IOP Conf. Series: Materials Science and Engineering **397** (2018) 012114 doi:10.1088/1757-899X/397/1/012114

Experimental research on surface roughness of milling medical magnesium alloy

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Abstract. Magnesium alloy is more suitable for biomedical metal material compared with traditional metal materials, as it has the similar mechanical properties with human bone and biodegradable property.Surface roughness influences the friction and ware properties, corrosion resistance and fatigue resistance, then the service life of parts. It is important to search the influence of magnesium alloy milling process on surface roughness as a certain connection exists between roughness and corrosion resistance. In this paper, the influence of cutting speed, feed, axial and radial depth of cut on surface roughness had been analyzed after the orthogonal milling experiments. Finished surface roughness model had been established and verified.

1. Introduction

Magnesium and its alloys have attracted great interest for biomedical applications, because of its good mechanical and biodegradable properties [1-3].

In view of the mechanical properties and corrosion resistance of magnesium calcium alloys, a series of studies have been carried out by domestic and foreign scholars. These results show that [4-6], the mechanical and corrosion resistance and biocompatibility of magnesium calcium alloy materials are changed by controlling the content of Ca elements to improve the structure of the alloy.

Cutting is one of the most widely used processing methods for the mechanical industry in a very long period of time and in the future. The cutting process and cutting tools should not only improve the efficiency of production, realize high quality processing, but also make the parts get higher surface quality[7-9].As a degradable medical metal material, the surface roughness of magnesium calcium alloy is very important to its service life. Therefore, it is of great significance to study the influence of the milling process of magnesium calcium alloy on the surface roughness.

2. Experimental Conditions

Milling experiment was processed by YCM-V116B type vertical machining canter. Experimental material was self-made magnesium and calcium alloy (MgCa0.8) extruded by the process of extrusion ratio 8.1, extrusion temperature 250°C, extrusion speed 10mm/s. The tensile strength of the alloy was 212.71MPa, bending strength 379.2MPa, and Poisson’s ratio 0.327. Work pieces were cuboids with the dimension of 35×35×40mm.

Usually tools with large rake and rear angles were chosen in cutting process, as magnesium alloy was easy to cut with low energy consumption and high quality of finished surface. SEEX1204AFN-E08, H25 blade (carbide with no coating) and R220.53-0050-12-4A cutter head of SECO were chosen in this paper. The parameters of the blade and cutter head are listed in Table 1 and Table 2.

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Table 1. Parameters of blade

Blade shape	Material	Rake/°	Rear/°	Cutting edge angle/°	Radius of tool nose /mm	Radius of cutting edge/mm	Coating
Square	Carbide	25	20	45	1.6	0.04	No

Table 2. Parameters of cutter head

Type	Cutter head /mm	Axial rake/°	Radical rake/°
Face milling cutter	50	20	-5

3. Experiment Plan

The influence of parameters cutting speed, feed rate, axial and radial depth of cut on finished surface roughness were examined in the experiment, in which several levels of each parameter were selected. Orthogonal test that could avoid cumbersome single factor experiment and easily summarize regular conclusion was applied. A single blade was equipped to avoid the impact of spindle rotation accuracy.

Table 3. Orthogonal plan of milling experiment

Experiment No.	v_c/m·min-1	f_z/mm·z-1	a_p/mm	a_e/mm
1	500	0.05	3	6
2	500	0.13	4.5	15
3	500	0.21	6	9
4	500	0.29	7.5	12
5	650	0.05	4.5	12
6	650	0.13	3	9
7	650	0.21	7.5	15
8	650	0.29	6	6
9	800	0.05	6	15
10	800	0.13	7.5	6
11	800	0.21	3	12
12	800	0.29	4.5	9
13	950	0.05	7.5	9
14	950	0.13	6	12
15	950	0.21	4.5	6
16	950	0.29	3	15

High cutting speed and feed rate could be used as magnesium alloy was easy to cut. Four levels of each parameter were selected in experiment: v_c: 500, 650, 800, 950m/min; f_z: 0.05, 0.13, 0.21, 0.29mm/z; a_p: 3, 4.5, 6, 7.5mm; a_e: 6, 9, 12, 15mm. L16 (4^5) orthogonal table was selected. Table 3shows the experiment plan with experimental parameters and levels in.

