International Research Journal of Natural and Applied Sciences
ISSN: (2349-4077)
Impact Factor- 5.46, Volume 5, Issue 3, March 2018
Website- www.aarf.asia, **Email** : editor@aarf.asia , editoraarf@gmail.com

EXPERIMENTAL INVESTIGATION OF ROLLER BURNISHING PROCESS FOR SURFACE ROUGHNESS USING TAGUCHI ORTHOGONAL ARRAY

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ABSTRACT

Burnishing is a post machining process that is traditionally used to impart specific physical, mechanical properties on surfaces. Optimization of surface microhardness using Taguchi orthogonal array L25 is reported in the present study. The material selected for the experiment is aluminum alloy 63400 grade. Carbide roller burnishing tool is used in the experiment. The factors that are controlled are speed, feed, depth of penetration and number of passes.Surface roughness tester SURFTEST SJ-210 is used to measure a surface roughness. In the present investigation for analyzing the data, plot of average response curves, plot of signal to noise ratio(S/N), response graphs and analysis of variance (ANOVA) for S/N data is used. Depth of penetration and feed are the most contributing factors in surface roughness. Optimum condition from Taguchi analysis is speed 27 m/min, 0.5 mm/rev feed, depth of penetration 0.06 mm and number of passes two.

I. INTRODUCTION

A surface can be defined as a border between a machined work piece and its environment. The term surface integrity describes the state and attributes of a machined surface and its relationship to functional performance. In general, surface integrity can be divided into two aspects: first the external topography of surfaces (surface finish) and second, the microstructure, mechanical properties (microhardness) and residual stresses of the internal subsurface layer. For example, surface integrity is commonly defined as “the topographical, mechanical, chemical, and metallurgical state of a machined surface and its relationship to functional performance.” Performance characteristics that are usually sensitive to surface integrity include, for example, fatigue strength, fracture strength, corrosion rate, tribological behavior (friction, wear and lubrication, dimensional accuracy, etc.). as reported by (Astakhov 2010).

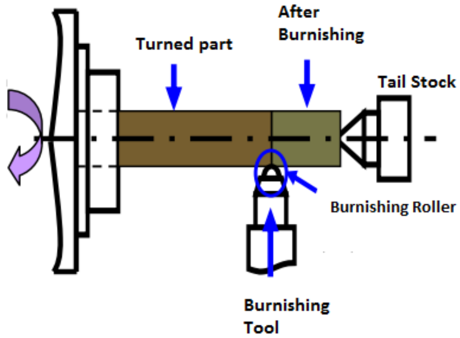

FIGURE 1. SCHEMATIC REPRESENTATION OF BURNISHING PROCESS.

The nature of the surface that results from manufacturing processes has long been recognized as having a significant impact on the product performance, longevity, and reliability. Surface alterations may include mechanical, metallurgical, chemical, and other changes. These changes, although confined to a small surface layer, may limit the component quality or may, in some cases, render the surface unacceptable. A basic understanding of the changes in the condition of the surface is very much required if improvement in product quality is to be attained. Surface integrity (SI) reveals the influence of surface properties and condition upon which materials are likely to perform. It has long been known that the method of surface finishing and the complex combination of surface roughness, residual stress, cold work, and even phase transformations strongly influence the service behavior of manufactured parts as fatigue and stress corrosion is reported by (Astakhov 2010)

II. EXPERIMENTAL WORK

Burnishing is a post machining process that is traditionally used to impart specific physical, mechanical properties on surfaces as shown in the Figure 1. The principle of the burnishing process is based on plastic deformation, achieved via the application of a highly polished ball or roller subjected to external force on the surface of the work piece. Engineering components are usually left with residual machining marks of irregular heights and spacing. Therefore, when the applied pressure surpasses the yield strength of the material, the asperities will be compressed plastically and flow permanently into the valleys, leading to a smooth and uniform surface texture reported by (K.O. Lowa 2011).

