Parametric Optimization of Ball Burnishing Process Parameter for Surface Roughness of Aluminum Alloy 6061

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Abstract— The aim of these study deals with optimization of newly design ball burnishing tool and process parameters in conventional lathe machine using taguchi method. The work piece materials used is Aluminium Alloy 6061 and ball of high chromium high carbon with 8mm diameter. The input parameters during process are selected on basis of one factor at a time experiment and are burnishing force, burnishing feed, burnishing speed and number of passes. The response parameters are surface roughness. The optimum set of parameter is 250 rpm speed, 0.18 mm/rev feed, 8 kgf forces and 4 numbers of passes for minimum surface roughness.

Key words: Ball Burnishing, Surface Roughness, Hardness, Taguchi Analysis

I. INTRODUCTION

In today's manufacturing industry, special attention is given on surface finish along with dimensional accuracy and geometrical tolerance. Comparing with other finishing process such as grinding, honing, burnishing is chip less process. Burnishing is a cold working surface finishing process which is carried out on material surfaces to induce compressive residual stresses and enhance surface qualities. A burnishing tool typically consists of a hardened sphere which is pressed onto/across the part being processed which results in plastic deformation of asperities into valleys. In burnishing process in which initial asperities are compressed beyond yield strength against load. The surface of the material is progressively compressed, then plasticized as resultant stresses reach a steady maximum value and finally wiped a superfine finish.

The principle of the burnishing process, shown in Figure 3.1 is based on the rolling movement of a tool (a ball or a roller) against the workpiece surface, a normal force being applied at the tool. As soon as the yield point of the workpiece material is exceeded, plastic flow of the original asperities takes place. This phenomenon leads to a smoother surface. At the same time, compressive stresses are induced in the surface layer, followed by strain hardening and a series of beneficial effect on mechanical properties. Burnishing can improve both the surface strength and roughness. The increase of surface strength mainly serves to improve fatigue resistance under dynamic loads.

