International Journal of Mechanical Engineering
and Technology (IJMET), ISSN 0976 – 6340(Print)
ISSN 0976 – 6359(Online) Volume 2
Number 1, Jan - April (2011), pp. 22-35

STUDY OF ROLLER BURNISHING PROCESS ON ALUMINUM WORK PIECES USING DESIGN OF EXPERIMENTS

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ABSTRACT

Roller Burnishing is a method of producing an accurately sized, finely finished and densely compacted surface that resists wear. Hardened and highly polished steel rollers are brought into pressure contact with a softer work piece. As the pressure exceeds the yield point of the work piece material, the surface is plastically deformed by cold-flowing of subsurface material. Roller burnishing is a metal displacement process. Microscopic "peaks" on the machined surface are caused to cold follow into the "valleys", creating a plateau- like profile in which sharpness is reduced or eliminated in the contact plane. Design of Experiments and Mini Tab 15 software are used to find out optimum values of process parameters. In this study surface roughness is the main response variable and the process parameters under consideration are spindle speed, tool feed and number of passes. The material under consideration is Aluminum, which is commonly used in industries and aerospace applications. Design of Experiments (DOE) techniques enables designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design.

Keywords: Roller burnishing, surface roughness value R_a, spindle speed, feed rate, no. of passes, taguchi techniques.

I. INTRODUCTION

In today's cost-conscious manufacturing environment, production manager would be excited about achieving accurate size and fine finish on the original machine on which parts are produced. Roller Burnishing can help users eliminate secondary operations for substantial time and cost savings, while at the same time improving the quality of their product. Roller burnishing is a method of producing an accurately sized, finely finished and densely compacted surface that resists wear. Hardened and highly polished steel rollers are brought into pressure contact with a softer work piece, as shown in Figure 1. As the pressure exceeds the yield point of the work piece material, the surface is plastically deformed by cold-flowing of subsurface material.

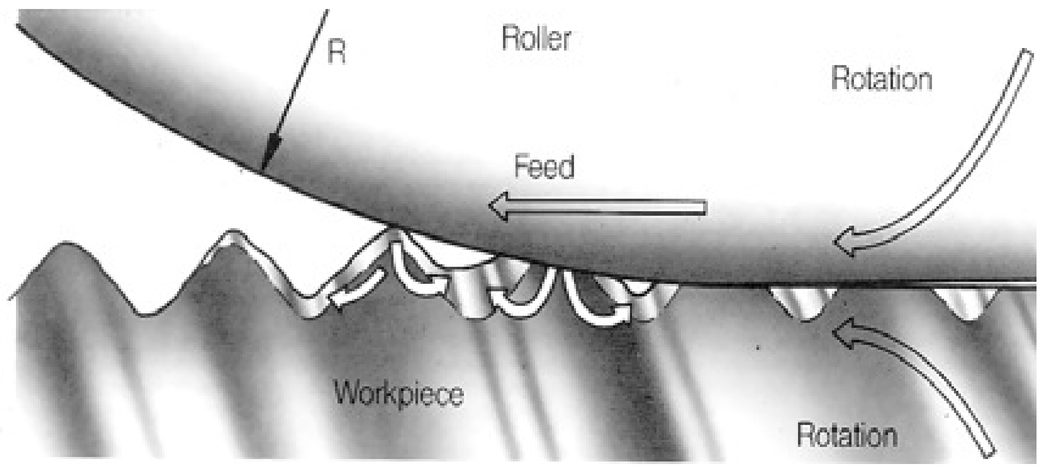

Figure 1 Schematic of Roller burnishing process

A burnished surface is actually smoother than an abrasively finished surface of the same profile meter reading. Profilometers measure roughness height. Abrasive metal removal methods lower the roughness height, but they leave sharp projections in the contact plane of the machined surface. Roller burnishing is a metal displacement process. Microscopic "peaks" on the machined surface are caused to cold flow into the "valleys", creating a plateau-like profile in which sharpness is reduced or eliminated in the contact plane, as shown in Figure 2 and Figure 3.

