A Study on the Effect of Roller Burnishing Parameters on the Surface Roughness and Surface Hardness of Titanium Grade-V(Ti6Al4V) by Optimizing the Burnishing Parameters through DOE.

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Abstract- Burnishing is a very simple and effective method for improvement in surface finish and can be carried out using conventional machines such as a lathe or a CNC lathe. On account of its high output, it also saves more on production costs than other conventional processes such as super finishing, lapping, honing and grinding. Also, the burnished surface has a high wear resistance and better fatigue life. This paper focuses on the surface roughness and surface hardness aspects of Titanium Grade-V(Ti6Al4V) alloy, using Taguchi Method of DOE. The evaluation of the surface roughness and surface hardness on the work material will be observed in terms of determining the effects of various burnishing process parameters such as spindle speed, feed rate, depth of cut and number of roller passes on the surface roughness and fatigue strength, and identifying the most significant factors from the selected parameters, their order of significance and deciding the levels of factors for maximizing the surface hardness and minimizing the surface roughness.

Index Terms- Burnishing, Super Finishing, Surface Hardening, LPB, Titanium Grade-V(Ti6Al4V), Surface Roughness, Burnishing Parameters.

1. Introduction

The LPB (low plasticity burnishing) process is analogous to other burnishing processes in which a burnishing element in contact with the surface of a element is forcefully passed over the preferred area. The effect is usually a surface compressive stress and smothers surface finish than when the process was initiated. In LPB, the roller is maintained in a spherical socket with fluid abounding to the top of the roller. Fluid supplied to the socket applies the force and prevents the roller from making direct contact with the socket. The roller will roll over the surface with the help of fluid film formed and reduces the risk of the roller jamming in the socket.

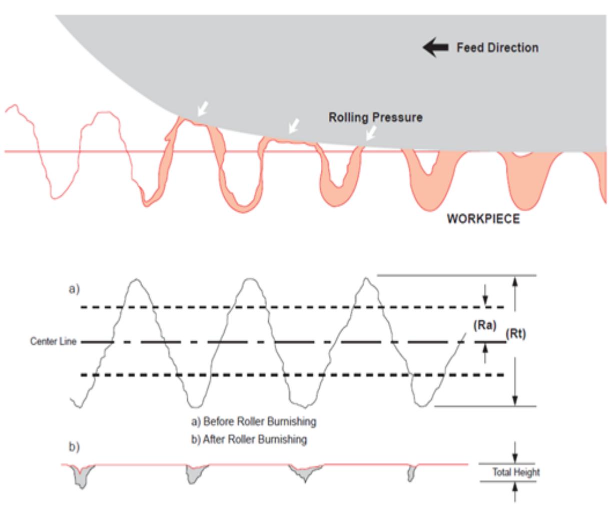

Figure 1-Roller Burnishing Process

2. Benefits of LPB

The LPB process includes a unique and patented way of analyzing, designing, and testing metallic components in the order to develop the unique metal treatment necessary to improve performance and reduce metal fatigue, SCC, and corrosion fatigue failures. Lambda designs a new tool for each component to provide the best results possible and to make sure that the apparatus reaches every inch on the component. LPB has even been shown to have the capability to produce through-thickness compression in blades and vanes, to a great extent increasing their damage tolerance over 10-times, effectively extenuating most FOD and reducing inspection necessities. No material is detached during this process, even when correcting damage by corrosion. The major benefit of LPB is the improved high cycle fatigue life. An LPB treated surface is resistant to foreign object damage and stress corrosion cracking. Shallow cracks, less than 0.010" deep, have had their growth arrested after being treated by LPB. [2] The LPB process can control the plastic deformation that the material undergoes for the duration of the process. Both the depth of compression and amount of cold work being applied on the surface of the component can be controlled. Residual compressive stresses can be set on surface of mechanical component with a process that is predictable and repeatable from part to part. The depth of burnishing with LPB can be as much as 1mm (0.040") with very low cold work, less than 5%. In contrast, shot peening typically produces 20 % to 70% cold work and much shallower compression. The burnishing can be applied to all types of steels including alloy steels, low and

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medium carbon steels, stainless steel, cast iron, AISI 1040, aluminum, and nickel-based super alloys.

3. Problem Definition

Thus, the problem can be defined as "An investigation of effect of roller burnishing parameters on surface properties of Titanium Grade-V(Ti6Al4V) alloy by optimizing burnishing parameters through DOE".

4. Objective

For augmenting life of the machined component, it is necessary to improve a surface of the component. Since all fatigue, fracture and corrosion related failures originates from a surface produced by the manufacturing process. It is a general procedure to introduce a layer of compressive residual stress on the surface machined component which leads to increase fatigue strength.