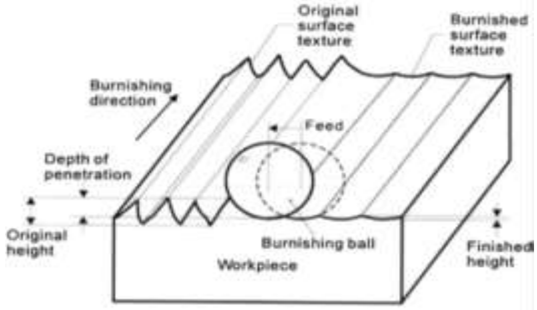

Fig. 1: Schematic diagram of the ball burnishing process

The literature review indicates that earlier investigations concentrated on the effect of the ball burnishing process dealing mostly with surface finish and surface hardness with little focus on optimization of the burnishing parameters. M.H. El-Axira et al. used simple newly designed internal ball burnishing tool to burnish the internal machined surfaces. They carried out an experiment on AA 2014 with having diameter 100 mm and analyzed effect of four internal ball burnishing parameters; namely, burnishing speed, feed rate, depth of penetration and number of passes on surface roundness and surface micro hardness using Response surface method (RSM) [1]. Aysun Sagbas et al. experiment on AA7178 and studied the effect of the main burnishing parameters burnishing force, feed rate and number of passes on surface hardness on CNC machine using full factorial design, analysis of variance (ANOVA) and taguchi's L9 orthogonal array analysis of S/N ratio with larger is better condition. [2]. Aysun Sagbas et al. Carried out ball burnishing process on 7178 aluminium alloy with stainless steel ball of 18mm diameter on CNC .They carried out optimization using desirability function approach (DFA) and quadratic regression model was developed to predict surface roughness using RSM with rotatable central composite design (CCD) with parameters burnishing force, number of passes, feed rate and burnishing speed [3]. J. A. Travieso-Rodríguez et al. analyzed the ball burnishing process is done to improve the surface finish of aluminium A92017 and steel G10380 with concave and convex surfaces considering the curvature radius as parameter along with speed and feed with tungsten carbide ball. And concluded that for aluminium Al 92017, better results obtain with a smaller radius in convex surfaces and with a bigger radius in concave surfaces. For steel 1038 the prior peak height as parameter on milling machine ,effect the indexes of surface roughness [4]. PRASAD BHARDWAJ et al. investigate effect of burnishing parameters on the AISI D3 tool steel material using burnishing tool having carbide ball of 8 and 10 mm diameter , which is supported by two balls of 4mm diameter . (FEM) finite element method used for analysis purpose based software DEFORM-2. They conclude that hardness, residual stress, out of roundness also improves along with surface roughness [5]. R. Aviles et al. analysed improvement fatigue strength of AISI 1045 normalized steel with after ball burnishing with ceramic ball of 6mm diameter pressed hydraulically by means of pump at max 40MPa. By using hydrostatic burnishing tools the ball head can freely move 6–8 mm .After burnishing surface roughness improves from 0.68 - 0.12 μm and hardness increases by up to 20%. They determine that the bending fatigue limit is increased by 21.25%[6]. Wit Grzesik et al. Carried out the functionality comparison with in CBN hard turning, Si_3N_4 ceramic 12mm dia ball burnishing and super finishing techniques for improving the surface finish of low alloy 41Cr4 steel and characterized machined surfaces using 3D scanning techniques. They conclude that Dry hard turning produced surface roughness upto Ra=0.5 µm, Ball burnishing improves Ra upto 0.02 µm and superfinshing improves Ra 0.06 µm at feed 0.10mm/rev, speed 25mm/rev [7]. R. Sadeler et.al investigated the fatigue behaviour of AISI 1045 steel at different Pressures varied from 100 to 300 bar. The hard steel HG6 ball of 6mm diameter was hydrostatically forced toward workpiece. They conclude that roughness improve with increasing pressure from 0.299 µm to 0.099 µm and also enhance both fatigue limit from 332 to 362 after 300 bar pressure [8]. P. S. Dabeer et al. Carried out experiment on brass material on lathe machine with high chromium high carbon ball having varying diameter with range of 6 - 10 mm. RSM central composite second order rotatable design used to develop mathematical model to correlate effect of burnishing parameter on material, using ANOVA techniques and F-test effects on surface roughness[9]. D. B. Patel et al. Carried out experiment on aluminium alloy using burnishing tool having hardened alloy steel ball on lathe machine. Taguchi method is used for experiment and S/N ratio with smaller is better condition for analysis of surface roughness [10]. Pavan Kumar et al. developed ball burnishing tool. Ball burnishing adapter with roller burnishing interchanging adapter type tool. The ball adapter has made up of EN 8 material, Design of square casing: this is made of mild steel and has dimensions of 150 mm*25mm*25mm. Specification of spring: D= 25 mm d= 3 mm. The force is measured by means of spring deflections in the tool [11].

The present work, aims at systematically studying the effect of process parameters like speed, feed, burnishing force, number of passes and their interactions on the surface finish for the component surface produced by newly developed ball burnishing tool. One factor at a time is carried out to identify the range of parameters used for experiment. Experiments will be planned according to statistical design of experiments using taguchi's orthogonal array method, signal to noise ratio is used to improve the reliability of results.

II. EXPERIMENTAL DETAILS

Experiments were conducted on a HMT lathe. A simple new burnishing tool was designed to carry out the experimental work on Aluminium Alloy 6061 using high chromium high carbon ball of 8mm diameter. The ball holder was supported elastically by a pre-calibrated spring, which could apply the required force when pressed onto the workpiece surface. The use of the spring was important for reducing sticking due to friction between the ball and the workpiece. The amount of spring compression with relation to the applied vertical force (Py). Only the effect of the vertical force was studied, as the effects of other forces were negligible.

The burnishing tool design consists of following components as shown in Figure 2.