In this work, Aluminum (Al 64300) was used as work piece material. The chemical composition of the material is as shown in the Table I.This material was selected because:

1. Its importance in industry and its susceptibility to degradation when burnished through surface and subsurface damage.

TABLE I
CHEMICAL COMPOSITION OF ALUMINUM ALLOY

Si	Cu	Fe	Zn	Mn	Mg	Pb	Al
0.349	0.070	0.367	0.057	0.067	0.40	0.064	98.54

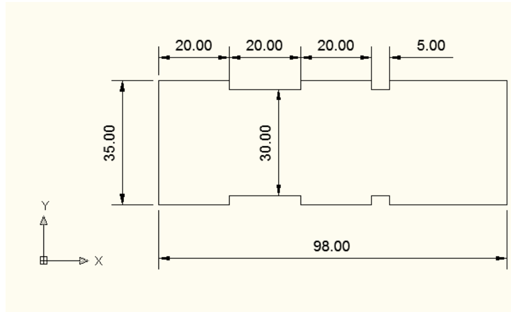

FIGURE 2. WORK PIECE GEOMETRY

2. Aluminum alloys are particularly well suited for parts and structures requiring high strength-to-weight ratio and are the probably the best-known materials used extensively in aircraft and truck wheels.

The material was received in the form of bars, external diameter of 38 mm. and length 100 mm. The raw size of work piece is of 38 mm diameter. During turning operation, the excess material of 3 mm is reduced, and final test work piece of size 35 mm is formed. The work pieces were prepared with three parts A, B, and C.as shown in the Figure 2. Part A was left without burnishing for the purpose of comparison. Initial turning conditions were unified for all work pieces as speed = 400 rpm, feed = 0.2 mm/rev and depth of cut = 0.5 mm. CNC lathe was chosen for machining and burnishing the inner surface of the tubular work pieces. This is a high accuracy lathe with 5Hp spindle motor, it has step-less spindle speeds ranging from 76 – 725 rpm. The distance between the centers is 800 mm. It has 300 mm swing over bed and 190 mm swing over cross slide. The chuck size is 148 mm diameter. It has longitudinal feed of 0.1 – 0.9 mm/rev and cross feed of 0.05 – 0.52 mm/rev. The initial surface roughness Ra of most of the material pieces is found to be in the range of 1.7 to 2.18 µm.

The single roller carbide burnishing tool (SRT) shown in the Figure 3is used for burnishing. To improve its hardness heat treated shank is made of mild steel. The shank of roller burnishing tool has square cross section (30mm * 30mm) which is hold in the tool holder. Using a bolt and nut assembly is use provision to fix the roller at the end of the square shank, which looks like a fork. Tool steel and high carbon high chromium steel is used for manufacturing the roller of burnishing tool. These materials made the roller of burnishing tool wear resistance, toughness, and high hardness. Basically, care is taken in the design of the roller. The surface of the roller is made to provide certain nose radius, so eliminate sharp edges. After machining, the rollers are subjected to heat treatment to improve the hardness. The surface of the roller is cleaned by buffing to remove the scale deposited during heat treatment. With help of bolt and nut, the roller is fitted in the shank.The setup for the burnishing process used in this work is shown in the Figure 4... Burnishing with normal lubricant is carried out. Cleaning of roller was carried out continuously to

FIGURE 3. CARBIDE BURNISHING TOOL

FIGURE 4. EXPERIMENTAL SETUP

prevent hard particles from entering the contact surface between the tool and the work piece.

A. ***Surface roughness tester***

As a stylus instrument, we used surface roughness tester (MITUTOYO Model – SURFTEST SJ-210) as shown in the

Figure 5. The working principle of surface roughness tester is based on moving the probe of tester on surface whose roughness is to be measure. Generally, the probe is made up of hard material to resist the wear as it is continuously in contact with surface whose roughness is to measure.

