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Research Article

THE OPTIMIZATION OF SURFACE ROUGHNESS OF AZ91D MAGNESIUM ALLOY USING ANOVA IN BALL BURNISHING PROCESS

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ABSTRACT

Ball burnishing is a simple, cost-effective and fast finishing process generally applied to better the surface roughness of machine parts. In this study, the Taguchi L_{18} orthogonal array method is used to find the optimal surface roughness in ball burnishing of AZ91D magnesium alloy. The orthogonal array, the signal-to-noise ratio, and ANOVA (analysis of variance) method is employed to study the performance characteristics in ball burnishing process of AZ91D alloy bars. The purpose of this study is to perform an ANOVA to determine the effects of the (burnishing force, burnishing speed, feed rate and number of passes parameters) on the surface roughness data obtained after the ball burnishing applied to the AZ91D bars. The optimum burnishing parameter was determined based on signal-to-noise (S/N) ratio. Data was analyzed by means of the ANOVA method. The main results of the statistical analysis highlight the great influence of the feed rate, burnishing force and number of passes on surface roughness among the set of factors and their interactions considered.

Keywords: *Surface roughness, Taguchi method, Ball burnishing, ANOVA*

1. INTRODUCTION

Magnesium and magnesium alloys have been extensively studied and applied in the automotive, aerospace and defense industries due to their low densities, high strength to weight ratio, high specific toughness and good workability [Buldum et al., 2013, Gnedenkov et al., 2013, Buldum, 2013].

The use of magnesium metal, which has been highly demanded in recent years, is evolving along with industrial and technological developments. Because of the lightness, durability and longevity of magnesium, its use in industry is of interest. [Buldum et al., 2013]. However, due to the disadvantages of cast magnesium alloys such as limited ductility and low fatigue performance, it is difficult to use these materials in load bearing parts of the industry. [Zhang et al., 2005]. But also its use due to its high corrosion sensitivity which is another disadvantage. [Mahajan et al. 2013].

Surface properties of materials are one of the most important parameters in the manufacturing industry. Surface roughness properties are a feature that affects machine performance increase and production costs [Luca et al., 2005]. Machine parts must be manufactured to account for superior dimensional, geometric accuracy and surface roughness to ensure reliable performance and continuous production [Mahajan et al. 2013, Hamamci et al., 2014]. The surface roughness has a significant role in affecting functional characteristics such as corrosion behavior, fatigue strength, wear resistance and power loss because of friction [Mahajan et al. 2013, Hamamci et al., 2014].]. Different methods are used in cases where desired surface roughness values, lathe, milling and conventional grinding cannot be achieved by conventional machining methods.

Burnishing operations are increasingly being demanded as a finishing procedure due to the advantages such as increased surface hardness, fatigue strength and increased wear resistance [López de Lacalle et al., 2005]. Burnishing is generally used to provide good surface roughness. Moreover, these features are provided by inexpensive equipment or fast processing. Ball burnishing is a rapid, simple, practical and affordable mechanical surface treatment (Fig. 1.) [López de Lacalle et al., 2005, Esme, 2010]. Thus, ball burnishing can replace other surface finishing processes, such as lapping, honing, grinding or polishing [Rodriguez et al., 2010].

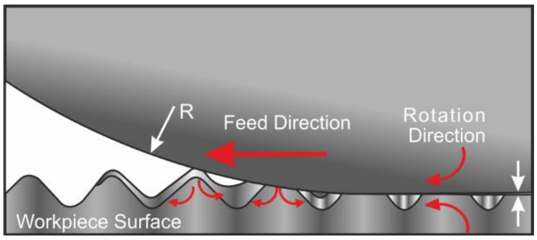


Fig 1. Scheme of Ball burnishing process

The parameters influencing the surface roughness are burnishing speed and force, a number of passes, feed rate, ball material, workpiece material, ball size and lubricant. Many researchers have experimentally explored this process, addressing the effects of burnishing speed and force, feed rate and a number of passes [El-Taweel et al., 2009, Sagbas, 2011, Dabeer et al., 2010, Ibrahim et al., 2009, Low et al., 2011].

In spite of performing ball burnishing process for surface quality development experiments of steel, aluminum, polymer, titanium or nickel made workpiece [López de Lacalle et al., 2005, Sagbas, 2011, Dabeer et al., 2010, Ibrahim et al., 2009, Low et al., 2011, El-Axir et al., 2008, Gokce et al., 2015, Kayali et al., 2013, Grzesik et al., 2012, Thamizhmnaii et al., 2008, Tian et al., 2007], usage of magnesium made workpiece are limited. Work on the development of the above mentioned materials is still being carried out by other researchers in this area.

