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Improvement of Surface Roughness using ANOVA for AZ31B Magnesium Alloy with Ball Burnishing Process

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***Abstract*—Magnesium alloys, which are widely used in automotive, aerospace and manufacturing industries as lightweight and high strength materials, have some limitations due to inadequate corrosion resistance and low surface quality. In order to overcome these limitations and to improve the surface properties in particular, the magnesium alloy ball correction process is applied with different parameters (burnishing force, number of passes, feed rate and burnishing speed). The Taguchi method was used to reduce the number of experiments and the better burnishing conditions were determined considering the S/N ratios. Data obtained from the experiments were analyzed by variance analysis (ANOVA) method; it is seen that the feed rate, the burnishing speed and the number of passes have a significant effect on the surface roughness when the analyzed factors and their interactions are considered in the analysis result. In terms of the results of the surface roughness tests, it has been found that the feed rate and burnishing force are important parameters for increasing the surface quality. When the low feed rate and high force parameters are selected, the better surface roughness value is achieved.**

Keywords— Magnesium alloy, Surface Roughness, Ball burnishing, Taguchi method, ANOVA

I. INTRODUCTION

Magnesium is attracting interest as a widely used material in industry due to its low density and good strength. Magnesium alloys are very attractive materials for engineering applications due to their advantages such as light weight, high strength and high specific hardness such as biomaterial, automobile and aviation industry [1-6]. For this reason, interest in the use of magnesium alloys as basic materials has increased in many applications in recent years, and the use of aluminum alloys in automotive industries has been particularly emphasized. Although the mechanical properties of Mg and its alloys are of interest because they increase their industrial applications, applications are generally limited due to unsatisfactory corrosion performance and poor surface properties. The surface properties of Mg alloys should be improved in order to overcome these deficiencies. Surface modification is a common way to improve surface properties. Surface properties are important for better machine life for structural parts used for various machines and engineering applications.

Recently, dimensional precision and surface treatments for the manufacturing industry have become more intriguing. Conventional chip removal processes such as honing, grinding and polishing are used to improve the quality of the product. However, the removal of these depends on the skill and experience of the operator. In order to overcome these problems, a ball burnishing process is used for better surface roughness, with less chipping, simple and shorter processing times. Ball burnishing is a cold process that uses plastic deformation without material loss to achieve better surface roughness. [7-10].

Burnishing is generally used to provide good surface roughness. Moreover, these features are provided by inexpensive equipment or fast processing. The enhancement in surface values include increase in surface hardness the production of compressive residual stresses which are favorable for cold work hardening of the surface, improves tensile strength and corrosion resistance, also maintains dimensional stability fatigue life as result of the produced compressive residual stress [12-14].

Hassan et al. were used ball-burnishing process in order to improve the surface hardness and roughness of brass alloys. They were investigated the effect of different forces and a number of tool passes. The results obtained from the wear tests show that the burnishing process was improved the wear resistance of the brass alloys [15]. El-Axir et al. were studied four ball burnishing parameters for aluminum alloy 2014 which is the depth of penetration, feed rate, a number of passes and burnishing speed. A remarkable increasing surface microhardness in specimens was obtained [16]. Hassan et al. were examined the surface roughness, proof stress, hardness, fatigue strength and ultimate tensile before and after burnishing properties of non-ferrous metals. The results were showed some recuperation on these properties due to the burnishing process [17]. Cheng et al. were investigated the optimal surface parameters for the NAK80 mold tool steel via using the Taguchi's L_{18} orthogonal table. The burnished surface roughness of the samples were enhanced from about Ra 0.06 μm to 0.016 μm in average using the determined optimal parameters [18]. Hassan et al. were studied the effects of the force and the number of passes on the surface hardness and roughness of aluminum and brass. They were obtained that improvements in the surface roughness and increases in the surface hardness values [19]. Rodriguez et al. was used a finite element model of ball-burnishing to find out and estimate residual stress values. They were found that burnishing is an economical and possible process for the quality improvement of materials, not only in surface roughness but in compressive residual stresses as well [20]. Studies in the literature concerning the optimization of the surface roughness of AZ31B magnesium alloys are limited.

In this work, optimization of the surface roughness data of AZ31B magnesium alloys is aimed using the ball burnishing process. 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 better burnishing parameters of ball burnishing process of AZ31B 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.