The purpose of this work is to investigate surface characteristics of Titanium Grade-V (Ti6Al4V) alloy, using Taguchi technique of DOE. The assessment of the surface characteristics of work piece is carried out, by evaluating the effect of burnishing parameters, determining the dominant factor from the selected burnishing parameters, to decide order of significance and setting the levels of the factors for enhancing surface characteristics like surface roughness and surface hardness.

5. Material Selection

The usage of Titanium Grade-V (Ti6Al4V) alloy is almost 50% of the total usage of all titanium alloys. Some of the important benefits of this alloy are very high strength, excellent resistance to corrosion, weldability & machinability. The wide range of its applications covers aerospace industries, marine industry, power industry, biomedical industry etc.

Applications: Blades, rings, discs, fasteners, airframes components, vessels, hubs, cases, forgings, biomedical implants. [6]

6. Burnishing Test Rig and specimen fabrication

Roller burnishing test rig used is shown in figure 2. Also, the specimens of required size of selected material are fabricated and as shown in figure 3

Figure 2- Roller Burnishing Tool

7. Experimentation

Surface characteristics of mechanical materials are governed by mentioned burnishing factors and their level of interaction. It is important to know quantitatively about the influence of these factors and their interactions on the response variables. The experimental work is carried out to assess the effect of the different burnishing parameters on surface roughness & surface hardness of Titanium Grade-V(Ti6Al4V) alloy. LPB on these material increases dislocation density near the surface, which in turn reduces grain size. Since Titanium Grade-V(Ti6Al4V) is more ductile, the plastic deformation on this material will be more. Because of the effect of more cold work, it has got finer grain size.

Since the bulk of the material constrains the deformed area, the deformed zone is left in compression after the roller passes. The surface is permanently displaced inward and no material is removed during this process. The small amount of deformations that are associated in the LPB process, are definitely encouraging to improve many desirable properties in a holistic approach, without causing any undesirable side effects. Further, LPB smoothes surface asperities and thereby improves the surface finish.

Actual experimentation stage includes burnishing of fabricated specimen on CNC Lathe machine with the help of Roller burnishing test rig.

Figure 3- Titanium Grade-5 Specimen Rod

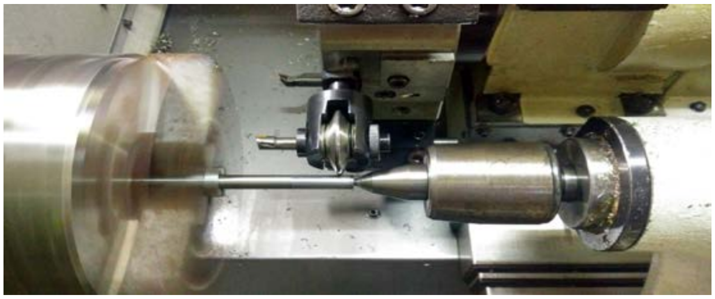

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Figure 4- Roller Burnishing Tool mounted on a CNC Lathe during Operation

8. Surface Roughness Tester

Measuring of surface roughness parameters for burnished test specimen is done by a Mitutoyo Surftest SJ - 400 surface roughness measuring device. It is also used for unburnished test specimens. It measures Ra value. It also measures Rz value.

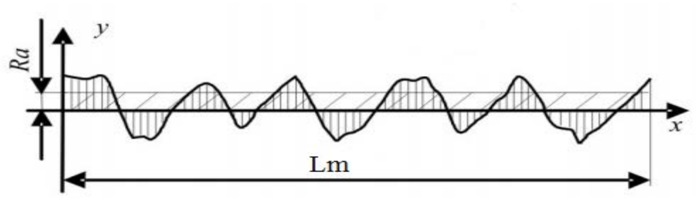

Figure 5- Measurement of Surface Roughness

9. Surface Hardness Tester

Along with surface roughness, burnishing process enhances the hardness properties too. To measure the increment in the hardness of the specimens, the Rockwell Hardness Tester was used

10. Experimental Design Matrix

Experiments have been carried out using Taguchi's L9 Orthogonal Array (OA) experimental design which consists of nine combinations of burnishing speed, burnishing feed, number of roller passes and depth of impression of the tool. As per Taguchi method, L9 Orthogonal Array is used in experimentation of present work. The detailed array is shown in table 1.

TABLE 1 - EXPERIMENTAL DESIGN MATRIX IN CODED FORM AND WITH ACTUAL VALUES

Expt. No	Coded Factors				Actual Values			
	A	B	C	D	Speed (rpm)	Feed (mm/rev)	No. of Passes	Depth of Impression (mm)
1	1	1	1	1	300	0.08	1	0.5
2	1	2	2	2	300	0.09	2	1.0
3	1	3	3	3	300	0.10	3	1.5
4	2	1	2	3	400	0.08	2	1.5
5	2	2	3	1	400	0.09	3	0.5
6	2	3	1	2	400	0.10	1	1.0
7	3	1	3	2	500	0.08	3	1.0
8	3	2	1	3	500	0.09	1	1.5
9	3	3	2	1	500	0.10	2	0.5

11. Results for Surface Roughness

Table 2 consists of the observed values of surface roughness on the test specimens before and after the experimentation. These values are tabulated below.