In the present study, optimization is performed by using the results obtained from our experimental results using the Taguchi method. We used ANOVA method in this analysis. In this view, it is analyzed which parameters used during the experiment are more effective on the surface roughness results and which parameter combinations are efficient. The best burnishing parameters of ball burnishing process of AZ91D magnesium alloy, such as burnishing speed, burnishing force, feed rate, and number of passes of workpiece were found out in order to get the better surface roughness.

2. EXPERIMENTAL

Taguchi method has been used widely in engineering analysis to significantly decrease the number experiments [Cicek et al., 2015]. Taguchi method is an important method for the design of high-quality systems and low-cost design solution. Taguchi method exhibits a systematic method that is simple and effective in order to optimize designs for cost, performance and quality [Cicek et al., 2015, Oktem et al., 2006, Pishbin et al., 2010]. Selection of orthogonal array is one of the important steps in Taguchi method. It will further assist to perform experiments to determine the optimum level for each process parameters.

The initial step of Taguchi method is the choice of a proper orthogonal array. The choice of a proper orthogonal array according to the total degrees of freedom of process parameters. In order to choose orthogonal array for experiments properly, the total degrees of freedom needs to be calculated. In this study, three three-levels (Burnishing Force, Burnishing Speed, Feed rate) and one two-levels (Number of passes) as four control factors of mixed level (2 and 3 levels). Therefore, the total degrees of freedom of parameters are equal to 11. Fundamentally, the degrees of freedom for the orthogonal array should be greater than or at least equal to those for the process parameters. Thus, in this study experiments were carried out as per Taguchi's L_{18} (2^2x3^3) mixed orthogonal array (Table 1) to optimize of ball burnishing with multiple performance characteristics of the results of surface roughness and microhardness.

Ball burnishing parameters and their limits used in this study are shown in Table 2. The process parameters were determined using MINITAB 17 statistical software based on Taguchi L_{18} orthogonal array.

Table 1. Factors and levels used in the experiment

Experiment Number	Control factors and levels			
	Number of passes (A)	Burnishing Force (B)	Burnishing Speed (C)	Feed rate (D)
1	1	1	1	1
2	1	1	2	2
3	1	1	3	3
4	1	2	1	1
5	1	2	2	2
6	1	2	3	3
7	1	3	1	2
8	1	3	2	3
9	1	3	3	1
10	2	1	1	3
11	2	1	2	1
12	2	1	3	2
13	2	2	1	2
14	2	2	2	3
15	2	2	3	1
16	2	3	1	3
17	2	3	2	1
18	2	3	3	2

Table 2. Process parameters and their limits

Factors		Level		
		1	2	3
A	Number of passes	1	2	-
B	Burnishing Force (N)	50	150	250
C	Burnishing Speed (rpm)	200	400	600
D	Feed rate (mm/min)	0.1	0.25	0.5

In this study, the experimental material was AZ91D magnesium alloy bar (Yuanhong Alloy Materials Co.,Ltd, China), the chemical composition of which is given in Table 3. This material is widely used in automotive, aerospace and defense industries.

In this work, two specimens were used for AZ91D which the dimension of workpiece material has a diameter of 35 mm and 200 mm in length as demonstrated Fig. 2a. Each specimen was divided into 9 different segments a length of 25 mm and the 5 mm groove between parts. By performing different parameters on each segment.

Table 3. Chemical composition of AZ91D magnesium alloy (wt. %)

Material	Al	Zn	Mn	Fe	Be	Si	Cu	Ni	Mg
AZ91D	9.21	0.45	0.17	0.0018	0.00084	0.016	0.002	0.00085	Balance

(a) (b)

Fig 2. a) AZ91D workpiece material, b) CNC lathe

The ball burnishing process was carried out on a CNC lathe as demonstrated Fig. 2b. The experimental set up used for the burnishing experiments is shown in Fig. 3. Also, the force gauge, as shown in Fig. 4., was used to investigate the effect of burnishing force on ball burnishing process. To prevent any particles from ingress the surface of contact between the tool and specimen, cleaning of the ball was carried out during the ball burnishing process. The workpiece was interlocked by the three jaw chuck and tailstock center of the machine. No coolant was used throughout this ball burnishing process.

Fig. 3. The experimental set up

Fig. 4. Force gauge

Average surface roughness values were taken on three different sections of the cylindrical surface along the workpiece (AZ91D magnesium alloy bar). Surface roughness values were measured using a Mitutoyo portable roughness meter model Surftest SJ 201.

ANOVA is basically used in this experiment to determine, which cutting factors mostly affect the roughness value. Basically ANOVA is a collection of statistical models which is used to analyze the variation among the groups. ANOVA is a statistical analysis which is commonly applied to evaluate the data of experiments. In this research, the analysis of direct and interactive effect of the input factors (Burnishing speed, burnishing force, feed rate and number of passes) on the surface roughness is conducted through ANOVA. The regression equation and investigated factors are called to be statistically significant if the p-value in ANOVA result is less than 0.05. Besides, the percentage contribution of terms in the estimated model on the total variation is also considered to evaluate the influence degree of the controllable factors on the model.