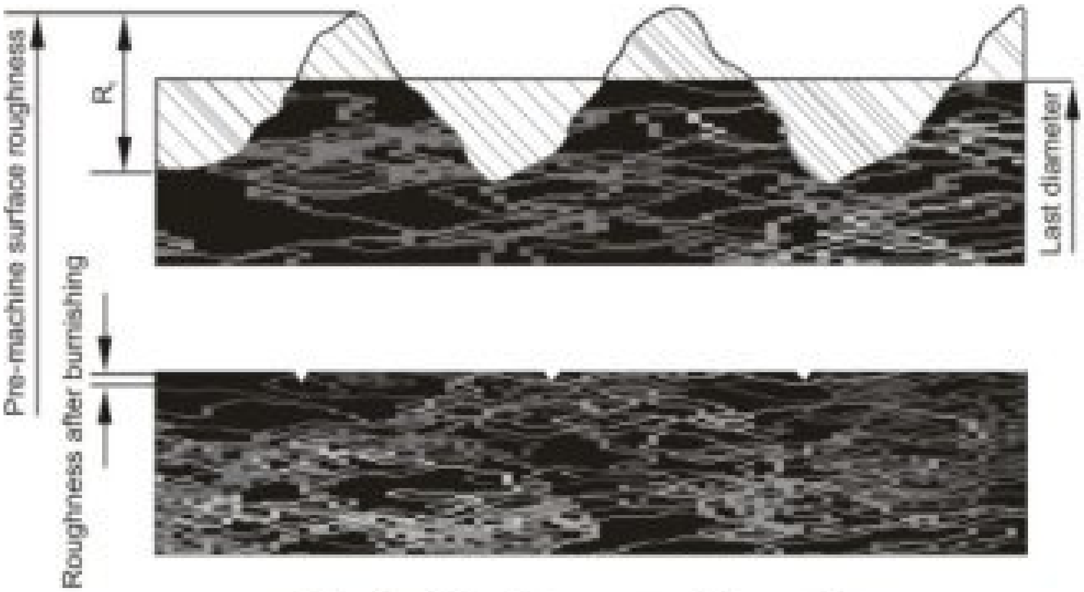

Fig.2 - Surface profiles after pre-machining and roller burnishing

Figure 2 Surface profiles after pre- machining and Roller burnishing

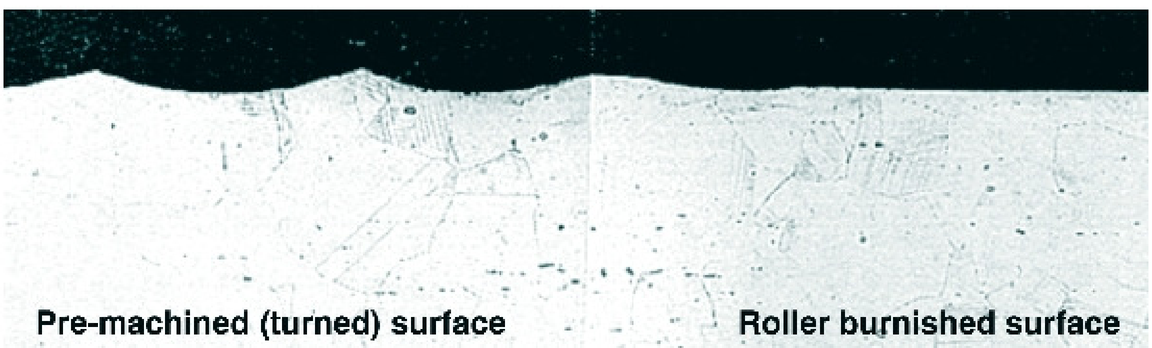

Figure 3 Comparison of Pre- machined surface and Roller burnished surface.

The burnished surface will therefore resist wear better than the abraded surface in metal-to-metal contact, as when a shaft is rotating in a bushing.

DESIGN OF EXPERIMENTS

Design of Experiments (DOE) techniques enables designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design. DOE also provides a full insight of interaction between design elements; therefore, it helps turn any standard design into a robust one. Simply put, DOE helps to pin point the sensitive parts and sensitive areas in designs that cause problems in Yield. Designers are then able to fix these problems and produce robust and higher yield designs prior going into production.

Part Quality and Process Improvements

Due to the work hardening of the surface during burnishing, there will be a hardened layer on the surface and it is expected to increase the fatigue resistance of the component. Apart from improvement in surface finish and fatigue strength, burnishing process imparts improved wear and corrosion resistance. The roller material is hardened alloy steel. In this paper, experiments with Roller burnishing tool are presented.

II. LITERATURE REVIEW

R. L. Murthy [1] et al discussed the types and working methods of burnishing process. Burnishing is considered as a cold working process which can be used to improve surface characteristics. Surface roughness and hardness plays an important role in many areas and is factor of great importance for the functioning of machined parts. A. M. Hassan [2] et al explained the effects of ball and roller burnishing on the surface roughness and hardness of some non- ferrous metals. It was suggested by many investigators that an improvement in wear resistance can be achieved by burnishing process. Yu. G. Shneider [3] studied the characteristics of burnished components. Wear has important technological and economical significance because it changes the shape of the work piece, and the tool and the interference. N. H. Loh [4] et al presented the investigations on the surface roughness produced by Ball burnishing. S. Thamizhmnaii [5] et al presented the surface roughness and hardness investigations on titanium alloy using a roller burnishing tool. M. H. El- Axir [6] presented his experimental investigations in to roller burnishing and the parameters which will affect the surface roughness values on the specimens.

A. Parameters affected by Burnishing

Because of plastic deformation in burnishing operation under cold working conditions, the surface finish of the work piece is improved. Also, work piece surface is work hardened. The surface hardness increases considerably. Also, the metal flows on the surface of the work piece during burnishing operation. Due to this flow of metal, any burrs, scratches, micro cracks, etc. on this surface of the work are filled up. As a result, the number of stress raisers on the surface decreases, there by increasing the fatigue strength of the work piece. Because of improvement in the surface hardness and surface finish, the surface would become resistant to corrosion and wear.

B. Industrial Applications of Roller Burnishing

A typical application for the Roller Burnishing process includes production of components for the hydraulic industry, where a precise sealing surface is required. The seal is often produced by an O- ring or rubber seal rubbing over the surface of a hardened steel shaft. Roller burnishing was first applied in American Industry in the 1930s to improve the fatigue life of railroad car axles and rotating machinery shafts. By the 1960s, roller burnishing was more widely applied, particularly in the automotive industry, as other process advantages were recognized.

