Effect of Diamond Burnishing Process on Surface Roughness of AISI 4140 Alloy Steel

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Abstract* – *This research work focuses on effect of burnishing process parameters on surface roughness. Speed (m/min), feed (mm/rev) and burnishing force (N) are considered as input process parameters while surface roughness (µm) is considered as a response variable. Analysis of process parameters is carried out by using ANOVA which is statistical method that gives percentage contribution of each parameter on response variables. Experimentation is carried out on MTAB CNC Lathe machine by using Diamond Burnishing Tool (DBT). From the ranges and levels of each process parameter, L9 Orthogonal array was designed and burnishing operation was carried out according to orthogonal array. Statistical analysis is carried out with the help of ANOVA, which gave percentage contribution of each process parameter on response variable. It is found that Burnishing force is most influencing parameter for surface roughness and its percentage contribution is 93.16%. The experiment predicted that an optimum surface finish of 0.131 µm (Ra value) can be obtained.

Keywords— Burnishing, Diamond Burnishing Tool (DBT), Orthogonal Array (OA), Analysis of Variance (ANOVA), Surface roughness

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1. INTRODUCTION

Burnishing is the super finishing process which plays an important role in enhancing the surface properties. Burnishing process has major effect on the surface integrities like surface roughness, residual stresses, fatigue strength, hardness, microstructure, etc. and improves the surface integrities. There are also other processes such as honing, polishing, shot peening but burnishing is one of the most economical process for the surface characteristics enhancement. Conventional machining processes such as turning and milling have inherent irregularities and defects like tool marks and scratches that cause energy dissipation (friction) and surface damage (wear). Due to simple operations and chip less process, burnishing is attractive post-machining alternative.

Burnishing also increases the compressive residual stresses [1]. Laser shock peening and shot peening are also processes used to increase the compressive stresses however, when exposed to heat, these stresses are found to be relaxed. Component life shortens due to the thermal relaxation of compressive stresses. So burnishing came up as the process that could impart thermal stable surface compressive stresses. Improved fatigue strength of component, due to the burnishing operation, results in delayed crack initiation and retarded crack propagation from the surface. By reducing the peak to valley height on the surface of component, reduces the surface roughness. As shown in Fig. 1, due to the compressive action made by burnishing ball, after applied burnishing force, plastic deformation on surface takes place which results in metal to flow plastically from peaks to fill valleys on component surface which leads to improved surface finish.

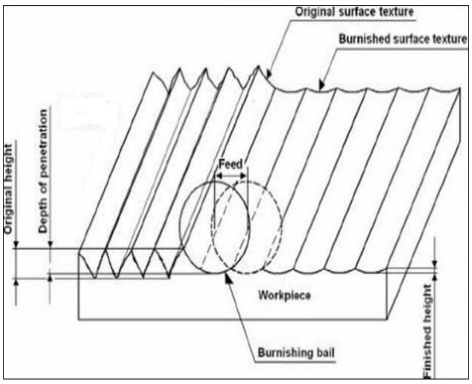

Fig. 1 Burnishing Process [9]

It is a low-cost surface treatment process and can be applied to improve surface quality. Burnishing does not involve material removal hence; it is useful to maintain dimensions of workpiece. Burnishing operation can be done on lathe machine or CNC Lathe with burnishing tool; there is no other special requirement for it. Burnishing operation is very simple operation so there is no requirement of skilled worker. The plastic deformation associated with burnishing will harden the surface and generate compressive residual stresses which increase the life of workpiece. For the best surface finish, the optimum process parameters are required. Burnishing force plays an important role to achieve great surface finish because degree of plastic deformation in material, on which burnishing is done, depends on burnishing force [1] [3] [7]. The burnishing force and the number of passes of burnishing tool are two main parameters which affect the surface finish of material. Unlike majority of researchers, Hassan et al.[6] used response surface methodology (statical experimental design) in which for correlating the main parameters i.e., burnishing force and number of passes with the surface finish, a mathematical model was established. Compressive residual stress increases with increase in burnishing force. The depth of induced plastic deformation increases in burnishing process as burnishing force increases [1] and also increases the fatigue strength of the component as well as fatigue life [2]. The number of passes also plays an important role in burnishing process. If maximum force is applied then one number of pass is sufficient but if force is less than maximum then number of passes should be two or three for better results [5]. In this study, numbers of passes are kept constant. For all experimentation two number of passes were used. For the feed parameter, increase in feed rate results in decreases the surface roughness to minimum value, and then starts to increase under given working conditions. For Aluminium and brass material, feed rate ranging from 0.06-0.08 mm/rev gives minimum surface roughness with a ball diameter 10mm [3]. In the next section details of experimental work is presented.