3. RESULTS AND DISCUSSION

Taguchi's loss function is used to calculate the deviation between the experimental value and the desired value [Gaitonde et al., 2006, Carou et al., 2014]. Then the value of this function is converted to the signal-to-noise (S/N) ratio. Taguchi's philosophy comprises three general approaches to assessing the relationship between quality and variability [Gaitonde et al., 2006, Carou et al., 2014]. There is three approach of signal-to-noise available is subject to the approach of characteristics. These are 'Nominal is better approach', 'Smaller is better approach' and 'Larger is better approach' [Phadke, 1989]. In this study, the smallest optimal value of surface roughness was selected for the signal-to-ratio of better performances of factors. 'Smaller is better approach' was calculated by the following equation (1). S/N ratios of surface roughness is shown in Table 4. and their main effects plot are demonstrated in Fig. 5.

$$S/N = -10\log\left(\frac{1}{N}\left(\sum_{i=1}^{n} Y_i^2\right)\right) \qquad (1)$$

Y_i is the value of surface roughness for first equation (1) for the i^{th} test, n the number of tests and N the total number of data points.

In this study, the effect of the number of passes, burnishing force, burnishing speed, feed rate has been researched on surface roughness. The data acquired by applying the ball burnishing process are shown in Table 4.

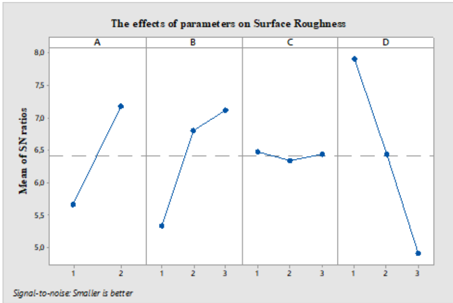


Fig. 5. The effects of parameters on Surface Roughness

Table 4. Process Parameters and Experimental results after ball burnishing process

Experiment Number	Process Parameters				Experimental Results	S/N ratio (dB)
	(A) Number of passes	(B) Burnishing Force	(C) Burnishing Speed	(D) Feed rate	Ra (µm)	Ra (µm)
1	1	50	200	0.1	0.481	6.36
2	1	50	400	0.25	0.631	3.99
3	1	50	600	0.5	0.718	2.88
4	1	150	200	0.1	0.434	7.25
5	1	150	400	0.25	0.519	5.70
6	1	150	600	0.5	0.550	5.19
7	1	250	200	0.25	0.448	6.97
8	1	250	400	0.5	0.559	5.05
9	1	250	600	0.1	0.424	7.45
10	2	50	200	0.5	0.599	4.44
11	2	50	400	0.1	0.402	7.90
12	2	50	600	0.25	0.480	6.38
13	2	150	200	0.25	0.407	7.80
14	2	150	400	0.5	0.508	5.88

15	2	150	600	0.1	0.358	8.93
16	2	250	200	0.5	0.504	5.95
17	2	250	400	0.1	0.336	9.47
18	2	250	600	0.25	0.409	7.76

Table 5. ANOM for surface roughness based on S/N

	Factors	Level			Optimum level
		1	2	3	
A	Number of passes	5.653	7.172	-	2
B	Burnishing Force (N)	5.330	6.795	7.113	3
C	Burnishing Speed (rpm)	6.467	6.338	6.434	1
D	Feed rate (mm/min)	7.897	6.437	2.994	1

Table 6. ANOVA for surface roughness based on S/N ratio

Parameter code	Degrees of freedom	Sum of squares	Mean squares	% Contribution
A	1	10.3844	10.3844	20.65
B	2	10.8565	5.4282	21.59
C	2	0.0535	0.0268	0.11
D	2	26.8890	13.4445	53.47
Error	10	2.1017	0.2102	
Total	17	50.2852		

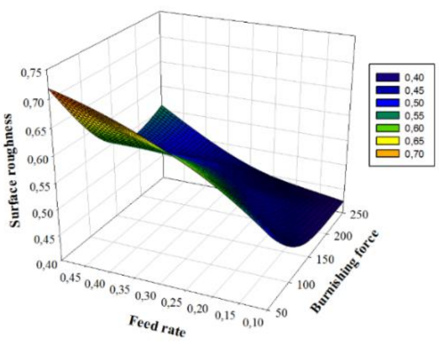
The analysis of means (ANOM) based on S/N ratio was performed to decide the optimal levels of factors, the sum is shown in Table 5. The level of a control factor with the highest S/N ratio is the optimal level. The best combination control factor setting is A2, B3, C1 and D1 for minimum surface roughness.