Roller burnishing has long been used on a wide variety of automotive and heavy equipment components (construction, agricultural, mining and so on), including piston and connecting rod bores, brake system components, transmission parts and torque converter hubs. Burnishing tools are also now widely applied in non-automotive applications for a variety of benefits to produce better and longer lasting seal surfaces, to improve wear life, to reduce friction and noise levels in running parts, and to enhance cosmetic appearance. Examples include valves, pistons for hydraulic or pneumatic cylinders, lawn and garden equipment components, shafts for pumps, shafts running in bushings, bearing bores, and plumbing fixtures.

Parts in the automobile sector are finished economically by roller burnishing process. Also, majority of the components used in aircraft industry and aerospace technologies have got limitations with respect to weight. Hence, for such applications, light weight materials preferred are aluminum and its alloys. These materials are finished conveniently by roller burnishing process.

C. Benefits of Roller Burnishing

In Roller burnishing, tool marks are rolled out. The size of parts can be changed as little as 0.002 mm in one pass in a few seconds, as shown in Figure 4.

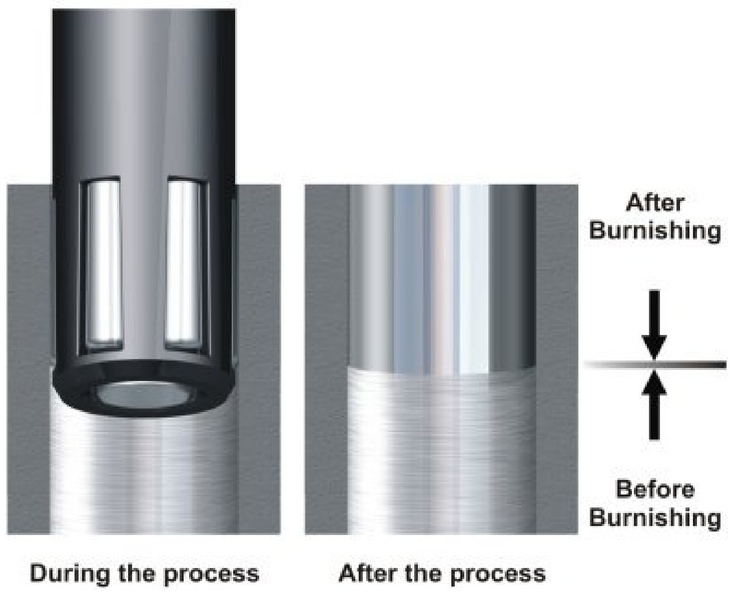

Figure 4 Mirror like Surface finish is produced after Roller burnishing operation

The grain structure is condensed and refined and compacted surface is smoother, harder and longer wearing than ground or honed surfaces. Hence, the corrosion resistance of burnished surface is higher than the open surfaces produced by grinding or honing. Due to the plastic deformation by this operation, residual compressive stresses are included in the surface of the component. The compressive stresses greatly increase the strength properties and fatigue life of the component. Thousands of parts can be finished with little or no burnishing tool wear. Setting up of the burnishing tool takes less than minute time. Unskilled operators can produce close tolerance. Hence, there is great saving in the wages of workers. The primary benefits, related to part quality, are as follows:

Perfect and accurate size control (tolerances within 0.0005 inch or better, depending on material type and other variables).

Excellent surface finishes (typically between 1 to 10 micro inches R_a)

Increased surface hardness (by as much as 5 to 10 percent or more)

III ROLLER BURNISHING TOOL

A Roller burnishing tool is designed and fabricated as shown in Figure 5. It consists of the following parts. i. Roller ii. Special bolt iii. Nut iv. Bush v. Washers vi. Shank. The shank is fixed in the dynamometer and it is tightened with two bolts. The chemical composition of Roller material is given below:
Fe 97.003, Si 0.18, Mn 0.26, Ni 0.12, Cr 1.44, C 0.99, S 0.007
The Roller has the following properties.
Surface roughness value R_a = 0.12 μm, Hardness = 61 HRC

