Journal of Materials and Environmental Sciences
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2020, Volume 11, Issue 3, Page 421-428

http://www.jmaterenvironsci.com

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Investigation Studies on the Influence of Abrasive Particles in Ball Burnishing Process

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Received 02 Oct 2019,
Revised 05 Feb 2020,
Accepted 07 Feb 2020

Keywords
- ✓ *Burnishing,*
- ✓ Cold-working,
- ✓ Abrasive particles
- ✓ Surface roughness,
- ✓ Surface hardness,
- ✓ RSM.

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Abstract
Burnishing is a cold-working, finishing process by employing which surface properties of machined surfaces can be enhanced. The ball and roller burnishing are two forms of burnishing tools and can be applied to materials of any form and size. In current work, the ball burnishing process is employed on EN24 Steel workpiece surface in presence of silicon carbide (SiC) abrasive particles. The experiments are systematically designed using response surface method (RSM). Effect of four burnishing process parameters such as burnishing force, burnishing speed, burnishing feed and number of passes on responses i.e. surface roughness and microhardness is established by using Analysis of Variance results. Mathematical models are obtained for responses in terms of process parameters. The Scanning Electron Microscope (SEM) images are taken to compare burnished specimen with turned specimen. The results obtained show that surface roughness can be decreased by 96% and surface hardness can be improved by 47% with respect turned specimens.

1. Introduction
Burnishing is a chip-less finishing process employed on machined surfaces to improve various surface characteristics. The process can be carried out by using ball burnishing tool or roller burnishing tool. Ball or roller used in respective tools act as a deformer and applies force greater than the yield strength of workpiece material to deform surface layers plastically. The randomly distributed peaks present over machined surface (produced by the cutter) flattened during the burnishing process and results in a plastic flow of peaks into valleys. On the other hand, plastic deformation of surface layers increases microhardness and induces compressive stresses [1]. The schematic representation of burnishing process is given in figure 1. The surface properties such as wear-resistance, corrosion resistance, fatigue strength, tensile strength [2] are also enhanced. Burnishing process can also be used to correct out-of-roundness errors [3] of the cylindrical surfaces as well. The process can be carried out on the same machine tool in which workpiece undergoes machining operation. The simple tooling and easiness of operation make this process more user-friendly. The process can be employed for almost all materials with hardness ranging from 40-65HRC [4] and of any forms.
Extensive works have been carried out in the burnishing process by many researchers. The influence of burnishing parameters such as burnishing force, burnishing speed, burnishing feed, number of tool passes, ball diameter, initial surface conditions [5] etc. on various surface characteristics are investigated. It was noticed that burnishing force and number of passes are governing parameters to control surface characteristics of brass and aluminium workpiece materials. The burnishing process has been tested on

ferrous and non-ferrous materials like brass, aluminium, Al-Cu alloy [5], Mild Steel [6], Al-7075 [7], AISI-5140 [8], Titanium alloy [9], etc.