ANOVA based on S/N ratio has been performed to know the relative importance of each of the control factors. Table 6 present the results of ANOVA for surface roughness. From ANOVA, it is observed that number of passes (20.65%), burnishing force (21.59%) and feed rate (53.47%) play significant roles in minimizing the surface roughness; while there is almost no effect of burnishing speed.

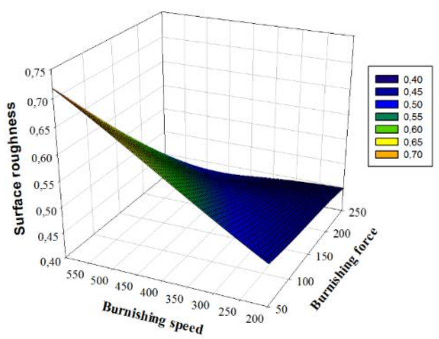
As shown in Fig. 7a., when the feed rate raises up, the surface roughness is increasing. As the burnishing force raise up, the surface roughness is decreasing. It appears that to have no change in the surface roughness results, considering the experiments the burnishing force range of 150 N to 250 N at 0.1 mm/min feed rate. Fig. 7a. exhibits that the notable parameters effect of surface roughness is feed rate and burnishing force.

As it is seen the Fig. 7b., the effect of burnishing force couldn't be significantly observed on the surface roughness. However, the burnishing force (400 rpm and 600 rpm) increases with decrease the surface roughness except to 200 rpm. As the burnishing speed increases the surface roughness increases.

As indicated in Fig. 8a., the burnishing speed increases with increase the microhardness. When the burnishing force increases from 50 N to 150 N the microhardness decreases but it increases from 150 N to 250 N. Besides, the feed rate increases with increase the microhardness. When the feed rate increases from 0.1 mm/min to 0.25 mm/min the microhardness decreases but it increases from 0.25 mm/min to 0.5 mm/min (Fig. 8b.).

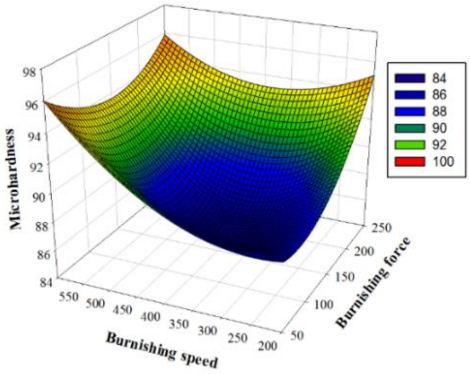


(a)

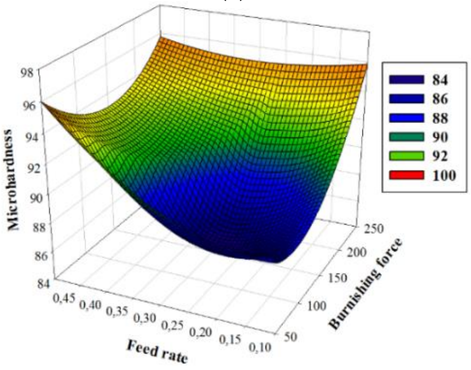


(b)

Fig. 7. a) Effect of burnishing force and feed rate on surface roughness b) Effect of burnishing speed and burnishing force on surface roughness



(a)



(b)

Fig. 8. a) Effect of burnishing speed and burnishing force on surface roughness b) Effect of feed and burnishing force on surface roughness

4. CONCLUSION

In this paper, the effect of the number of passes, burnishing force, burnishing speed and feed rate was researched on surface roughness. Taguchi method was used for optimization of these parameters, assisted in the optimization process. Conclusions from present research are given below;

• The optimal parameter combination for the minimum surface finish was obtained by using the analysis of signal-to-noise ratio. The combination of parameters and their levels for optimum surface roughness is A2B3C1D1.

• Generally, the surface roughness increases with increased feed rate. The effect of burnishing force couldn't significantly observe on the surface roughness. Also, the surface roughness decreases with increased number of passes.

• The best surface roughness value was obtained at two passes as a number of passes, 250 N burnishing force, 400 rpm burnishing speed and 0.1 mm/min feed rate settings.

• ANOVA based on S/N ratio has been performed to know the relative importance of each of the control factors. From ANOVA, it is observed that number of passes (20.65%), burnishing force (21.59%) and feed rate (53.47%) play significant roles in minimizing the surface roughness; while there is almost no effect of burnishing speed.

• From ANOVA, the results indicate that the control factors such as number of passes, burnishing force, burnishing speed and feed rate have a significant effect on surface roughness at a reliability level of 95.82%.

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