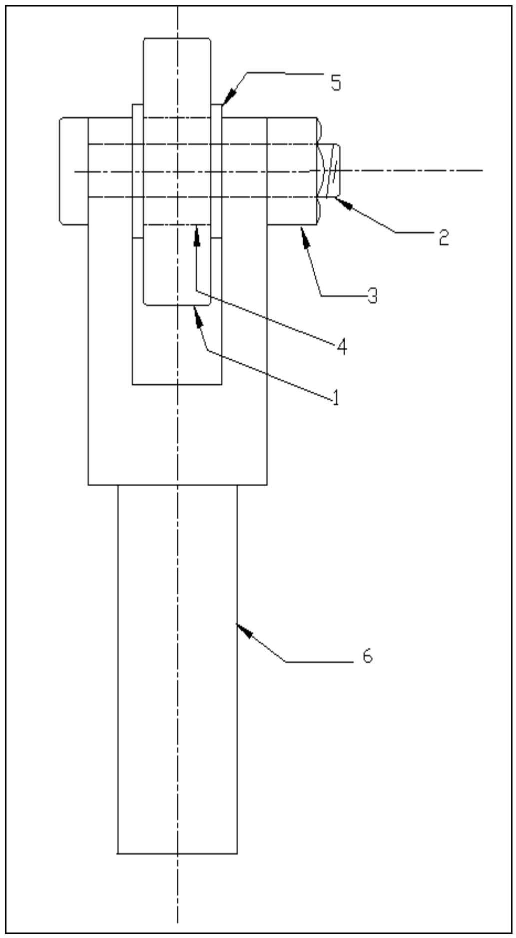

Figure 5 Roller Burnishing Tool assembly

IV EXPERIMENTAL SET UP

A. The Roller burnishing tool is fixed on the Lathe. The experimental set up is shown in Figure. 6. It consists of the following parts. i. Three jaw chuck ii. Live center iii. Dead center iv. Aluminum work piece v. Roller Burnishing tool vi. Dynamometer fixed to the cross slide of Lathe vii. Hand wheel for cross slide viii. Input power to the Dynamometer ix. Strain reader.

Burnishing experiments are conducted on turned aluminum work piece, which is very ductile, corrosive resistant, good conductor and available in the form of round bars. The chemical composition of aluminum specimen (wt %) is given below:
Al 93.73, Cu 5.34, Fe 0.3, Si 0.05, Mn 0.55, Zn 0.03

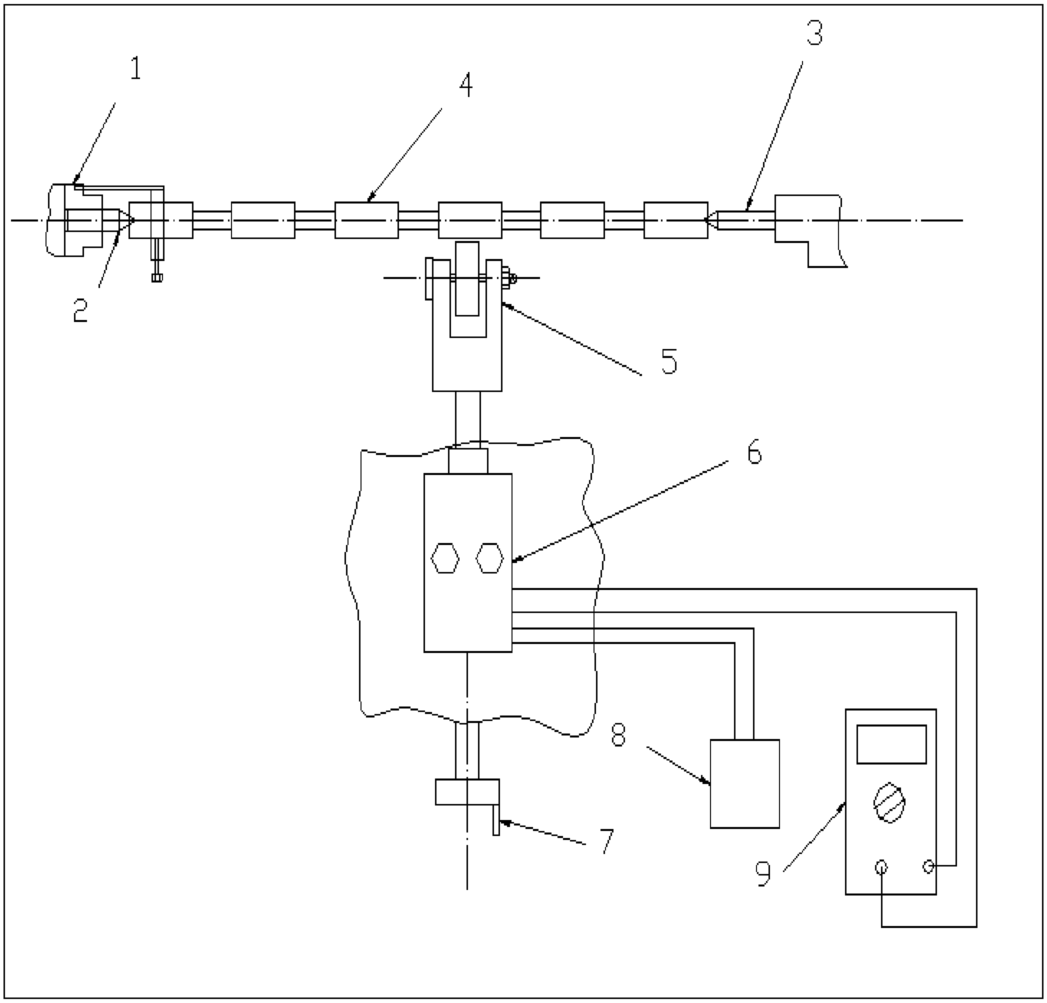

Figure 6 Experimental set up with Roller burnishing tool

To conduct experiments with roller burnishing tool, a round bar made of aluminum material is chosen as work piece material. The aluminum work piece is specially fabricated, as shown in Figure 7. All the dimensions are shown in millimeters in this figure.

First, the work piece is held in 3- jaw chuck of lathe and facing operation is completed on both sides and centre drilling is completed on both the faces. Then, the work piece is held in between centers of lathe and it is driven through the lathe drive dog. A high speed steel (H. S. S.) single point cutting tool is fixed in the tool post of the lathe and work piece is turned to have 6 steps and grooves in between them. In actual experiments, by applying different parameters on each step, this long work piece can be utilized as 6 different work pieces.