TABLE 2. SURFACE ROUGHNESS VALUES BEFORE AND AFTER EXPERIMENTATION

Exp no	Input Parameters				Observed values			
	A	B	C	D	**Before Burnishing**		**After Burnishing**	
					Ra_1 (µm)	Ra_2 (µm)	Ra_1' (µm)	Ra_2' (µm)
1	300	0.08	1	0.5	0.509	0.491	0.383	0.361
2	300	0.09	2	1.0	0.523	0.459	0.261	0.331
3	300	0.10	3	1.5	0.492	0.527	0.358	0.313
4	400	0.08	2	1.5	0.488	0.584	0.391	0.312
5	400	0.09	3	0.5	0.541	0.652	0.354	0.322
6	400	0.10	1	1.0	0.547	0.584	0.448	0.405
7	500	0.08	3	1.0	0.551	0.484	0.276	0.349
8	500	0.09	1	1.5	0.571	0.496	0.401	0.402
9	500	0.10	2	0.5	0.527	0.510	0.235	0.108

Figure 6 shows the main effects of burnishing parameters on the mean values of surface roughness. Also, since smaller surface roughness is desirable, the quality characteristics applicable in this case are *smaller the better*.

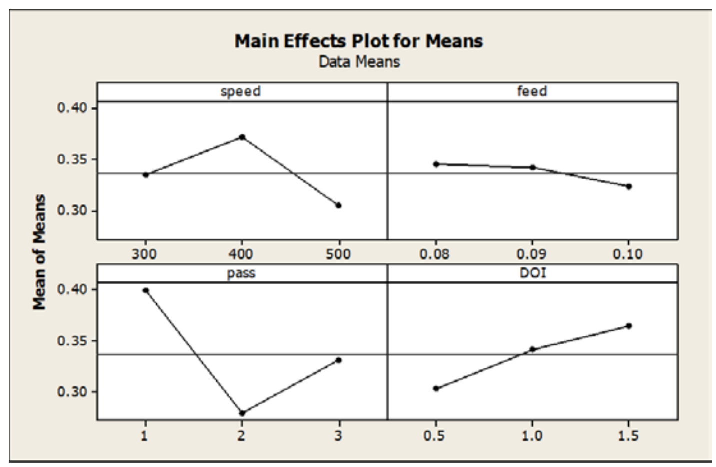

Figure 6- Main Effects Plot for Means, for Surface Roughness

For *smaller the better* quality characteristics of surface roughness, the main effects plot for signal to noise ratio is shown in figure 7.

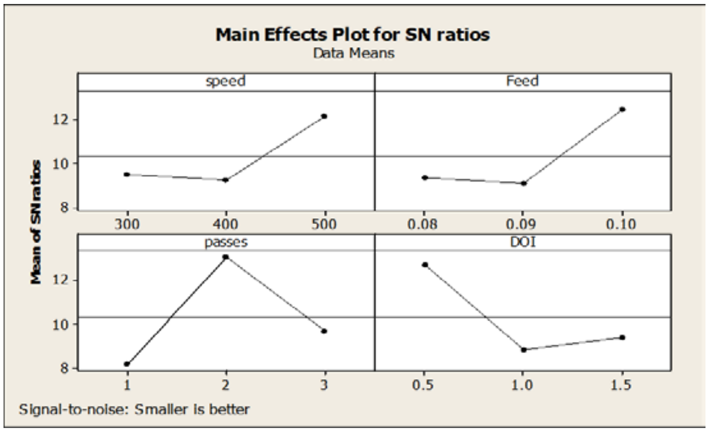

Figure 7- Main Effects Plot for S/N Ratio, for Surface Roughness

By using equation of the S/N ratios for the three levels of each control factor, the values are computed to determine the relative significances of the different parameters. From the analysis of the surface roughness data, it is observed that the number of roller passes and depth of impression of the tool play a significant role in determining the surface roughness. Furthermore, the burnishing speed and burnishing feed are less significant parameters.

Thus, it can be seen that the optimal burnishing performance for the surface roughness (based on means) was obtained at A3B3C2D1.

Speed (rpm)	**Feed (mm/rev)**	**No. Passes**	**Depth of Impression(mm)**
500	0.10	2	0.5 mm

12. Results for Surface Hardness

Table 2 consists of the observed values of surface roughness on the test specimens before and after the experimentation. These values are tabulated below.