2. EXPERIMENTAL WORKS

A. Work piece material and specimen preparation

The AISI 4140 alloy steel was used as workpiece material having hardness 13HRC. The chemical composition of this material is shown below in table I.

Table IV Chemical Composition of AISI 4140 Alloy Steel

Element	% Content
Fe	97.10
Cr	1.03
Mn	0.76
C	0.44
Si	0.23
Mo	0.21
S	0.02
P	0.01

The workpieces of length 100 mm and diameter of 14 mm are used for experimentation. The workpiece have initial surface roughness is in the range of 2.3 to 2.5 µm. Then burnishing operations were carried out on turned surfaces by varying the process parameters as per the orthogonal array used.

B. Burnishing conditions

Mech-india's diamond burnishing tool (DBT) was used to perform the experimental work. The tool is shown in Figure 2. DBT was used, having 6mm radius diamond tip and 20 mm square shank size.

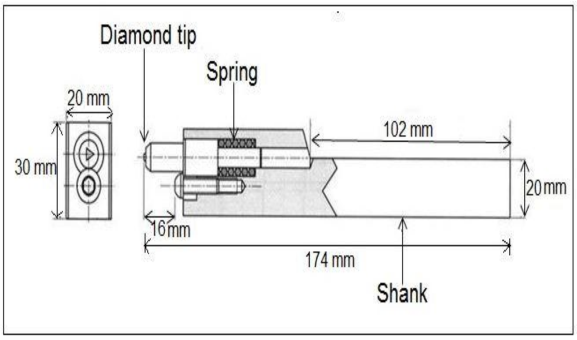

Fig. 2 Schematic of diamond burnishing tool (DBT)

Burnishing process was carried out on MTAB CNC Lathe. The burnishing operations were carried out with coolant (IPOL ST Cut 91 SF). In this study, burnishing parameters, namely, speed, feed and burnishing force were investigated and the response parameter is surface roughness. Two number of DBT passes were used for entire experimentation. The surface roughness of all workpieces was measured by Mitutoyo's surface roughness tester. The surface roughness values were measured in terms of Ra (µm) and recorded for the analysis. After experiments three Ra values were measured at different locations within burnishing region. Then the average values of these three reading were used.

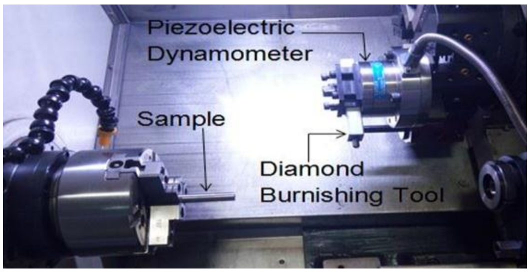

Fig. 3 Kistler Piezoelectric Dynamometer

Kistler piezoelectric dynamometer 9272 was used for measuring applied burnishing forces. Kistler piezoelectric dynamometer is shown in Figure 3. Burnishing force is varied in steps of 20 N between 220 N to 300 N. Figure 4 shows the contact between DBT and cylindrical workpiece. δ is normal displacement (in mm). The relative normal displacement (δ) of DBT is proportional to burnishing force.

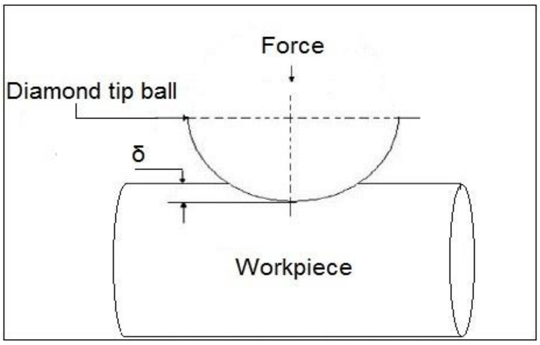

Fig. 4 Contact between DBT and Workpiece

Table II shows the relation between δ and burnishing force.