III. Experimental Design

Taguchi defined a good quality, as 'A correspondence of product characteristic's expected value to the objective value satisfying the minimum variance condition.' For his good quality, he suggested Taguchi Method, which is called robust design, which is irrelevant to the effect of these noise factors. Taguchi Method which has many success examples, and which is used by many manufacturing industry. However, optimal solution of Taguchi Method is one among the experiments, which is not optimal area of experiment point. On the other hand, Response Surface Method (RSM), which has advantage to find optimal solution area experiments, points by approximate

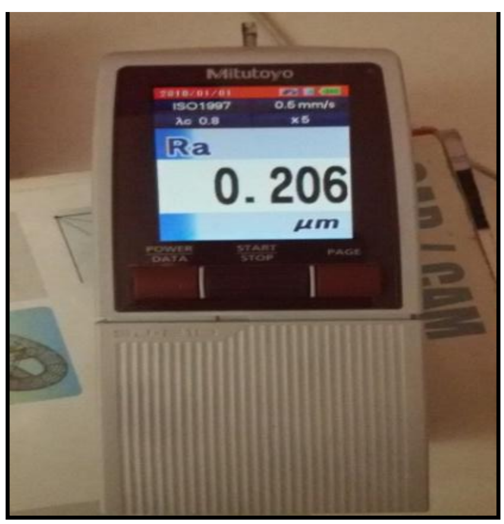

FIGURE 5. SURFACE ROUGHNESS TESTER

TABLE II
FACTORS AND LEVELS

Levels	Speed m/min	Feed mm/rev	Depth of Penetration mm	Number of Passes
1	07	0.4	0.04	1
2	10	0.5	0.06	2
3	27	0.6	0.08	3
4	43	0.7	0.1	4
5	68	0.8	0.12	5

polynomial regression. However, Optimal of RSM is depended on initial point and RSM cannot use many factors because of a great many experiment. In this paper, we combine the Taguchi Method and the Response Surface Method with each advantage, which is called Taguchi-RSM. Taguchi-RSM has two-step, first step to find first solution by Taguchi Method, second step to find optimal solution by RSM with initial point as first step solution. (Ree, Kim et al. 2010).

Yung-Tsan (Jou, Lin et al. 2014) used Taguchi Method to screen the variables that have significant effects on the contraction rate of the outer coating. The combined Taguchi method and response surface analysis (RSA) was employed to evaluate the effects of key operational factors in some Nano fiber study by Meng (Chong, Zhu et al. 2010) .(Petropoulos, Ntziantzias et al. 2005) presents the development of a predictive model for cutting force components in longitudinal turning of constructional steel with a coated carbide tool. The model is formulated in terms of the cutting conditions. Taguchi method is used for the plan of experiments and the analysis is performed using response surface methodology. The effects of cryogenic treatment and drilling parameters on surface and whole quality were investigated in the drilling of AISI 304 stainless steel under dry drilling conditions by (Çiçek, Kıvak et al. 2015).The control factors to provide better surface roughness (Ra) and roundness error (Re) were determined using the Taguchi method. RSM was also used to determine interactions among the control factors. In addition, analysis of variance was employed to determine the most significant control factors on the surface roughness and roundness error.

(Chen, Lin et al. 2014) combined the Taguchi method with the genetic algorithm (GA) to analyze the optimal design parameters of the thermal distribution in an air-core linear brushless permanent magnet motor (ALBPMM). First, this study adopted an L18 (21×37) orthogonal array to determine the significant factors, including active currents, the length of magnets, and pole distance of magnets, air-gap length, and thickness and width of coils. Then, the study uses response surface methodology (RSM) to construct the predictive model .(Lee and Kwon 2010) used combined Taguchi and RSM .Taguchi method and RSM (response surface method) are two of the most well-known DOE (design of experiment) techniques. The levels of parameters are recommended to be taken far apart in the Taguchi method to cover a wide region to increase the chance of capturing nonlinearity of the relationship between the control and control factors. On the contrary, if the optimum is located within the region, RSM needs it to be as small as possible to identify the exact optimum. In this study, the Taguchi method is used to determine the rough region first, followed by RSM technique to determine the exact optimum value during turning on a CNC lathe.