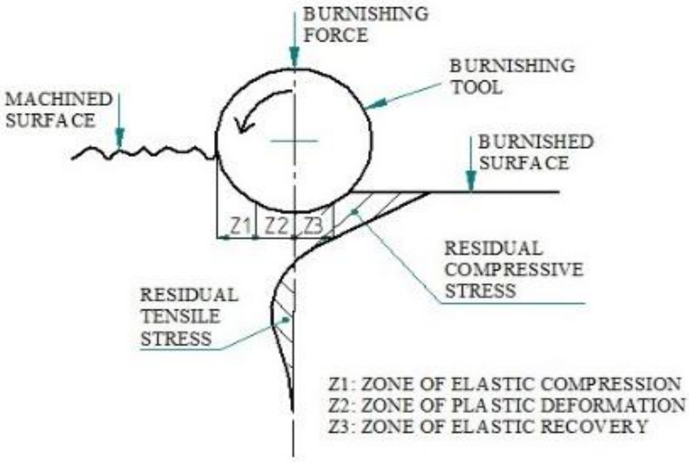


Figure 1: *Schematic representation of the burnishing process*

The result shows that significant improvement in surface finish and microhardness can be achieved in all materials by the application of burnishing process. The responses in burnishing process depends on workpiece characteristics such as workability, toughness and strength. High workability materials will yield better results when they are burnished compared to brittle materials. Experiments are carried out to find the improvement in fatigue life of IN718 and Ti-Al-4V materials which are commonly used in making of compressor/turbine blades [10]. The result shows that components sustained fatigue life up to 4 million cycles over non-burnished components cycle of 52200 and 48900 for IN718 and Ti-Al-4V respectively. The bearing property and fluid retention ability increased in burnished 41Cr4 steel specimens compared with hard turned specimens [11]. End milled polyethylene (LDPE) surfaces are ball burnished [12] with an objective of roughness minimization and the minimum value 0.57 µm was achieved after burnishing. Microhardness and scratch resistance values improved with respect to milled specimens. The burnishing process also decreased wear rate by 58%. The wear tests conducted on ball burnished titanium alloy (Ti-6Al-4V) revealed 52% reduction in specific wear rate and 64% reduction in coefficient of friction [13]. The influence of burnishing process on corrosion resistance of AISI 1045 steel is reported [14]. Considerable improvement in corrosion resistance along with improvement in hardness and reduction in roughness.

Al7175 cylindrical specimens were ball burnished [15] in dry and Nano fluid burnishing condition (Nano fluid containing ethanol alcohol and alumina nanoparticles). Results showed that the surface roughness can be decreased and microhardness can be improved significantly using alumina Nano fluid compared to dry burnishing. Further the Nano fluid burnishing improved hardness of sub-surface and formed alumina ceramic on the surface of the aluminium workpiece. Recent study [16], based on particle swarm optimization reported that the burnishing process can reduce energy consumption by 39.50% while burnishing H13 steel. The commonly used finishing methods like grinding, lapping, honing, etc. causes abrasion in workpiece surfaces by using abrasive particle to produce a better surface finish. The rubbing action of abrasive grains results in material removal from a workpiece in the form of fine particles. Thus use of abrasive grains will result in better surface finish. In this context, in current work, the Silicon Carbide abrasive particles are used in burnishing process to establish their role.

2. Material and Methods

2.1. Workpiece material

EN24 Steel is used as a workpiece material due to its extensive use in industry for making shaft, hubs, bolts etc. Material is procured in the form of round bar having a diameter of 20mm in wrought form. The chemical and mechanical properties are listed in table 1. Workpiece material is used in wrought form without any pre-treatment during burnishing operation.

Table1: Chemical composition and mechanical properties of EN24 Steel

Chemical Composition (wt. %)								Mechanical Properties		
C	Si	Mn	P	S	Cr	Mo	Ni	Yield Stress (N/mm^2)	UTS (N/mm^2)	Hardness (HV30)
0.413	0.234	0.584	0.016	0.019	0.956	0.256	1.406	489.433	683.423	180

2.2. Ball burnishing tool

Ball burnishing tool, as shown in figure 2 is used to conduct experiments in current work. The tool is developed according to the tool holder dimensions of UNITECH MT366 lathe. The force applied during burnishing operation is measured with the help of spring deflection inserted in tool. The stiffness of spring is found to be 2.32 kg/mm. Carbon chromium ball of ϕ8 mm is used in the tool as a deformer. The initial surface roughness and microhardness of ball are 0.012 µm and 63HRC.

2.3. Methodology

The EN24 Steel bar is cut into appropriate length to make it suitable for burnishing operation. The bar was cut to 165 mm length and turned under similar turning parameters to ensure even surface finish in an entire workpiece. CNC turning centre is used to turn the workpiece. Three burnishing samples of length 30 mm were made in 165 mm rod by forming a 1 mm deep groove. UNITECH MTT366 lathe is used to carry out burnishing operation. The surface roughness is measured using TALYSURF50 with 2.5 mm as a cut of length and microhardness is measured using Vickers Microhardness tester under 1kgf load with 10 seconds as dwell time. The turned surface of EN24 samples after turning are having surface roughness and microhardness values of 2.4138 and 216HV respectively.