Table V Burnishing Force corresponding to normal Displacement of dbt

Normal Displacement (δ) of DBT (mm)	Force (N)
0.2	220
0.4	240
0.6	260
0.8	280
1	300

Other process parameters such as speed and feed vary in the range from 40 to 270 m/min for the ϕ14 mm workpiece and 0.02 – 0.2 mm/rev respectively. The levels were selected on the basis of one-factor-at-a-time method. The selected levels for process parameters are shown in Table III.

Table VI Process Parameters and their Levels

Symbol	Parameter	Unit	Level 1	Level 2	Level 3
A	Speed	m/min	70	90	110
B	Feed	mm/rev	0.02	0.06	0.1
C	Burnishing Force	N	260	280	300

Each parameter had three levels and interactions between the parameters were not considered in the present study. The experimental set up is shown in figure 5.

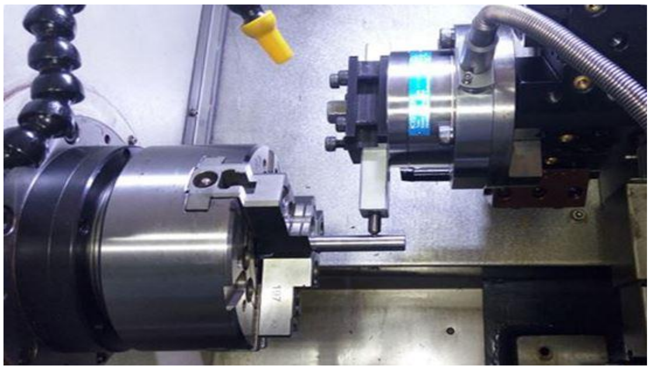

Fig. 5 Experimental Set-up

C. Design of Experiment (DOE)

The DOE was based on Taguchi orthogonal array considering three factors each at three levels. In the present analysis total 9 numbers of runs have been taken. The experimental layout for the parameters using the L9 OA is shown in Table IV. Each row of this table represents an experiment with different combination of parameters and their levels, obtained by using software package Minitab-17 software.

Table VII Experimental Plan L9 OA

A. **xperiment** *B.* **Number**	*C.* **A**	*D.* **B**	*E.* **C**
F. **1**	*G.* 1	*H.* 1	*I.* 1
J. **2**	*K.* 1	*L.* 2	*M.* 2
N. **3**	*O.* 1	*P.* 3	*Q.* 3
R. **4**	*S.* 2	*T.* 1	*U.* 2
V. **5**	*W.* 2	*X.* 2	*Y.* 3
Z. **6**	*AA.* 2	*BB.* 3	*CC.* 1
DD. **7**	*EE.* 3	*FF.* 1	*GG.* 3
HH. **8**	*II.* 3	*JJ.* 2	*KK.* 1
LL. **9**	*MM.* 3	*NN.* 3	*OO.* 2

3. RESULTS AND DISCUSSIONS

After performing the experiments, the average value of surface roughness (Ra value) of each run is shown in table V.

Table V Experimental Results for Burnishing

Expt. No.	Speed (m/min)	Feed (mm/rev)	Burnishing Force (N)	Surface Roughness (μm)
1	70	0.02	260	0.215
2	70	0.06	280	0.200
3	70	0.1	300	0.160
4	90	0.02	280	0.220
5	90	0.06	300	0.136
6	90	0.1	260	0.215
7	110	0.02	300	0.131
8	110	0.06	260	0.220
9	110	0.1	280	0.221

Considering the process parameters and surface roughness results, the main effect for surface roughness data means was plotted with the help of Minitab17 software. The experimental design proposed by Taguchi involves orthogonal array which organize the parameters which affect the processes and levels at which they should be varied. From figure 5 below, it can be concluded that burnishing force is most dominating parameter.

