Analysis of Surface Roughness and Micro-hardness in Roller Burnishing of Aluminum Alloy 6061

Amin Poursafar[1*]
[1]Department of Mechanical Engineering, Dehaghan Branch, Islamic Azad University, Dehaghan, Isfahan, Iran
[*]Email of Corresponding Author: amin.poursafar@dehaghan.ac.ir
Received: May 21, 2018; Accepted: November 9, 2018

Abstract
Burnishing is a chip-less finishing process, in which a hard roller or ball presses the surface layer of part to perform plastic deformation in the surface layer and produce improved finish, enhanced hardness and compressive residual stresses on the surface of special materials such as Aluminum and Brass. In the following research, the effect of input parameters such as feed rate, cutting speed, number of passes , burnishing force and cooling system which is applying by minimum quantity of lubrication (MQL) on surface roughness and micro-hardness in roller burnishing of Aluminum alloy 6061 has been investigated. Taguchi method is used for design of experiments and special burnishing tool is used for this research. The optimization results show that the effect of feed rate and burnishing speed is significant on surface roughness and burnishing force and the number of passes plays important role in micro-hardness. The minimum surface roughness in burnishing of aluminum alloy 6061 was 0.138 μm and the maximum was 0.475 μm. The maximum micro-hardness in roller burnishing Aluminum alloy 6061was found 122 HB and the minimum was 100 HB.

Keywords
Roller burnishing, Surface roughness, Micro-hardness, Minimum quantity lubrication (MQL)

1. Introduction
Burnishing is a cold-working process that is based on rolling techniques and does not involve material removal and is used to improve surface roughness and tolerances of parts. Moreover, this process is distinct from traditional machining such as milling, lapping, honing, and polishing is the increase in both surface hardness and surface roughness [1]. Adel Mahmoud Hassan et al. [2] investigated the effect of feed rate, burnishing speed, burnishing force and the number of passes on the internal ball burnishing of a copper-aluminum alloy with applying flood cooling lubrication. The effect of lubricant's viscosity was found insignificant on surface roughness; however, the surface roughness was enhanced with increase in burnishing force. Yinggang Tian et al. [3] studied laser-aided burnishing which was found to offer a smoother and harder surface although it reduced fatigue life. Their study was done on dry condition. Gardian et al. [4] studied on fatigue fractures resulting from cracks in the roller-burnished workpieces with flood cooling.
Axira et al. [5] was investigated the effect of internal ball burnishing on the aluminum alloy 2024 with flood cooling. Their study is shown that the effect of this process on the surface roughness and the micro-hardness of internal hole is significant. The optimal number of passes in this study was

found 3 or 4 passes. Moreover, increasing the burnishing speed was found to reduce surface roughness and increasing micro-hardness and feed rate of 0.2-0.3 mm/rev are out of the process range.

Korzynski [6] analyzed a numerical model for ball burnishing and simulated the results as mathematical equations without lubrication system. Sagbas [7] investigated the burnishing parameters (burnishing force, number of passes, burnishing speed and feed rate) for ball burnishing of Aluminum alloy 7178applying wet lubrication system to obtain optimal surface quality, and extracted the optimal model. Hamadache et al. [8] studied the effects of burnishing force, feed rate, number of passes, and ball radius on the surface roughness and micro-hardness of 36Cr-Ni-Mo6 steel and found the optimal conditions applying flood cooling.

Revankar et al. [9] investigated the ball burnishing of a titanium alloy applying wet lubrication system. Based on their study, the effect of burnishing speed, burnishing force, feed rate and the number of passes on the surface roughness and micro-hardness were studied. A speed of 45 m/min, a feed rate of 0.05 mm/rev, and a force of 200 N in three passes were found to be conditions providing the best surface roughness on this alloy. Moreover, it was found that the optimal hardness was attained with a speed of 15 m/min, a feed rate of 0.15 mm/rev, and a force of 350 N in four passes.

In this research,Taguchi method is used for design of experiments, the micro-hardness and surface roughness are measured as response in roller burnishing of Aluminum 6061 with applying minimum quantitylubrication (MQL).There have been many attempts to reduce the amounts of fluids used. The MQL fluid delivery technique reduces fluid usage and improves the machining condition.