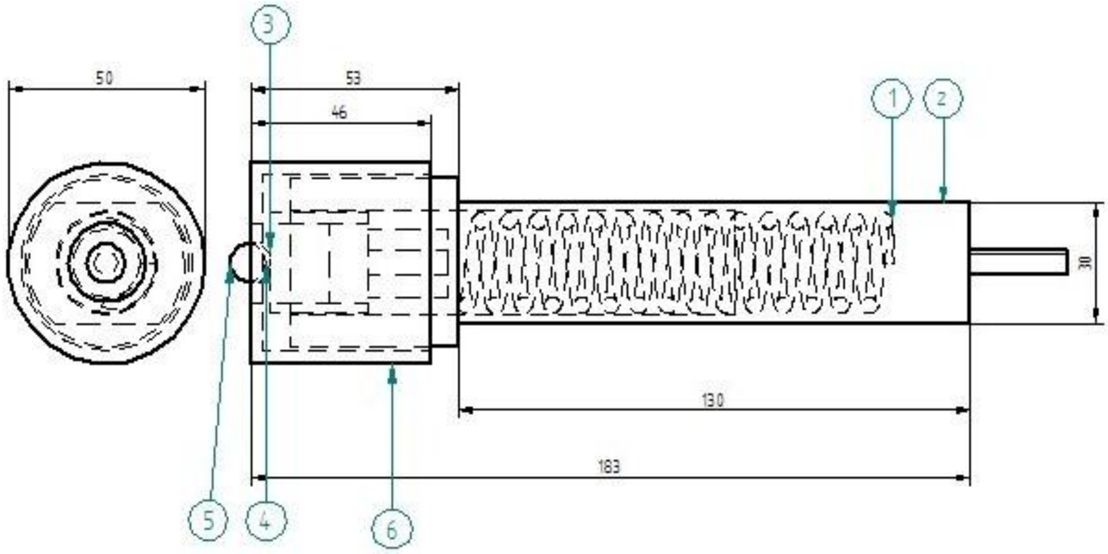


Figure 2: *Details of the developed ball burnishing tool*

Parts: 1. Spring 2. Lower casing 3. Ball holding casing 4. Carbide supporter for ball 5. ball 6. Upper casing

2.4. Design of experiments

Response Surface Methodology is adopted to design the experiments. The advantage of using such a tool is to obtain curvature effects between the parameters with a minimal number of experiments. MINITAB17 software tool is used to generate experimental runs and to develop mathematical models in terms of process parameters. 31 experiments are conducted according to RSM as per the design matrix is given in table 3. The levels of parameters selected in the investigation are presented in table 2. The significance of parameters is determined by using P-Values of Analysis of Variance (ANOVA) results. The models developed are judged for their adequacy by means of R-sq. (pred.) values. The combined optimization of responses is also presented to obtain low surface roughness and high microhardness values.

Table2: Parameters and levels

Description	Levels in coded form				
	2	**1**	**0**	**-1**	**-2**
Force, kgf (N)	30 (294.3)	25 (245.81)	20 (196.2)	15 (147.15)	10 (98.1)
Speed, rpm	910	735	560	385	210
Feed, mm/rev	0.209	0.1634	0.1195	0.076	0.0325
Number of passes (nop)	5	4	3	2	1

3. Results and discussion

Results of Abrasive Assisted Burnishing (AAB) conducted on EN24 Steel are presented in table 3. The lowest surface roughness and high surface hardness achieved were 0.1023 µm and 317 HV. The surface roughness was reduced by 96% and improvement in microhardness attained was 47% with respect to turned samples.

Table3: Experimental runs and responses in ball burnishing of EN24 Steel

Sl. No.	Force (kgf)	Speed (rpm)	Feed (mm/min)	No. of Passes	Surface roughness, Ra (µm)	Surface hardness, HV
1	15	735	0.163	4	1.3584	292
2	15	385	0.163	4	1.3352	303
3	20	910	0.1195	3	0.9008	272
4	20	560	0.1195	3	0.2376	287
5	15	735	0.076	2	0.8891	270
6	15	385	0.076	4	0.3092	291
7	20	560	0.1195	3	0.2608	291
8	30	560	0.1195	3	0.6073	306
9	15	385	0.163	2	1.2444	280
10	25	385	0.076	4	0.9813	317
11	20	560	0.1195	3	0.2128	286
12	20	210	0.1195	3	0.5689	301
13	20	560	0.1195	3	0.2301	285
14	25	735	0.076	2	0.9396	289
15	20	560	0.1195	1	0.9096	273
16	20	560	0.1195	3	0.2531	290
17	20	560	0.0325	3	0.4572	290
18	25	735	0.163	4	0.2101	292
19	20	560	0.2065	3	0.9013	283
20	25	385	0.163	4	0.4073	310
21	15	385	0.076	2	0.2709	276
22	20	560	0.1195	3	0.2475	286
23	20	560	0.1195	3	0.2227	289
24	25	385	0.163	2	0.1023	292
25	25	385	0.076	2	0.6000	301
26	25	735	0.163	2	0.3813	268
27	15	735	0.163	2	1.9856	261
28	25	735	0.076	4	0.7005	300
29	20	560	0.1195	5	0.6631	316
30	10	560	0.1195	3	1.4834	275
31	15	735	0.076	4	0.3506	282

The lowest surface roughness can be achieved by using the combinations of following parameters; burnishing force=25 kgf, burnishing speed=385 rpm, burnishing feed=0.163 mm/rev and number of passes=2. The higher microhardness can be obtained with the parameter settings; burnishing force=25 kgf, burnishing speed=385 rpm, burnishing feed=0.076 mm/rev and number of passes=4.
The mathematical models for responses are given in equation 1 & 2.