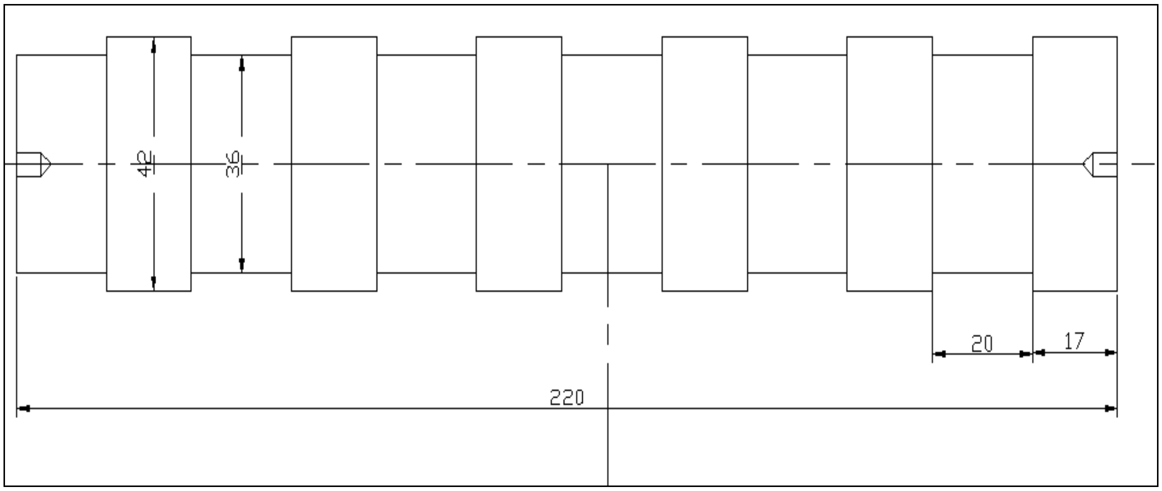

Figure 7 Aluminum Work piece for Roller Burnishing.

In the present work, roller having outside diamante of 40 mm is used for roller burnishing. The tool post and compound rest are removed from the lathe. Dynamometer together with its fixture is held on the cross slide of Condor lathe, Gedee Weiler make, Coimbatore and it is tightened with two fixing bolts. The roller burnishing tool assembly is kept in the tool holder of dynamometer and it is held rigidly by two bolts. Burnishing Force i.e., radial component of cutting force (in y- direction) is measured by dynamometer.

Figure 8 shows the photograph of the experimental set up when roller burnishing tool with 40 mm diameter roller burnishes an aluminum work piece in Gedee Weiler Condor lathe. The dynamometer, Roller burnishing tool, aluminum work piece, etc. are shown in the close up view clearly in Figure 9.