TABLE III
EXPERIMENT MATRIX

Sr. No.	Speed *m/min*	Feed *mm/rev*	No. of passes	Depth of Penetration *mm*	Surface Roughness µm
1	1	1	1	1	0.573
2	1	2	2	2	0.536
3	1	3	3	3	0.509
4	1	4	4	4	0.489
5	1	5	5	5	0.426
6	2	1	2	3	0.523
7	2	2	3	4	0.511
8	2	3	4	5	0.436
9	2	4	5	1	0.425
10	2	5	1	2	0.500
11	3	1	3	5	0.503
12	3	2	4	1	0.476
13	3	3	5	2	0.421
14	3	4	1	3	0.543
15	3	5	2	4	0.565
16	4	1	4	2	0.486
17	4	2	5	3	0.425
18	4	3	1	4	0.531
19	4	4	2	5	0.543
20	4	5	3	1	0.506
21	5	1	5	4	0.425
22	5	2	1	5	0.527
23	5	3	2	1	0.456
24	5	4	3	2	0.510
25	5	5	4	3	0.536

A new region reducing algorithm is introduced by (Lee and Kwon 2010) to narrow down the region of the Taguchi method for RSM. To achieve the goal, the result from the Taguchi method is fed to train the artificial neural network (ANN), whose optimum value is used to drive the region reducing algorithm. The proposed algorithm is tested under different cutting condition with different insert and work material. Data located in the literature is also used to inspect the adequacy of the region-reducing algorithm. Both results show that the introduced algorithm has a good region reducing capability. In a separated experiment, it is shown that the obtained cutting condition from RSM gives a better result than that from the Taguchi method.

IV. TAGUCHI PROCEDURE FOR EXPERIMENTAL DESIGN AND ANALYSIS

A. Selection of Orthogonal Array

Selection of orthogonal array is based on

- Selection of process parameters and/or interactions to be evaluated.
- Selection of number of levels for the selected parameters.

Based on literature review for the current research work parameters selected are speed, feed, depth of cut and number of passes. In addition, number levels selected are five. Factors and levels are given in the Table II.

B. Experimentation and Data Collection

The experiment is performed against each of the trial conditions of the OA Table III. Randomization should is carried to reduce bias in the experiment. Each experiment at a trial condition is repeated simply twice. The data (raw

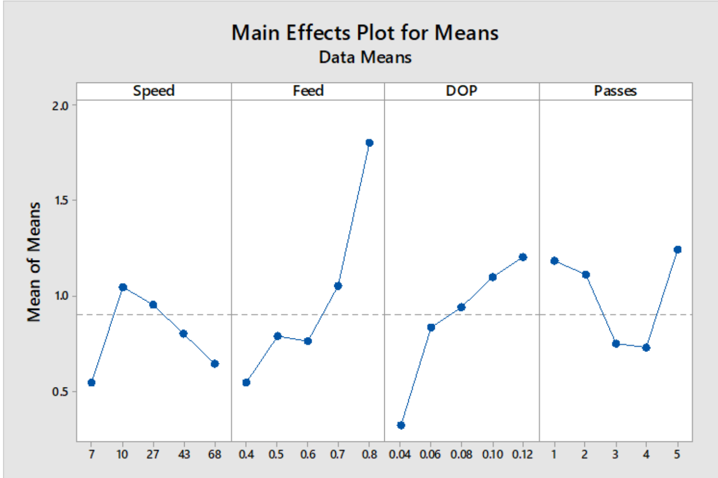

FIGURE 6. MAIN EFFECT PLOT

data) are recorded against each trial condition.