Surface roughness, Ra (µm) =1.087 – 0.1350 force + 0.000606 speed + 25.39 feed – 0.6599 nop + 0.007693 force*force + 0.000004 speed*speed + 53.27 feed*feed + 0.12758 nop*nop – 0.0000092 force*speed – 1.7886 force*feed + 0.01641 force*nop + 0.00105 speed*feed - 0.000854 speed*nop – 0.064 feed*nop (Eq.1)

Surface hardness, HV = 211.8 + 4.105 force + 0.0309 speed + 312.7 feed – 5.26 nop + 0.0245 force*force – 0.000013 speed*speed – 204 feed*feed + 1.613 nop*nop – 0.001857 force*speed – 17.82 force*feed – 0.150 force*nop – 0.2299 speed*feed + 0.00214 speed*nop + 60.3 feed*nop (Eq.2)

The R-sq. (pred.) values for surface roughness and surface hardness models at 95% confidence level are 97.39% and 93.66% respectively. The values indicate that models are adequate and can be used to find the responses within the range of parameters selected. The P-values of Analysis of Variance (ANOVA) results and percentage contributions of parameters on responses for surface roughness and microhardness are given in table 4. If P-values value is <0.005, it indicates that the parameter is having significant effect on responses and vice versa.

Table4. P-Values and % of contributions of parameters on responses

Regression coefficients	% Contribution on surface roughness		% Contribution on surface hardness	
	P-Value	AAB	P-Value	AAB
Model	<0.01	99.53	<0.01	98.47
Linear	<0.01	26.78	<0.01	88.58
Force	<0.01	17.25	<0.01	23.11
Speed	<0.01	3.20	<0.01	22.59
Feed	<0.01	5.32	0.02	1.32
Number of passes	<0.01	1.01	<0.01	41.56
Square	<0.01	26.47	0.011	1.78
Force*force	<0.01	16.37	*0.175	0.19
Speed *speed	<0.01	5.82	*0.384	0.08
Feed*feed	<0.01	4.50	*0.384	0.08
NOP*NOP	<0.01	7.20	0.002	1.33
Interactions	<0.01	46.27	<0.01	8.11
Force*speed	<0.01	1.59	0.013	0.76
Force*feed	<0.01	37.46	<0.01	4.30
Force*NOP	<0.01	1.67	*0.213	0.16
Speed*feed	0.475*	0.02	0.008	0.88
Speed*NOP	<0.01	5.53	*0.525	0.04
Feed*NOP	0.802*	0.00	<0.01	1.97

* Non-significant factors

The contribution of interactions is found be higher on surface roughness with 46.27% followed by contributions of linear (26.78%) and square (26.47%) effects. Force is the main parameter which governs the surface roughness as a linear and square term. The interaction between force and feed is having

37.46% contribution towards roughness. The contribution of linear parameters is most significant on surface hardness with 98.47% contribution. The parameter, number of passes with 41.56% is having major role in controlling surface hardness. The force and speed are contributing surface hardness with 23.11% and 22.59% respectively. The contribution of square and interaction effect towards surface hardness is found to be very minimal as compared to linear parameter contribution. The variation of responses with parameters is explained with the help of main and interaction effect plots.
The main and interaction plots of parameters on responses are given in figures 3-6. Figure 3 depicts that increase in force up to 20 kgf will reduce the surface roughness but beyond this surface roughness increases. This is attributed to repeated plastic deformation of the surface layers and maximum capability of work material to undergo plastic deformation. Abrasive particles have played a role in deformation of the irregularities up to 20 kgf force but after this point their role seems to be insignificant and caused increases in roughness. When speed rises, as seen in figure 3, the surface roughness tends to increase and this is due to increase in temperature at the surface.