2. Material and Methods

2.1 Materials

The Aluminum alloy 6061 is composed of 96% aluminum, 1% magnesium, 0.4% copper, 0.3% zinc, 0.7% iron and silicon, and 0.9% other alloying elements. The specimen shaft was selected with 40 mm diameter and 300mm length which was divided into equal segments for roller burnishing. The shaft was machined with TN50B lath machine to obtain surface roughness 1.5 μm and hardness of 87 HB.

SAE10 oil with low viscosity was used for lubrication. The MQL set used in this study is RSk100 pneumatic-electric micro control system. A roller burnishing was designed by researcher and made by tungsten carbide with a radius of 1.5 mm. A TN50B turning machine was used for burnishing. The lath machine has a 7.5 HP motor with 1450 rpm spindle speed. The arithmetic surface roughness was measured on the machined surface by using the Diavite-compact model. The accuracy of this equipment was 0.001 microns. Furthermore, a SaluTron D400 was used for micro-hardness test.

2.2 Design of Experiment

The Taguchi methods are mostly applied for configuring experiments since they consider the largest number of contrary effects with the fewest number of experiments [10, 11]. In order to carry out the experiments, first, a design is created in which the effective parameters are assumed as independent variables. The most important input parameters of the burnishing process are the number of passes, burnishing force, burnishing speed, and the feed rate [12]. Considering the fact that each of these parameters is selected at four levels, 256 experiments are required in full-factorial; this was reduced to 16 using the L16 Taguchi method in Minitab software and the experiments were designed as presented in Table 1.Also, amounts of input parameters in four levels were shown in Table 2.

Table1. Design of experiment

No	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

Table2. Amount of control input parameters

Code	Control factor	Level 1	Level 2	Level3	Level4
A	Burnishing speed(V) (m/min)	30	60	90	120
B	Feed rate(f) (mm/rev)	0.08	0.16	0.24	0.32
C	Burnishing force(F_b) (N)	100	200	300	400
D	Number of passes	1	3	5	7

2.3 Procedure

The shaft was divided into 40mm segments and turned into 35mm diameter to obtain same surface roughness (1.5 μm). Then MQL set was assembled to the machine. Figure 1 shows the burnishing roller at the start of the procedure. In this process the MQL should lubricate the cutting zone by using MQL nozzle. 6 bar clean air pressure was provided for MQL and 50 mm distance with 45 degree angle was set to burnishing zone. The vegetarian oil (fried Oila Oil) mixed with air in amount of 200 ml/h was applied into burnishing zone.