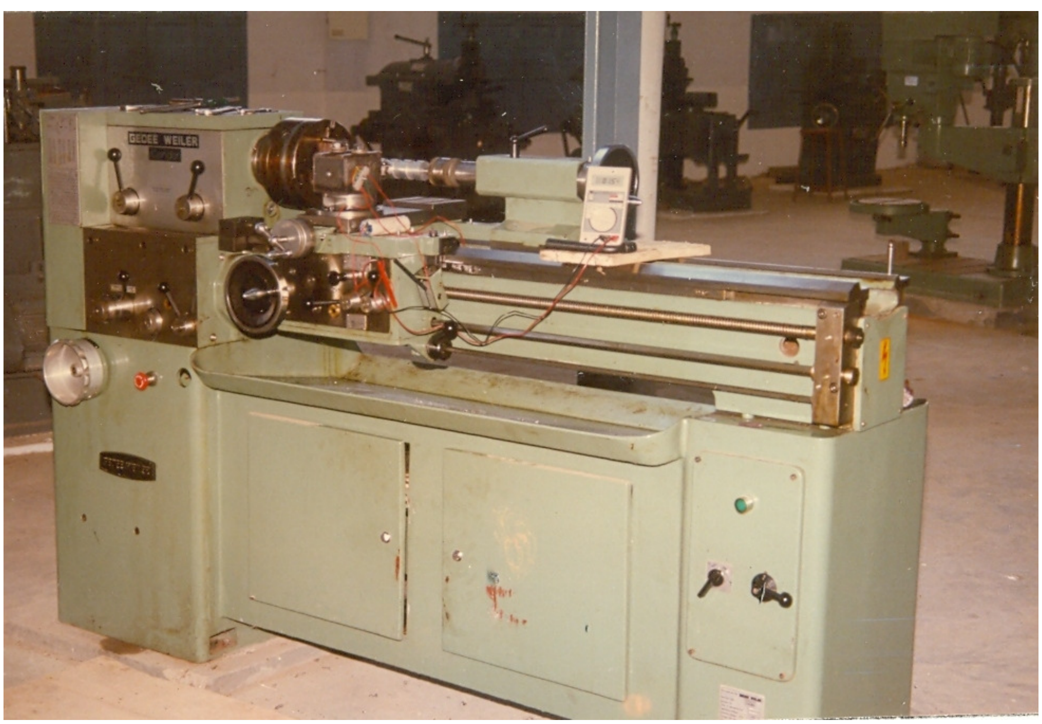

Figure 8 Photograph of experimental set up of Roller burnishing process on lathe

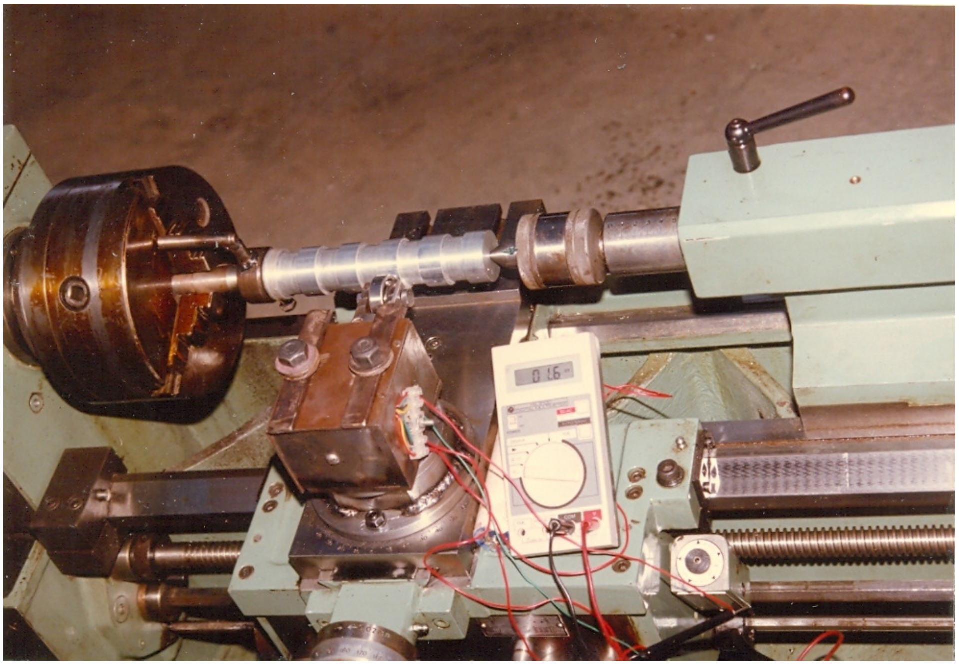

Figure 9 Photograph showing close up view of experimental set up on lathe

B. MEASUREMENT OF SURFACE ROUGHNESS VALUES:

Repetitive or random deviations from the nominal surface which forms the pattern of the surface is known as surface texture. It includes roughness, waviness, flaws, etc. Waviness is due to the geometric errors of machine tool and varying stiffness of the machine tool. Roughness is due to the inherent kinematic differences of the cutting process.

Various parameters of surface roughness i. e. R_a, R_z, R_{max} are measured by using Surface Roughness Tester – 211 Mitutoyo, Japan make, as shown in Figure. 10. Centre line average (C. L. A.) or R_a value is the arithmetic average roughness height. Average height difference between the five highest peaks and five lowest valleys within the traversing length are called peak to valley height (R_z).

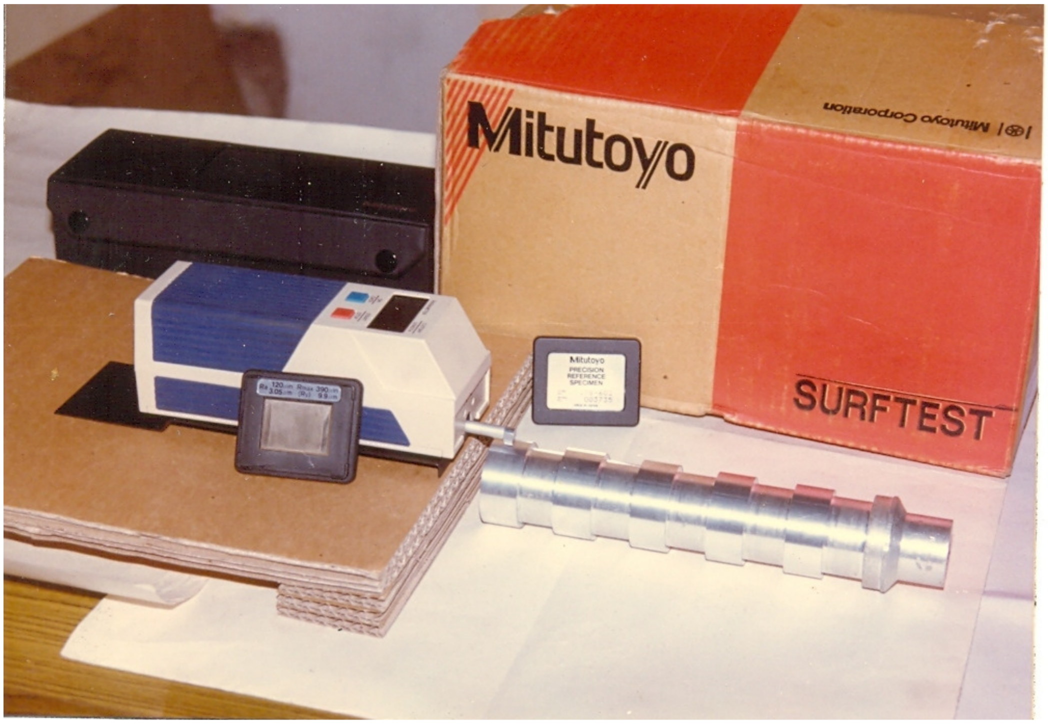

Figure 10 Photograph of 'Surftest – 211 model' Surface Roughness Tester

C. MATERIALS AND METHODS

In this present research paper, an effort is being made to understand the underlying mechanism of improvement in the surface finish of burnished surfaces along with the influence of the process parameters in aluminum material, which is commonly used in shafts, etc. Properly planned and executed work highly reduces the data collection and avoids large experimentation. In these studies, the fundamental mechanism of the process is being analyzed rather than developing any regression models. The Taguchi L9 orthogonal array has been used for discussing the results of various process parameters. Following process parameters are selected for Taguchi L9 orthogonal array as shown in Table 1.