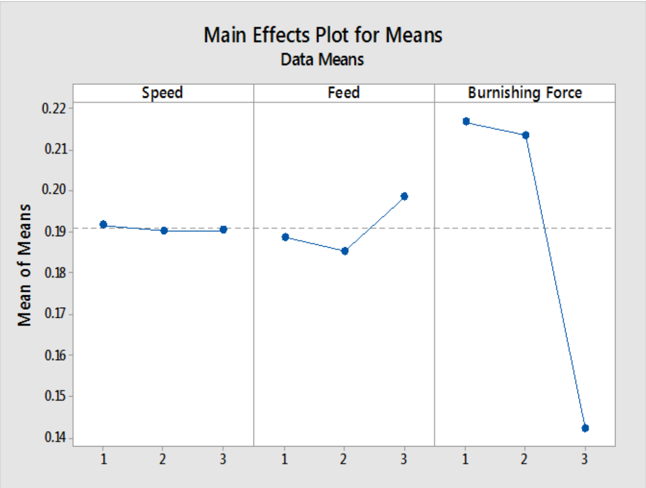

Fig. 5 Main Effect Plot for Surface roughness data means

The values of surface roughness for each factor, i.e., speed, feed and burnishing force at each level were obtained and summarized in Table VI.

Table VI Response Table for Means of Surface Roughness

Level	Speed	Feed	Burnishing Force
1	0.1918	0.1888	0.2168
2	0.1904	0.1853	0.2135
3	0.1905	0.1986	0.1423
Delta	0.0014	0.0133	0.0745
Rank	3	2	1

From above table, rank of burnishing force is one and so the Burnishing force is most dominating parameter in case of surface roughness.

4. ANALYSIS OF VARIANCE (ANOVA)

The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments to determine the percentage contribution of each factors. Study of ANOVA table for a given analysis helps to determine which of the factors need control and which are not. So ANOVA is used in this research work to find dominating parameter and its percentage contribution for surface roughness.

Table VII ANOVA for Surface Roughness

Source	DF	SS	MS	F-Value	% Contribution
Speed	2	0.000003	0.000002	0.01	0.03
Feed	2	0.000284	0.000142	0.59	2.51
Burnishing Force	2	0.010631	0.005315	22.0	93.16
Error	2	0.000483	0.000241		4.30
Total	8	0.011401			100

From table VII, percentage contribution of burnishing force on surface roughness is 93.16% followed by speed and feed. In above table F ratio is not required for error and total because F ratio is basically used for input process parameters to identify percentage contribution of each process parameter for various response variables.

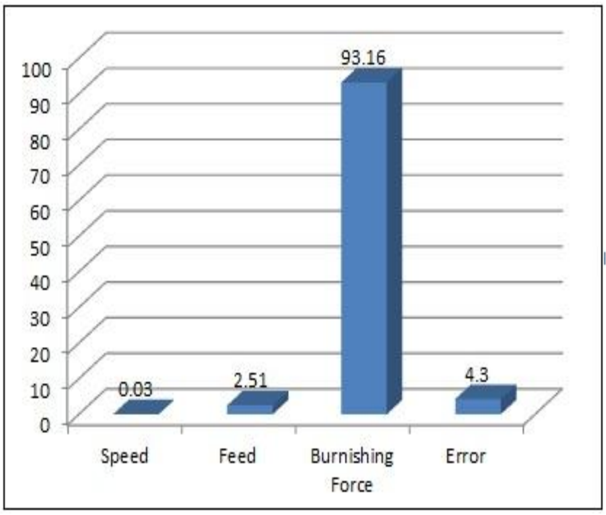

Fig 6 Percentage Contribution of Process Parameters for Surface Roughness

5. CONCLUSION

With the above comprehensive experimental work and subsequent analysis of results using Taguchi approach, speed of 110 m/min, feed of 0.02 mm/rev and burnishing force of 300 N are the optimum settings of burnishing parameters in order to achieve minimum surface roughness. By setting of this optimum parameter, we can reduce the initial surface roughness from 2.5 µm to 0.13 µm with two number of passes.

ANOVA presented in Table VII shows that burnishing force is the most influencing parameter in order to achieve better surface finish and its percentage contribution is 93.16%. So, manufacturer can adopt this diamond burnishing process to machined components in order to enhance surface finish.

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