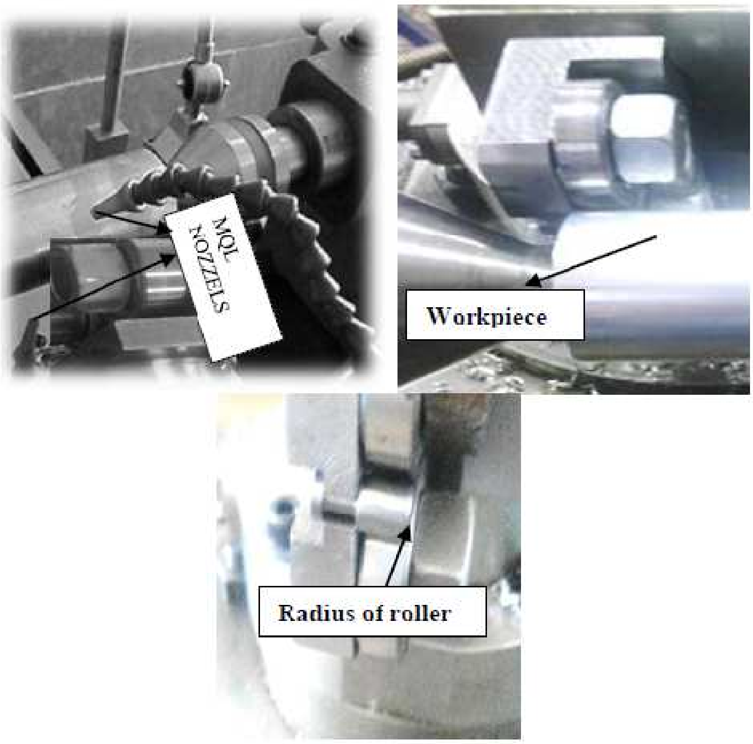

Figure1. Burnishing roller and MQL apparatus

3. Results and Discussion

3.1 Results

After roller burnishing, the surface roughness was measured three times based on R_a and the average of t was calculated. In this measurement, L_t is the total traversing length on the work piece surface, L_m is the measuring length and L_c is the cut-off length. In this study, L_c, L_m, and L_t were selected according to the catalog 0.8 mm, 3.2 mm and 4.8 mm, respectively. After that the micro-hardness was measured three times using a digital hardness tester in Brinell scale (HB) and then averaged. The results were presented in Table 3.

Table3. Results

No	A	B	C	D	Surface roughness (μm)	Hardness (HB)
1	1	1	1	1	0.324	101
2	1	2	2	2	0.311	108
3	1	3	3	3	0.420	119
4	1	4	4	4	0.475	122
5	2	1	2	3	0.138	112
6	2	2	1	4	0.196	112
7	2	3	4	1	0.180	106
8	2	4	3	2	0.182	107
9	3	1	3	4	0.241	111
10	3	2	4	3	0.270	111
11	3	3	1	2	0.253	102
12	3	4	2	1	0.268	100
13	4	1	4	2	0.375	107
14	4	2	3	1	0.376	101
15	4	3	2	4	0.381	104
16	4	4	1	3	0.446	105

3.2 Analysis of Surface Roughness and Micro-hardness

The effect of roller burnishing parameters on the surface roughness of the Aluminum alloy 6061 is presented in Figure 2.

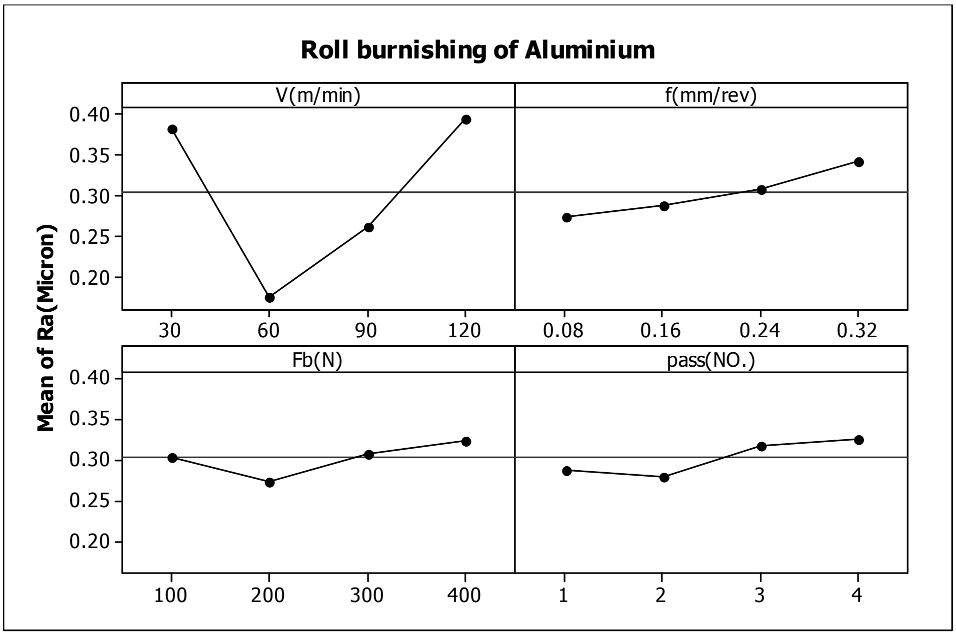

Figure2. Surface roughness in roller burnishing

According to these Figures, by increasing the burnishing speed (V) surface roughness initially decreased and then increased. The optimal speed is 60 m/min. Also increasing in feed rate (f) surface roughness is increased relatively, with 0.08 mm/rev being associated with the best surface roughness. By increasing the default burnishing force (F_b), the average surface roughness is decreased and then increased. The optimal force is 200N. Moreover, according to these diagram, when the number of passes is increased, the surface roughness decreases and then increases in the steady condition. 2 passes is the best choice for this procedure.