Table 1 Process parameters and their range

Process parameters	Roller Burnishing process		
Levels	1	2	3
Spindle Speed (RPM)	45	220	560
Tool feed rate (mm/rev)	0.024	0.060	0.103
No. of passes	1	2	3

V. RESULTS

The Roller burnishing experiment is conducted for 3 times and the corresponding surface roughness (R_a) values are taken and the average value of R_a is calculated in each case. The values in Table 2 and Table 3 are entered into the Mini Tab 15 Software.

Table 2 Process parameters and the corresponding average Surface roughness (R_a) value (µm)

A	B	C	Roughness(µm)
1	1	1	1.55
1	2	2	1.42
1	3	3	1.35
2	1	2	0.42
2	2	3	0.30
2	3	1	0.56
3	1	3	0.96
3	2	1	1.21
3	3	2	1.12

Table 3 Different values of the process parameters for the Roller burnishing experiment on Lathe.

S. No.	Spindle Speed RPM	Feed mm/rev,	No. of passes
1	45	0.024	1
2	45	0.060	2
3	45	0.103	3
4	220	0.024	2
5	220	0.060	3
6	220	0.103	1
7	560	0.024	3
8	560	0.060	2
9	560	0.103	1

The Main effects plot for Means is shown in Figure 11. Here, surface roughness value (R_a) is shown in µm. The Main effects plot for SN Ratios is shown in Figure 12

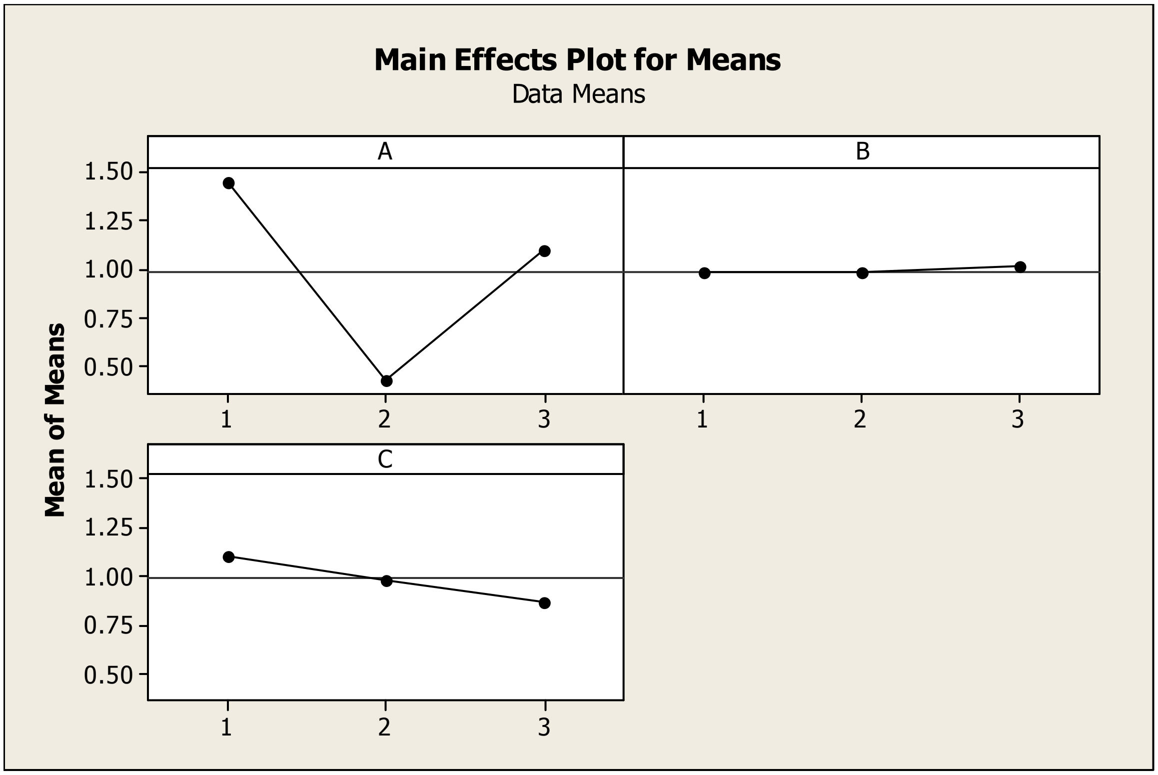

Figure 11 The Main effects plot for Means.