II. MATERIALS AND METHODS

In this study, AZ31B Mg alloys were used as a workpiece material. The chemical composition of this alloy is presented in Table I. AZ31B was chosen because of magnesium alloys are very attractive materials for engineering applications, such as biomaterial, automobile and aviation industries due to their advantages like lightweight, high strength and high specific stiffness.

A. Design of the Taguchi's orthogonal array

Conventional plastic deformation processes are complex and not easy to use. In addition, the machining process is also important for the manufacturer. Since the number of parameters is large, a number of experiments are required. Because of this problem, taguchi method is used with few experiments. Taguchi proposed signal to noise (S/N) ratio for defining optimum parameters of experiments. Experiments design problems can be divided into the smaller the better type, the larger the better type and the nominal the-best type. The signal to noise (S/N) ratio was used for optimizing a treatment for product design.

Table I. Chemical composition of AZ31B Mg alloy (wt. %)

Al	Zn	Mn	Fe	Si	Cu	Ni	Mg
8.73	0.56	0.23	0.0 026	0.0 21	0.0 018	0.0009	Balan ce

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). Consequently, for surface roughness smaller the better type (equation 1) is available. The S/N ratio, η, is defined by the following equations:

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

where *n* is the number of the experiment and *yi* is the results of the experiments under different parameters [21-24].

Essential burnishing parameters (feed rate, burnishing speed, burnishing force and number of passes) having significant effects on surface roughness can be determined efficiently using the taguchi method. Consequently, burnishing speed, feed rate, number of passes and burnishing force, were chosen as four experimental parameters (Table II). Two levels for a number of passes and three level of other parameters (feed rate, burnishing speed, burnishing force) were selected. The L_{18} orthogonal array (Table III) was chosen for one two level and three three-level factors of the ball burnishing process.

B. Sample properties and analyzes

In the experiments, commercially purchased AZ31B Mg alloys (Yuanhong Alloy Materials Co.,Ltd, China) were used with a diameter of 50 mm and a bar length of about 300 mm. The ball burnishing process was applied a Liouy Hsing GNC-450L CNC lathe. The experimental set up used for the burnishing experiments is shown in Fig. 1. Also, the force gauge was used to investigate the effect of burnishing force on ball burnishing process. The solid model of the ball burnishing tool is seen in Fig. 2a. The schematic view of work piece material demonstrated in Fig. 2b.

Table II. The value of using parameters for ball burnishing process

P	F (N)	V (rpm)	f (mm/min)
1	50	200	0.1
2	150	400	0.25
-	250	600	0.5

Finally, nine burnishing processes were developed for each of the two samples. The surface roughness of the burnished workpieces was determined using a surface roughness tester (Mitutoyo, Surftest SJ 201). Three measurements were made at Ra (μm) values at different points of the sample to determine the surface roughness quality and the averages were calculated.

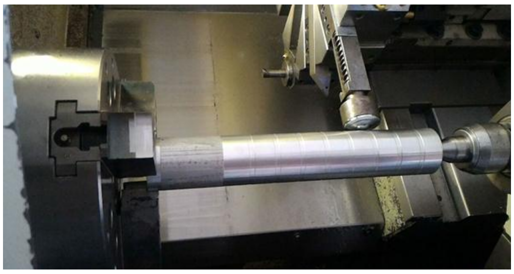

Fig. 1. The photograph of the AZ31B Mg alloy ball burnishing process

ANOVA is used to determine the effects of the single factor used in the experiments and the interactions between the factors. Basically ANOVA is a sum of statistical models used to analyze variation between groups. ANOVA is a statistical analysis which is commonly carried out to evaluate the data of experiments. In this study, the analysis of the direct and interacting effect of the input factors on the surface roughness was carried out by 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.