C. *Analyzing Experimental Data*

Taguchi has suggested a number of methods for analyzing the data viz. observation method, ranking method, column effect method, ANOVA, S/N ANOVA, plot of average response curves, interaction graphs etc. However, in the present investigation the methods used are; plot of average response curves; plot of S/N response graphs, and ANOVA for S/N data

The plot of average responses at each level of a parameter indicates the trend. It is a pictorial representation of the effect of parameter on the response. The change in the response characteristic with the change in levels of a parameter can easily be visualized from these graphs Figure 6.

D. *Signal to Noise Ratio*

Taguchi methods mainly transform quality characteristics into a signal-to-noise (S/N) ratio, to measure the quality of the product. It is used to reveal the extents of the influence of production or product quality and its error factors. The S/N ratio can reveal the optimal design in which the variance is low, and the quality characteristics are fair. The choice of quality characteristics can directly affect product quality. Thus, the S/N ratio is the indicator for evaluating quality. Its main function is to evaluate the stability of the process of production; the higher the S/N ratio is, the smaller the variance of the quality characteristics is and the more favorable the condition. The equation for calculating S/N ratios for "smaller is better" (LB) "; larger is better" (HB); and "nominal is best" (NB) types of characteristics are as follows:

$Smaller\ the\ better$

$$n = -10\ \ Log_{10}\left[mean\ of\ sum\ of\ squares\ of\ measured\ data\right]$$

$Larger\ the\ better$

$$n = -10\ \ Log_{10}\left[mean\ of\ sum\ squares\ of\ reciprocal\ of\ measured\ data\right]$$

$Nominal\ the\ best$

TABLE IV

SIGNAL TO NOISE RATIO

Response Table for Signal to Noise Ratios
Smaller is better

Level	Speed	Feed	Dop	Passes
1	5.949	6.027	5.445	6.291
2	6.039	6.582	5.626	6.292
3	6.425	6.138	7.445	5.930
4	6.084	6.021	6.311	6.214
5	6.216	5.945	5.886	5.987
Delta	0.476	0.637	2.000	0.362
Rank	3	2	1	4

$$n = -10 \quad Log_{10}\left[\frac{square\ of\ mean}{variance}\right]$$

The constant 10 has been purposely used to magnify S/N number for easy analysis and negative sign is used to set S/N ratio of "higher the better" relative to the square deviation of the "lower the better."

Taguchi analysis with Smaller is Better criteria calculates S/N data of surface roughness.An ANOVA Table V is commonly used to summarize the tests performed. It was statistically studied the relative effect of each burnishing parameters on the surface roughness by using ANOVA.The F statistic is a statistic for a test concerning the differences among means. The F statistic is typically used for comparing two-population variance. In statistical hypothesis testing, the p-value is the probability of obtaining a result at least as extreme as the one that was observed, given that the null hypothesis is true. The fact that p-values are based on this assumption is crucial to their correct interpretation. The value of p for the term of model is less than 0.05 indicates that it is considered statistically significant. Higher F value indicates that the variation of the process parameter makes big changes on the surface roughness.

Depth of Penetration is the most contributing factors in surface roughness. Optimum Condition from Taguchi

TABLE V

ANOVA TABLE FOR SURFACE ROUGHNESS

Analysis of Variance for Means

Source		Seq SS	Adj SS	Adj MS	F	P
Speed	4	0.002309	0.002309	0.000577	0.62	0.604
Feed	4	0.004138	0.004138	0.001035	1.34	0.353
Dop	4	0.038581	0.038581	0.009645	8.12	0.000
Passes	4	0.001887	0.001887	0.000472	0.59	0.682
Residual Error	8	0.006446	0.006446	0.000806		
Total	24	0.053361				

TABLE VI OPTIMUM CONDITION

Levels	Speed m/min	Feed mm/rev	Depth of Penetration mm	Number of Passes
1	07	0.4	0.04	1
2	10	**0.5**	**0.06**	**2**
3	**27**	0.6	0.08	3
4	43	0.7	0.1	4
5	68	0.8	0.12	5

Analysis is presented in the Table VI. But the experiment level is not in L25 array hence experiment is performed at this level and surface roughness is measured which is 0.36 µm.