The effect of roller burnishing parameters on the micro-hardness of the Aluminum alloy 6061 is presented in Figure 3.

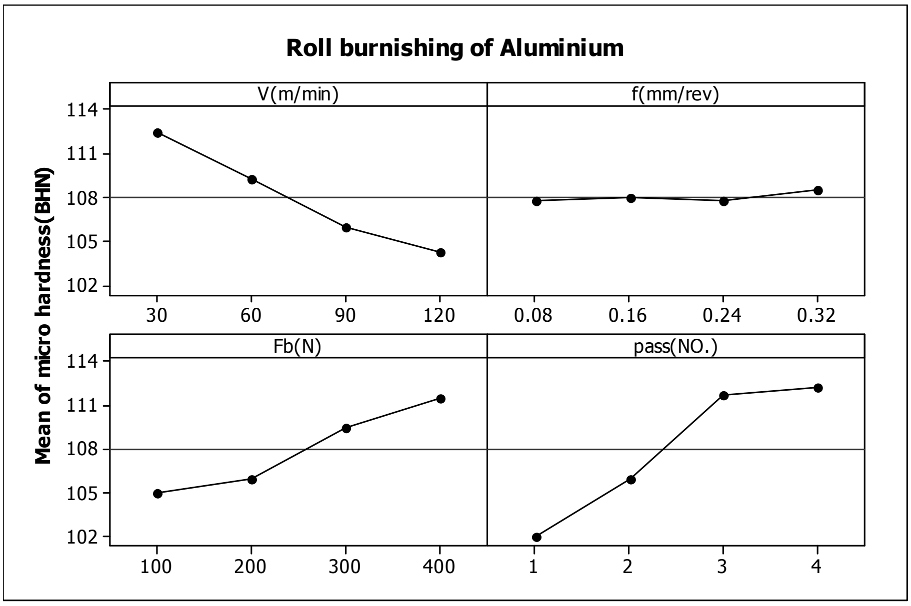

Figure3. Micro-hardness in roller burnishing

As a result, while burnishing speed (V) is increased, micro-hardness is decreased and the optimized speed is V=30 m/min. According to this research the micro-hardness is not changed while feed rate (f) is increased. The micro-hardness is increased rapidly while burnishing force (F_b) is increased. The maximum value is associated with F=400 N. During 300 to 400 N and 100 to 200 N, there is a steady increase in micro hardness. Moreover, the micro-hardness is increased as the number of passes is increased up to 3. However, micro-hardness after 4 passes is basically the same as it was after 3. Therefore, 3 passes are enough for attaining a favorable micro-hardness.

3.3 Extracting a Regression Model for Surface Roughness and Micro-hardness

The stepwise method was used in Minitab in order to obtain the regression model. In this method, the numerical value of input alpha and the optimum output was assumed 0.15 considering the previous studies which lead to a p-value above 0.05 and R^2 and R^2 (adj) above 90% proposed for the optimum model [11]. Table 4 shows R^2 and R^2 (adj) values of the regression models for surface roughness.

Table4. Regreesion values for surface roughness

Regression model	Degree 1	Degree 2	Degree 3
R^2	0.250	0.851	0.967
(adjR^2)	0.132	0.799	0.951

According to Table 4, third degree regression is acceptable. The following regression model is presented in Equation 1 for surface roughness.

$$\text{Ra} = 1.01 + 0.439f^2\text{Pass} - 0.000001V^3 - 0.0341\text{V} + 0.000417V^2 - 0.00071\text{VfPass} \quad (1)$$

Table 5 shows R^2 and R^2 (adj) values of the regression models for micro-hardness.