1) Ball Adapter
2) Spring Support Pin
3) Cover of Support Pin 1
4) Square Casing Spring
5) Support Pin 2
6) Ball of 8mm Dia
7) Spring

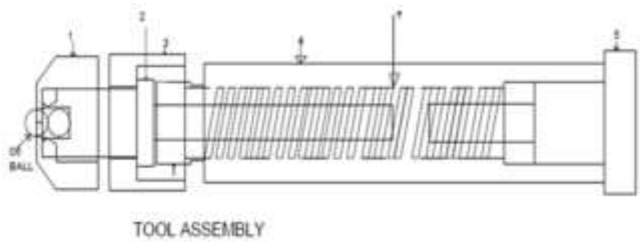

Fig. 2: Schematic diagram of the ball burnishing Tool

A. *Test Materials*

The workpieces used was Aluminium Alloy 6061 were received as cylindrical bars of 40-mm diameter. The bars were cut to appropriate lengths (270-310mm) and turned to a diameter of 38 mm. Each workpiece was divided into 8 regions of 25 mm having slot of 10mm length and 2mm depth

B. *Measuring Instrument*

The surface roughness (Ra) was measured using a MITUTOYO SJ-201 surface roughness instrument. The hardness measured Brinell harness Tester (BHN).

C. *Experimental Methods*

Experiments were planned according to Taguchi's analysis with L25 orthogonal array. The range of the burnishing parameter used in this experiment are decided on basis of one factor at a time experiment approach.Factors and levels for the experiments are as shown in Table 1.

Factors	Level 1	Level 2	Level 3	Level 4	Level 5
Speed v (m/min.)	63	125	250	350	500
Feed, f (mm/rev)	0.06	0.12	0.18	0.24	0.30
Force, F (kgf)	2	4	6	8	10
No. of tool passes	1	2	3	4	5

Table 1: Factors and levels for experiments

By using minitab-16 software the following array is generated to perform experiment. The experimental results were transferred to a signal-to-noise (S/N) ratio. There are three categories of quality characteristic in the analysis of the S/N ratio. The-smaller-the-better category was used to calculate the S/N ratio quality characteristics of surface roughness.

III. RESULTS AND DISCUSSION

L25 orthogonal array for the experiment with results are shown in Table 2.

Exp No.	**Speed (rpm)**	**Feed (mm / rev)**	**Force (kgf)**	**Passes**	**Surface Roughness (Ra)**
1	63	0.06	2	1	1.282
2	63	0.12	4	2	0.625
3	63	0.18	6	3	0.410
4	63	0.24	8	4	0.396
5	63	0.30	10	5	0.620
6	125	0.06	4	3	0.484

7	125	0.12	6	4	0.412
8	125	0.18	8	5	0.357
9	125	0.24	10	1	0.590
10	125	0.30	2	2	0.819
11	250	0.06	6	5	0.475
12	250	0.12	8	1	0.310
13	250	0.18	10	2	0.460
14	250	0.24	2	3	0.503
15	250	0.30	4	4	0.376
16	350	0.06	8	2	0.276
17	350	0.12	10	3	0.474
18	350	0.18	2	4	0.475
19	350	0.24	4	5	0.458
20	350	0.30	6	1	0.490
21	500	0.06	10	4	0.412
22	500	0.12	2	5	0.723
23	500	0.18	4	1	0.455
24	500	0.24	6	2	0.453
25	500	0.30	8	3	0.462