V. RESULTS AND DISCUSSION

*A. **Burnishing speed***

The effect of burnishing speed on average roughness at various feeds, depth of penetrations, and number of passes can be assessed from the Figure 6. It can generally be seen from the figures that the surface average roughness decreases slightly with an increase in burnishing speed at any value of feed, depth of penetration and number of passes. This is may be due to the stability of the roller-burnishing tool at high speeds.

*B. **Burnishing feed***

Burnishing feed is one of the very important internal burnishing parameters that affect the results of this internal roller-burnishing tool. It can be seen from the Figure 6 that for a given burnishing speed, and/or depth of penetrations, the average roughness decreases with an increase in burnishing feed. A further increase in burnishing feed causes an increase in average roughness. Therefore, low feeds are favorable because the deforming action of the roller-burnishing tool is greater and metal flow is regular at low feed. When burnishing at very low number of passes an increase in feed leads to a considerable reduction in surface roughness. It is recommended that to burnish at low feeds because the deforming action of the roller-burnishing tool is greater.

*C. **Depth of penetration***

The effect of depth of penetration on average roughness for different speeds, feeds, and number of passes can be assessed from Figure 6. The general trend of the results reveals that an increase in depth of penetration, within the range used in this study, leads to a decrease in surface response. The reduction in burnished surface roughness can be attributed to the increase of the ball pressure on the work piece surface resulting in compressing the most asperities and increasing the metal flow, which leads to the filling of more voids and/or valleys that were exited in subsurface layer due to machining operation.

*D. **Number of passes***

Figure 6.presents the effect of the burnishing number of passes on average roughness at various speeds, feeds, and depth of penetration. The results show that the number of passes is one of the most significant factors affecting the surface roughness.

Bibliography

[1.] Astakhov, V. P. (2010). "Surface integrity–definition and importance in functional performance." Surface Integrity in Machining: 1-35.

[2.] Chen, W., J. Lin, D. Chen and F. Nian (2014). "Optimisation design of a Taguchi-based real-code genetic algorithm for thermal reducing of air-core linear brushless permanent magnet motor." International Journal of Modeling and Optimization 4(5): 402.

[3.] Chong, M. N., H. Zhu and B. Jin (2010). "Response surface optimization of photocatalytic process for degradation of Congo Red using H-titanate nanofiber catalyst." Chemical Engineering Journal 156(2): 278-285.

[4.] Çiçek, A., T. Kıvak and E. Ekici (2015). "Optimization of drilling parameters using Taguchi technique and response surface methodology (RSM) in drilling of AISI 304 steel with cryogenically treated HSS drills." Journal of Intelligent Manufacturing 26(2): 295-305.

[5.] Jou, Y.-T., W.-T. Lin, W.-C. Lee and T.-M. Yeh (2014). "Integrating the Taguchi method and response surface methodology for process parameter optimization of the injection molding." Applied Mathematics & Information Sciences 8(3): 1277.

[6.] K.O. Lowa, K.J. Wongb (2011). "Influence of ball burnishing on surface quality and tribological characteristics of polymers under dry sliding conditions." Tribology International 44: 144-153.

[7.] Lee, H. W. and W. T. Kwon (2010). "Determination of the minute range for RSM to select the optimum cutting conditions during turning on CNC lathe." Journal of mechanical science and technology 24(8): 1637-1645.

[8.] Petropoulos, G., I. Ntziantzias and C. Anghel (2005). "A predictive model of cutting force in turning using Taguchi and response surface techniques." Proceedings of 1st IC-EpsMsO.

[9.] Ree, S.-B., Y.-S. Kim and S.-W. Yoon (2010). "The development of Taguchi and response surface method combined model." IE interfaces 23(3): 257-263.