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Table III. Taguchi design of experiments

	P	F (N)	V (rpm)	f (mm/dk)
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

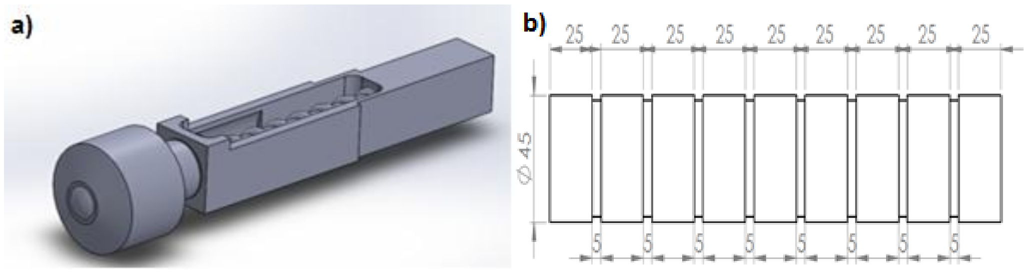

Fig. 2. a) Solid model of ball burnishing tool b) Schematic view of the specimens

III. RESULTS AND DISCUSSION

In the present study the effect of the different parameters (force, speed, feed rate and number of passes) on surface roughness of AZ31B Mg alloys were performed. For researching feed rate, burnishing speed and force three different level were applied. For number of passes 1 and 2 passes were studied. Although 54 experiments were required to investigate all these parameters, the study was made efficient using the Taguchi experimental design. 3 factors 3 levels and 1 factor 2 levels were set and the Taguchi mixed design was chosen. The number of experiments was reduced from 54 to 18 using the L_{18} orthogonal array.

The S/N ratios are calculated from the given equation 1. Calculated S/N ratios are presented in the Table IV and their main effects plot are demonstrated in Fig. 3. Considering the graphs in Fig. 3, better surface roughness is obtained when the burnishing force is 250 N, the number of passes is 2, the speed is 200 rpm and the feed rate is 0.1 mm / min.

Table IV. Taguchi L_{18} orthogonal array, measured values and S/N ratios

Number of experiments	Passes	Force (N)	Speed (rpm)	Feed rate (mm/dk)	Surface roughness (μm)	S/N ratio of surface roughess
1	1	50	200	0.1	0.483	6.321
2	1	50	400	0.25	0.551	5.177
3	1	50	600	0.5	0.677	3.388
4	1	150	200	0.1	0.355	8.995
5	1	150	400	0.25	0.475	6.466
6	1	150	600	0.5	0.639	3.890
7	1	250	200	0.25	0.382	8.358
8	1	250	400	0.5	0.539	5.368
9	1	250	600	0.1	0.316	10.006
10	2	50	200	0.5	0.550	5.192
11	2	50	400	0.1	0.419	7.555

12	2	50	600	0.25	0.508	5.882
13	2	150	200	0.25	0.399	7.980
14	2	150	400	0.5	0.539	5.368
15	2	150	600	0.1	0.344	9.268
16	2	250	200	0.5	0.485	6.285
17	2	250	400	0.1	0.333	9.551
18	2	250	600	0.25	0.390	8.178

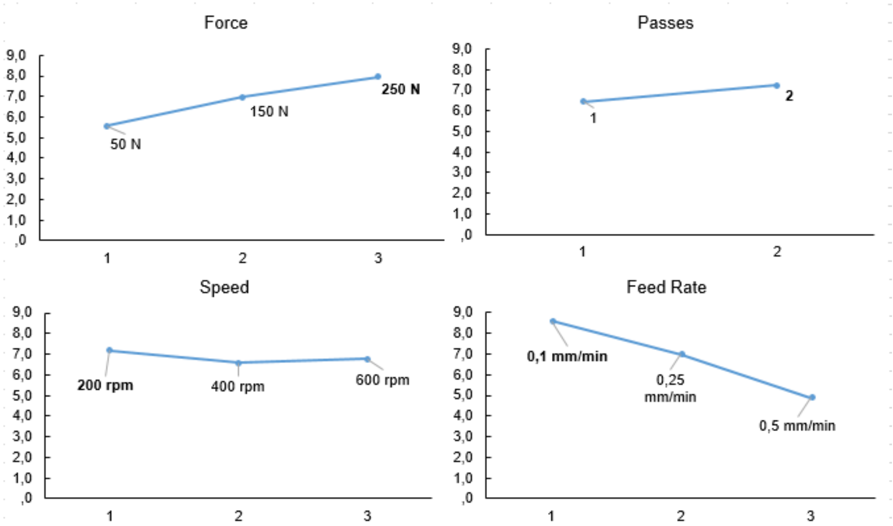

Fig. 3. Plots of S/N ratios for surface roughness

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 V. 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.