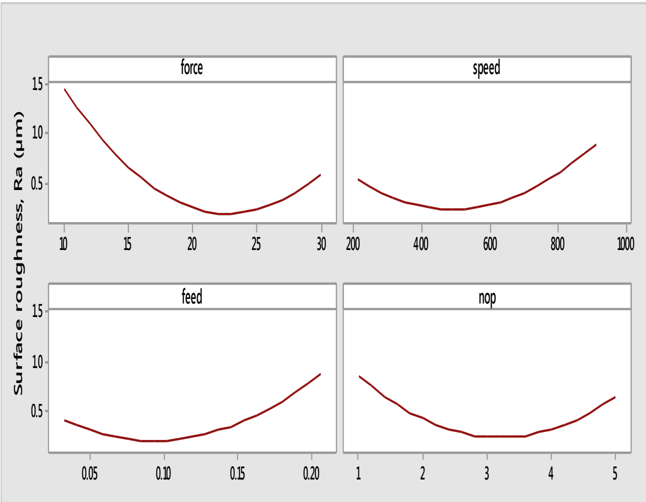


Figure 3. *Main effects of parameters on surface roughness*

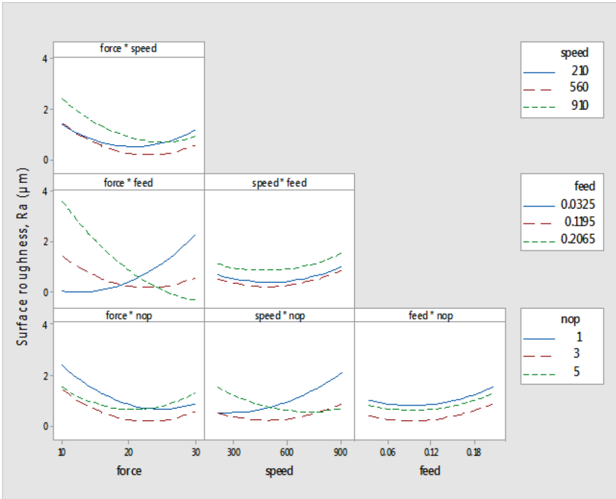


Figure 4. *Interaction effects of parameters on surface roughness*

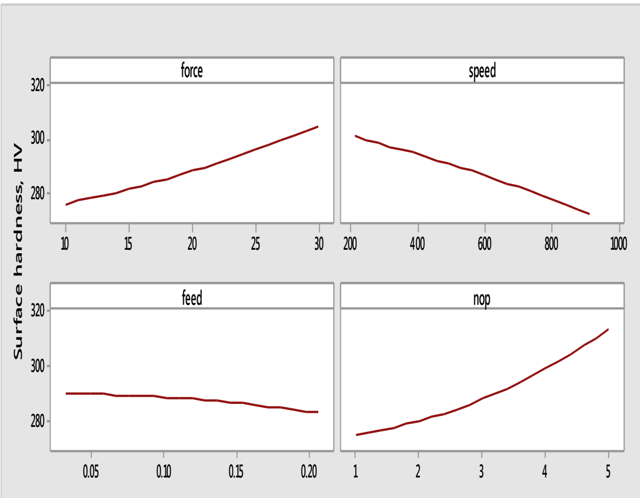


Figure 5. *Main effect of parameters on surface hardness*

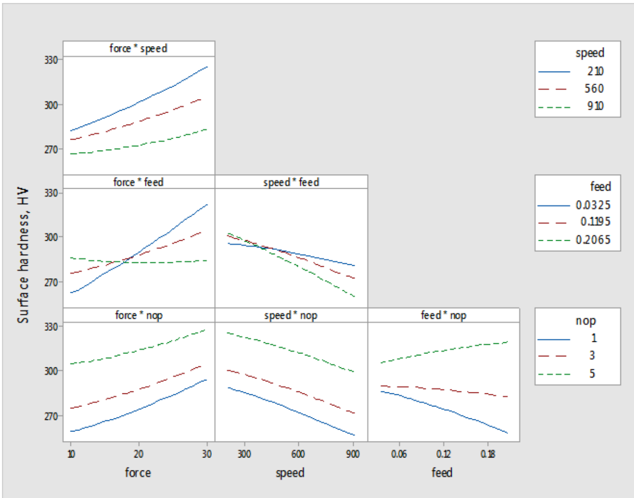
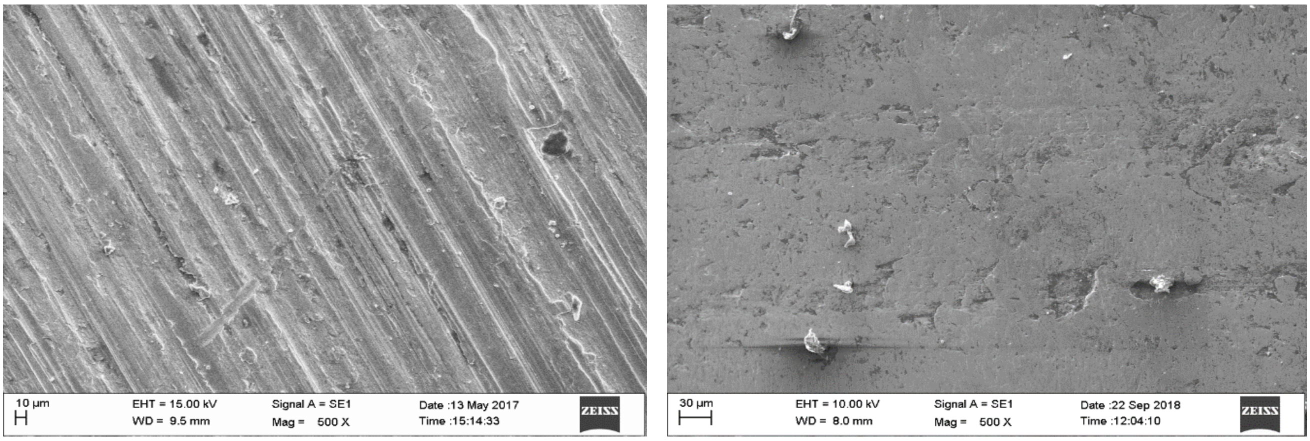


Figure 6. *Interaction effects of parameters on surface hardness*

There is a possibility of material exchange between the burnishing elements at higher temperatures causing deterioration of surface roughness. The presence of abrasive particles is also a reason for increased temperature resulting in poor surface finish.
The high feed rates (<0.01 mm/rev) increases distances between burnishing spots during the burnishing operation. When ball slides over the work part, these spots will not make intimate contact and hence the surface roughness not reduces to the maximum extent as indicated in figure 3. Abrasives particles struck

between ball and burnishing spots will slide away due to insufficient time and hence contribute less improvement in surface finish. Three number of tool passes will induce more plasticity in the surface layers to reduce surface roughness. The tool passes of order 4-5 will create chattering effect in burnishing tool thus enhances surface roughness.
The interaction effects of parameters on surface roughness are given in figure 4. It was noticed that all the interaction effects found to be significant except speed and feed, feed and number of passes. The high force and high speed will result in lower surface roughness as seen from figure 4. Figure also shows that high feed rates are beneficial to get better surface roughness at high force levels and vice versa. Single pass of the tool along with high force is also conducive to yield better roughness values and five passes of the tool will result in low roughness values at high speed levels.