Table 2: L25 orthogonal array for the experiments and Results

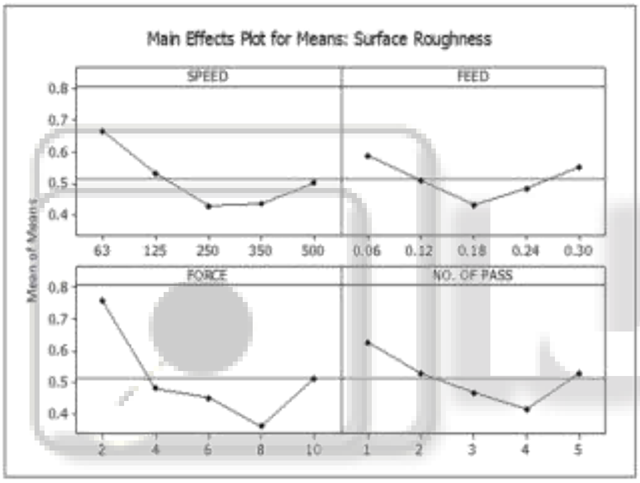

Fig. 3: Main effects plot for means: surface roughness

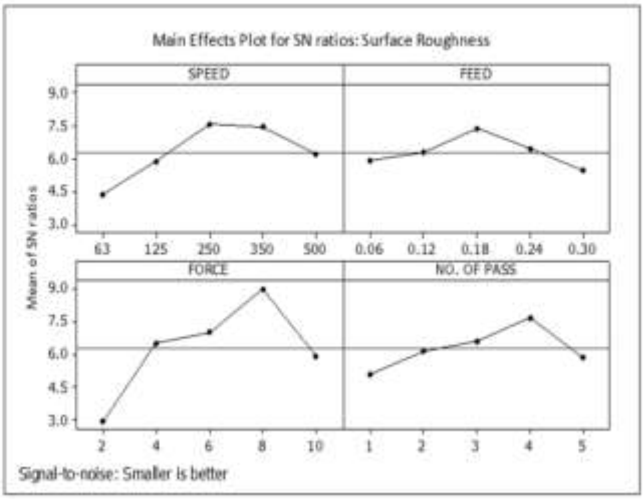

Fig. 4: Main effect plot for s/n ratio: surface roughness.

Figure 3 and Figure 4 show main effect plot for mean and s/n ratio for surface roughness. The effects of burnishing parameters are described below.

1) Speed: Initially when the speed was increased the roughness decreases up to burnishing speed upto 250 rpm, then with further increase in speed the surface roughness was increases.
2) Feed: The surface roughness decreases with the increase in feed rate up to 0.18 mm/rev, and then starts to increase under given working conditions. When feed rate is low the distance between successive traces will be small. As the ball passes along the work piece, it will cause a repeated deformation action on the surface.
3) Force: The surface roughness decreases to a minimum value of 8 kgf then starts to increase with increase in the burnishing force. As this force increases, the penetration depth of the ball inside the metallic surface will be increased, leading to a smoothing-out of the metallic surface, until this surface starts to show some deterioration, the latter being caused by the flaking of the surface due to the high work-hardening induced into the surface by the increase in the amount of plastic deformation as the burnishing force increases.
4) Number of Passes: A reduction in surface roughness is achieved up to the first four passes, but that beyond this number of tool passes the surface roughness starts to increase. In each pass, the tool is being applied under a constant burnishing force to the plastically-deformed surface of the previous pass.

From above discussion it has been founded that optimum set of parameter is speed=250 rpm, feed=0.18 mm/rev, force=8 kgf and Number of passes=4 as shown in Table 3. The optimum value of surface roughness with optimum set of parameter is given in Table 4.

Speed (rpm)	Feed (mm/rev)	Force (kgf)	Passes	Predicted Surface Roughness (Ra)	Experimental Surface Roughness (Ra)
250	0.18	8	4	0.09496	0.11

Table 4: Experimental and predicted surface roughness for optimum set of parameter

IV. Conclusions

The present investigation aimed at optimization of ball burnishing parameters for the surface roughness. This optimization is carried out by developing shear stress models based on L25 orthogonal array in Taguchi optimization technique. The Taguchi's method for parametric optimization draws the following conclusions.

- It is proved that each predicted Surface roughness is very close to the experimental results.
- It is also concluded that the Taguchi's method may be used as a good alternative for the analysis of the effects of ball burnishing parameters on the surface roughness.

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