Table 5.Regreesion values for micro-hardness

Regression model	Degree 1	Degree 2	Degree 3
R^2	0.750	0.858	0.986
(adjR^2)	0.722	0.798	0.968

According to Table 5, a third degree regression was acceptable .The following model which is presented in Equation 2 is for micro-hardness (HB) in burnishing of aluminum 6061.

$$Micro-hardness = 89.4 + 6.53Pass - 0.00856VPass^2 + 0.056F_b - 0.000317VF_b - 0.000143F_b^2\,\text{f} + 0.000002\,\text{V}^3 \quad (2)$$

4. Conclusion

The aim of this study was to optimize the output parameters (such as surface roughness, and micro-hardness) of a roller burnishing of Aluminum alloy 6061with the assistance of MQL. In this regard the effects of the most important input parameters (such as feed rate, cutting speed, number of passes and burnishing force) on the outputs were evaluated. A Taguchi method was designed and statistical analysis was applied to experimental data and then appropriate model was extracted and the following results were obtained:

1. The minimum surface roughness in roller burnishing of aluminum alloy 6061 was 0.138 μm and the maximum was 0.475 μm which is more suitable than other finishing process.
2. The maximum micro-hardness in roller burnishing aluminum alloys 6061was 122 HB and the minimum was 100 HB.
3. It is obvious that surface roughness is increased while the burnishing speed and feed rate are increased but it can be seen that the best performance is in the speed of 60 m/min and feed rate of 0.08 mm/rev.
4. During force acquisition, it can be found that 200 (N) is the optimized value which is acted to burnishing tool. Moreover, two burnishing passes are the best choice for this process because of time and surface roughness optimization.
5. The optimization results revealed that feed rate and burnishing speed are the significant parameters for minimizing the surface roughness, but burnishing force and number of passes plays important roles in maximizing the micro-hardness.

5. Acknowledgement

All experimental data are driven from research which is entitled “The study of burnishing process on outer surface for industrial workpieces” which is registered and performed in Islamic Azad University, Dehaghan branch.

6. References

[1] Mahajan, D. and Tajane, R. 2013. A Review on Ball Burnishing Process. International Journal of Scientific and Research Publications. 3(4): 1-8.

[2] Hassan, A. M. and Maqableh, A. M. 2000. The Effects of Initial Burnishing Parameters on Non-Ferrous Components. Journal of Materials Processing Technology. 102(1-3): 115-121.

[3] Tian, Y. and Shin, C. Y. 2007. Laser-assisted Burnishing of Metals. International Journal of Machine Tools & Manufacture. 47(1): 14–22.

[4] Gardin, C., Courtin, S., Bertheau, D., Bezine, G. and Ben Hadj Hamouda, H. 2007. The Influence of Roller Burnishing on the Fatigue Crack Propagation in Notched Round Bars – Experimental Observations under Three-point Bending. Fatigue & Fracture of Engineering Materials & Structures journal. 30(4): 342-350.

[5] El-Axira, M.H., Othmanb, O.M. and Abodiena, A.M. 2008. Improvements in Out of Roundness and Micro Hardness of Inner Surfaces by Internal Ball Burnishing Process. Journal of Materials Processing Technology. 196(1-3): 120–128.

[6] Korzynski, M. 2009. A Model of Smoothing Slide Ball-Burnishing and an Analysis of the Parameter Interaction. Journal of Materials Processing Technology. 209(1): 625–633.

[7] Sagbas, A. 2011. Analysis and Optimization of Surface Roughness in the Ball Burnishing Process Using Response Surface Methodology and Desirability Function. Advances in Engineering Software journal. 42(11): 992–998.

[8] Hamadache, H., Zemouri, Z., Laouar, L. and Dominiak, S. 2014. Improvement of Surface Conditions of 36 Cr Ni Mo 6 Steel by Ball Burnishing Process. Journal of Mechanical Science and Technology. 28(4): 1491–1498.

[9] Revankar, G.D., Shetty, R., Rao, S.S. and Gaitonde, V.N. 2014. Analysis of Surface Roughness and Hardness in Ball Burnishing of Titanium Alloy. Measurement Journal. 58: 256–268.

[10] Nikalje, A. M., Kumar, A. and Sai Srinadh, K. V. 2013. Influence of Parameters and Optimization of EDM Performance Measures on MDN 300 Steel Using Taguchi Method. International Journal Advanced Manufactoring Technology. 69(1-4): 41–49.

[11] MINITAB14 software/2005/help

[12] El-Tayeb, N.S.M., Low, K.O. and Brevern, P.V. 2006. Influence of Roller Burnishing Contact Width and Burnishing Orientation on Surface Quality and Tribological Behavior of Aluminium 6061. Journal of Materials Processing Technology. 186(1-3): 272–278.