The effect of parameters on hardness is illustrated in figure 5. The increase in force and number of passes increases hardness. As shown in figure 5, increase in force and number of passes increases plastic deformation in surface layers and increases hardness. It is observed that increase in speed reduces the hardness exponentially. This is attributed to recovery in work-hardening effect. The increase in feed, as explained earlier, increases the distance between burnishing spots and reduces plastic deformation action. This reduction in plastic flow of surface layers will result in decreased hardness. It is obvious from figure 6 that interaction between force and feed, speed and feed are significant on surface hardness. The combined action of high feed and force, high feed and speed result into low surface roughness as shown in figure 6. Figure 7 (a&b) shows the SEM images of turned and burnished specimens. It can be seen from the figures that feed marks present on turned specimen (a) is completely eliminated during burnishing (b) operation to produce better surface finish.



(a) **(b)**

Figure 7. *SEM images of the turned (a) and burnished (b) specimen*

Conclusion

The burnishing process has remarkable advantages over traditional finishing process and in current work the performance of developed burnishing tool has been tested in presence of abrasive particles. It was found that tool developed can be successfully used to carry out burnishing operation in conventional lathe machine. The use of silicon carbide abrasive particles resulted in improvement of surface characteristics such as surface finish and surface hardness of EN24 steel specimens. The surface roughness can be decreased to 0.1023 µm showing 96% improvement compared to turned specimens. Improvement in surface hardness achieves was 97% with 317 HV compared to 216 HV of turned specimens. The mathematical models developed in current work are adequate and can be used to predict the responses within the range of parameters selected in current work.

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