TABLE 3- SURFACE HARDNESS VALUES BEFORE AND AFTER EXPERIMENTATION

Exp no	Input Parameters				Observed values			
	A	B	C	D	**Before Burnishing**		**After Burnishing**	
1	300	0.08	1	0.5	43	44	46	47
2	300	0.09	2	1.0	44	45	44	47
3	300	0.10	3	1.5	45	45	46	48
4	400	0.08	2	1.5	43	44	46	45
5	400	0.09	3	0.5	45	44	47	47
6	400	0.10	1	1.0	46	45	47	49
7	500	0.08	3	1.0	45	44	48	49
8	500	0.09	1	1.5	45	45	48	48
9	500	0.10	2	0.5	45	43	48	48

Figure 8 shows the main effects of burnishing parameters on the mean values of surface hardness. Also, since higher surface hardness is desirable, the quality characteristics applicable in this case are *higher the better*.

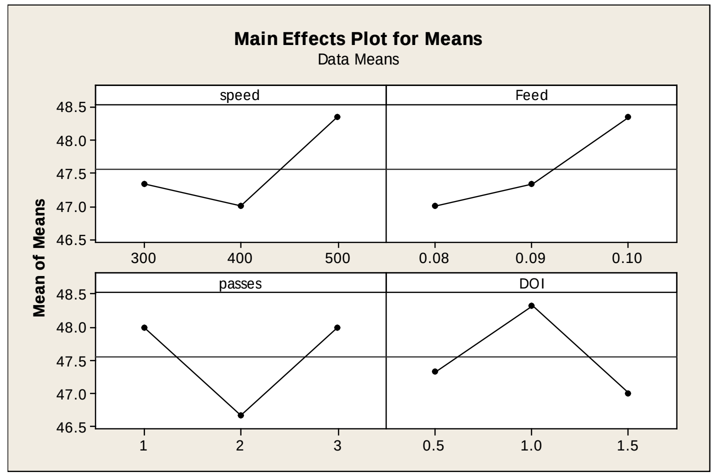

Figure 8- Main Effects Plot for Means, for Surface Hardness

For *higher the better* quality characteristics of surface hardness, the main effects plot for signal to noise ratio is shown in figure 9

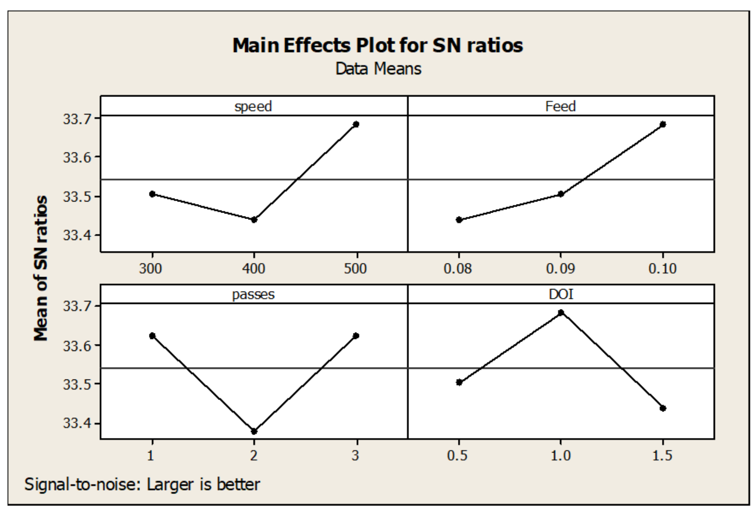

Figure 9- Main Effects Plot for S/N Ratio, for Surface Hardness

By using equation of the S/N ratios for the three levels of each control factor, the values are computed to determine the relative significances of the different parameters. From the analysis of the surface hardness data, it is observed that the burnishing feed and depth of impression of the tool play a significant role in determining the surface hardness. Furthermore, the burnishing speed and number of roller passes are less significant parameters.

Thus, it can be seen that the optimal burnishing performance for the surface hardness (based on means) was obtained at A3B3C3D2.

Speed (rpm)	Feed (mm/rev)	No. Passes	Depth of Impression (mm)
500	0.10	3	1.0

13. Conclusion

In the present work the roller burnishing process of Titanium Grade-5 (Ti6Al4V), based on Taguchi techniques, has been investigated. Based on the analysis of experimental results the following conclusions can be drawn:

The Chuck speed of 500 rpm for both surface roughness and surface hardness experimentations had the dominant effect on both the roughness and hardness of the test specimens.

The optimum conditions of burnishing parameters for surface roughness are as follows-
Burnishing speed = 500 rpm Burnishing feed = 0.10 mm/rev
Number of Roller Passes = 2 Depth of Impression = 0.5 mm
The optimum conditions of burnishing parameters for surface hardness are as follows:
Burnishing speed = 500 rpm Burnishing feed = 0.10 mm/rev
Number of Roller Passes = 3 Depth of Impression = 1.0 mm.

14. References

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