The analysis of variance (ANOVA) based on S/N ratio has been performed to know the relative importance of each of the control factors. Table VI present the results of ANOVA for surface roughness. From ANOVA, it is observed that number of passes (4.48%), burnishing force (25.91%) and feed rate (62.71%) play significant roles in minimizing the surface roughness; while there is almost no effect of burnishing speed.

As can be seen from Fig. 4a, the surface roughness values increase when the force values increase and the feed rate decreases. Although there is not much change in the surface roughness value when the force values are changed, the decrease in the feed speed significantly affects the surface roughness. As shown in Fig. 4b when using speed are increasing surface roughness was reached slightly better value. But as the feed rate decreases, the surface roughness value appears to increase significantly.

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

Factors		Level 1	Level 2	Level 3	Optimum level
A	Number of passes	6.441	7.252	-	2
B	Burnishing Force (N)	5.586	6.995	7.958	3
C	Burnishing Speed (rpm)	7.189	6.581	6.769	1
D	Feed rate (mm/min)	8.616	7.007	4.915	1

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

Parameter code	Degrees of freedom	Sum of squares	Mean squares	% Contribution
A	1	2.955	2.9547	4,48
B	2	17.075	8.5373	25.91
C	2	1.162	0.5811	1.76
D	2	41.325	20.6623	62.71
Error	10	3.377	0,3377	
Total	17	65.894		

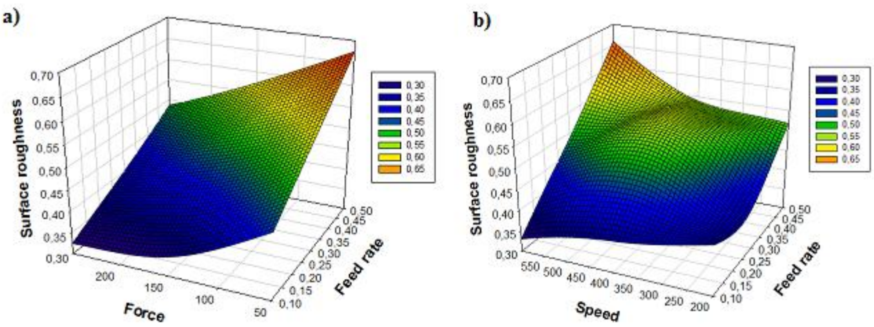

Fig. 4 a) Effect of burnishing force and burnishing feed rate on surface roughness b) Effect of burnishing speed and burnishing feed rate on surface roughness

As a result of the experiments; when the number of passes is increased from 1 to 2, the surface roughness value decreases. The same results are also seen in the work done by Revankar et. al [14]. When the burnishing force increases from 50 N to 250 N, the burnishing process occurs at a lower surface roughness. The reason for this is the increase in pressure on the surface between the sample and the ball. Therefore, the plastic deformation zone expands and the metal diffusion increases to fill the cavity on the sample. [25-28]. As the speed level increases, the surface roughness decrease with temperature and vibration effects, the speed raising beyond a certain limit can affect the metal flow on the sample, causing the surface roughness to increase. [29]. Surface roughness advance the increasing feed rate was caused decreasing on surface roughness. Lower feed rates are chosen because the deforming effect of the burnishing tool is greater and the metal flow is steady. [30]. The recovery of the deformation due to increase in metal flow and cause the filling of the cavity in the workpiece. [25].

IV. CONCLUSION

In this paper, effecting of burnishing parameter like feed rate, force, speed and number of passes on surface roughness of AZ31B Mg alloys was studied. Conclusions from present study are given below;

- As a result; burnishing force and feed rate parameters were found to be significantly effective on surface roughness. Increasing the number of passes improves the surface roughness value to a small extent and does not have a significant effect on the surface roughness of the burnishing speed. The raise in burnishing force was enhanced surface roughness. The lower level of feed rate was reached better surface roughness.

- In our experiments, the best surface roughness value was obtained at two passes as a number of passes, 250 N burnishing force, 200 rpm burnishing speed and 0.1 mm/min feed rate settings.

- The analysis of variance (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 (4.48%), burnishing force (25.91%) and feed rate (62.71%) 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 94.87%. tool bar.

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