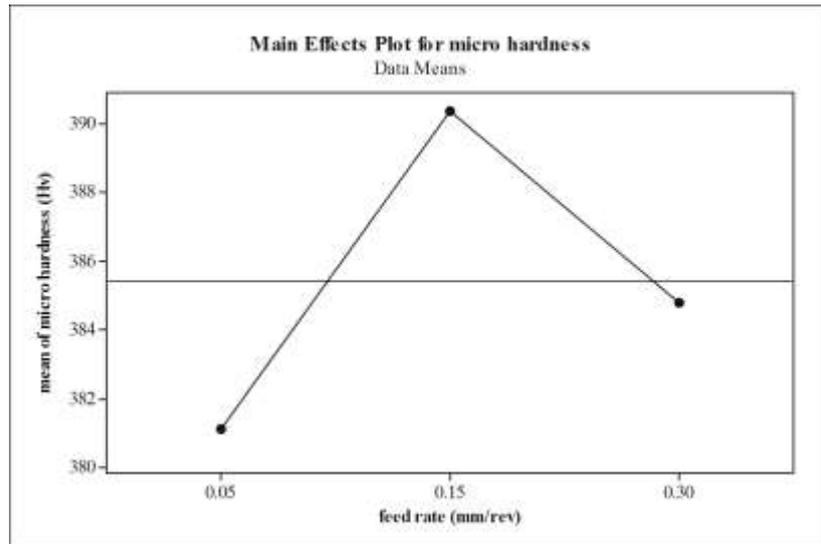


Figure10. The effect of the burnishing feed-rate on the micro-hardness

The increase in the feed rate increases the contact area between the tool and the workpiece, resulting in the increase of the exerted force and consequently; the micro-hardness. Further increase in the feed rate elevates the temperature, which softens the material and causes the micro-hardness to decrease.

### 3.2.3 The effect of the number of the burnishing passes on the micro-hardness

The effect of the number of passes on the micro-hardness is illustrated in Figure 11. The penetration depth increases 0.02 mm in each of the successive passes, which means that the exerted force is higher in higher passes.

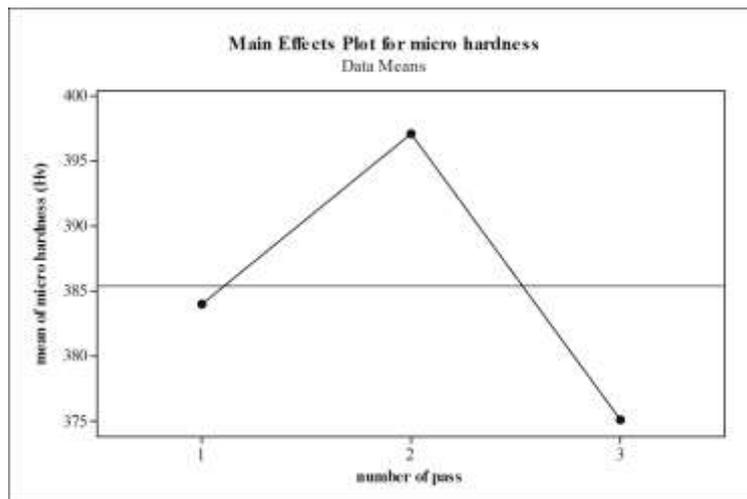


Figure 11. The effect of the number of passes on the micro-hardness

It can be observed from Figure 11 that the micro-hardness is increased in the workpieces with two burnishing passes in comparison with that in the work-pieces with a single burnishing pass. This is due to the work-hardening effect, and the fact that the micro-craters in the layers beneath the surface are filled with material, which increases the hardness even more. However, as the number of passes is increased from 2 to 3, the hardness is reduced, as can be seen in Figure 11. The main reason for such a change in the micro-hardness trend is that the increase in the burnishing depth increases the temperature, which results in the softening of the material.

#### 4. Conclusion

In this research, the effects of the burnishing parameters on the surface roughness and surface micro-hardness are experimentally studied. The obtained results are briefly outlined as follows:

- The main affecting parameter on the surface roughness is the feed-rate, while the number of the burnishing passes and burnishing speed are respectively the other two main factors. The surface roughness in the best combination of the parameters decreased by 87% in comparison with the unburnished work-piece. The surface roughness is increased as the feed-rate is increased. Furthermore, it is concluded that the increase in the number of passes from 2 to 3 does not significantly alter the surface roughness. The effect of the speed is controlled by two opposite mechanism, so that the increase of the speed up to 500 rpm excels the surface roughness, while further increase in the speed reduces the surface quality. The best combination of the parameters for obtaining the best surface quality is therefore: burnishing speed 500 rpm, feed-rate 0.05 mm/rev and two burnishing passes.
- The main affecting parameter on the surface micro-hardness is the burnishing speed. The increase in the burnishing speed from 300 rpm to 500 rpm decreases the micro-hardness, while it increases the micro-hardness as the burnishing speed is increased from 500 to 800. The increase in the feed-rate increases the micro-hardness; however, its effect on the surface micro-hardness is not as significant as the effect of the burnishing speed. The micro-hardness is also increased as a result of increasing the number of passes from 1 to 2, while a further increase in the number of passes from 2 to 3 diversely decreases the surface micro-

hardness. The optimum parameters for obtaining the highest surface micro-hardness are the burnishing speed 300 rpm, feed-rate 0.15 mm/rev and dual burnishing pass.

- From the above-mentioned results, it is obvious that the best combination of the input parameters for optimizing the surface roughness and surface micro-hardness is different. The only exception is the number of passes. The results show that the dual burnishing would have higher surface micro-hardness and lower surface roughness.

## 5. References

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