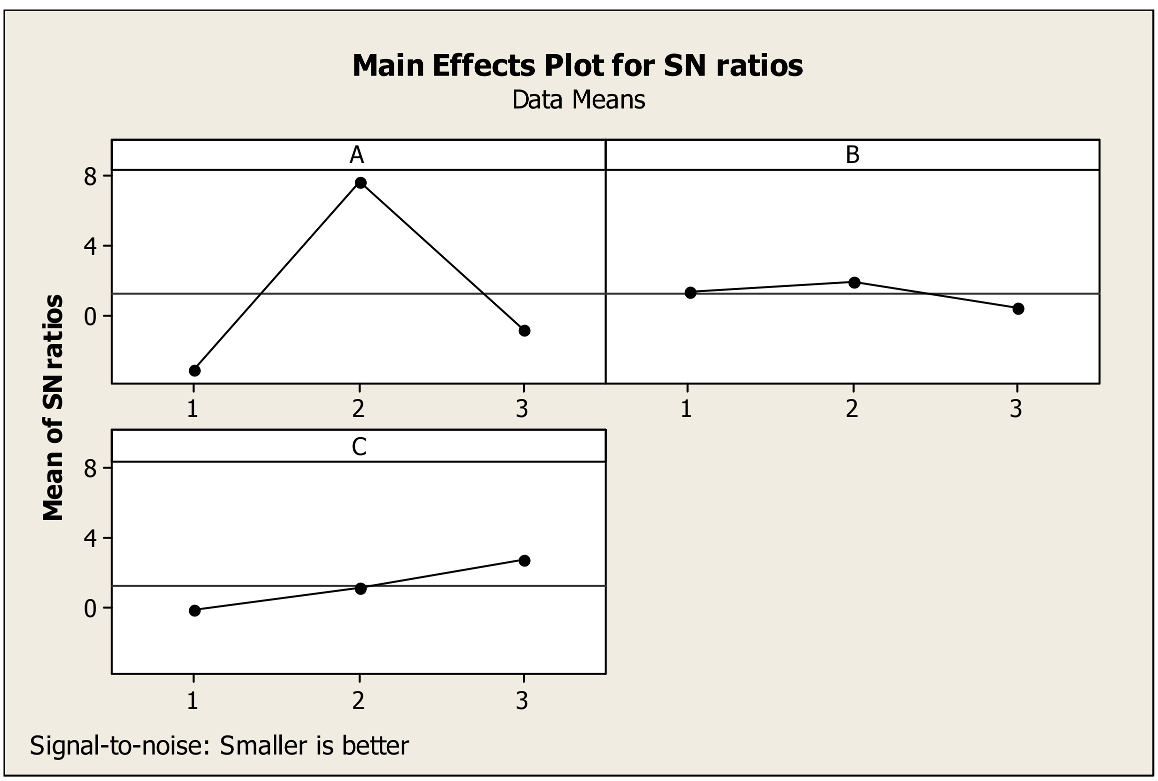

Figure 12 The Main effects plot for SN Ratios.

VII CONCLUSIONS

The following conclusions are made from Figure. 11, i.e. The Main effects plot for Means.

1. From Graph A, it is observed that the surface roughness value (R_a) is more initially. As the spindle speed is increased to an optimum value, the surface roughness reduces to a minimum value. Further increase of spindle speed beyond this optimum value increases the surface roughness value. The reason is that at lower speeds, much reduction in surface roughness is not observed because of the sticking of the asperities to the tool and forming a built- up edge on the tool causing surface rupture. At higher speeds the reduction in surface roughness is not much, because there is no sufficient time to burnish the asperities completely.

2. From Graph B, it is observed that the surface roughness value ($R_{a)}$ is more initially. As the feed rate is increased to an optimum value, the surface roughness reduces to a minimum value. Further increase of feed rate beyond this optimum value increases the surface roughness value. The reason for this is explained below. At lower feed rates, the filling up process may not be effective due to higher adhesion conditions. At higher feed rates, there may not be an effective match between the wave front and the burnishing action at the trailing portion of the burnishing zone. Further, increased vibrations at higher feed rates also cause surface finish deterioration. Also there will be no burnishing action at all at higher burnishing feeds, because of insufficient time for pressing the protrusions.

3. From Graph C, it is observed that the surface roughness value (R_a) is more initially. As the number of passes is increased from one to three, the surface roughness value decreases. In each number of pass, the burnishing force is being applied on the deformed asperities of the previous operation. Then, there will be a further deformation in the asperities in each number of pass, thereby the surface roughness will decrease with number of passes.

Roller burnishing process can be considered as one of the important processes for machining of precision components. Within the range of test conditions employed, the following conclusions can be drawn.

1. Roller burnishing produces superior surface finish with absence of tool feed marks. The finest (R_a value) observed is 0.32 μm.
2. Spindle speed, feed rate and no. of passes contribute maximum for surface roughness in burnishing for aluminum work piece.
3. Burnishing set up is possible on the same lathe where the turning has been done, thereby reducing the setting time to a great extent.
4. Excellent surface finish along with the increase in surface hardness makes the burnishing process superior over the others.
5. The optimum values as presented in the tables and graphs can help to get better results.

The end conclusion is that burnishing gives good results in terms of surface finish. By conducting Design of experiments and using the Mini Tab 15 software, we can easily and accurately predict the surface roughness values. Burnishing process can be applied to dynamically loaded components which have to undergo fatigue loading and require long service life.

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