4. Measurement and Analysis of Surface Roughness

4.1. Surface Roughness Measurement

Mitutoyo SJ-410 portable surface roughness meter showed in figure 1 was used to measure for finished surface. The equipment could measure sorts of roughness parameters, such as *Ra*, *Rq*, *Rz*, *Ry*, *Rp*, *Rv* and so on. Value Ra was the arithmetic average of five measurements that were randomly selected on finished surface perpendicular to the direction of feed.

Figure 1. Mitutoyo SJ-410 surface roughness meter

4.2. Analysis of Roughness Data

The range analysis of surface roughness of milling and inverse milling process are listed in Table 4, from which the influence of cutting parameters on finished surface roughness in milling process was obtained as the order: feed rate, radial depth of cut, cutting speed, axial depth of cut, slightly different from the order: feed rate, cutting speed, radial and axial depth of cut in inverse milling process. Figure 2displays the roughness obtained in the two processes. From the picture it was found that the trends of roughness change in two milling processes were similar and the values obtained in inverse milling were smaller. In milling process, cutting thickness and chip deformation reduced in each turn and cutting force reduced as well. Large cutting force brought impact and vibration at the beginning of cutting, which resulted large roughness. On the contrary, cutting thickness and force increased gradually in inverse milling, which made the cutting process relatively smooth. The fraction between tool flank face and elastic recovery layer reduced the residual cutting area. The two factors made the roughness small.

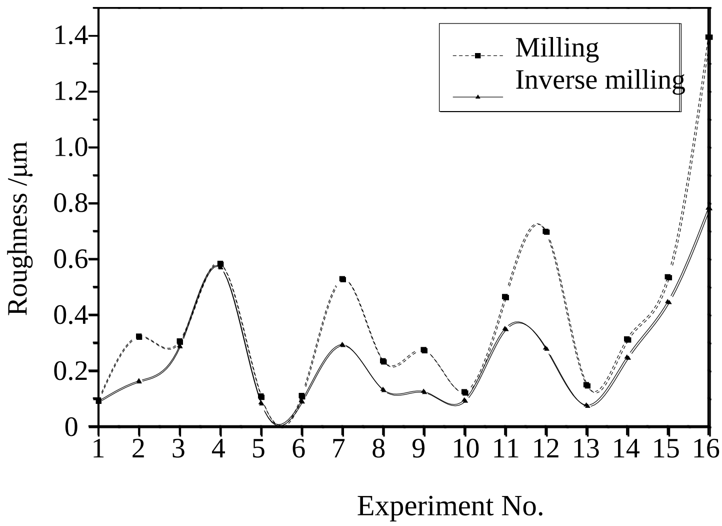

Figure 2. Roughness of milling and inverse milling

Table 4. Range analysis of surface roughness

Experiment No.		ACutting speed v_c/m·min^{-1}	B Feed f_z/mm·z^{-1}	C Axial depth of cut a_p/mm	D Radial depth of cut a_e/mm	Milling roughness R_a/μm	Inverse milling roughness R_a/μm
1		500	0.05	3	6	0.093	0.089
2		500	0.13	4.5	15	0.322	0.162
3		500	0.21	6	9	0.305	0.288
4		500	0.29	7.5	12	0.583	0.570
5		650	0.05	4.5	12	0.107	0.083
6		650	0.13	3	9	0.109	0.090
7		650	0.21	7.5	15	0.528	0.292
8		650	0.29	6	6	0.234	0.131
9		800	0.05	6	15	0.274	0.124
10		800	0.13	7.5	6	0.123	0.093
11		800	0.21	3	12	0.464	0.349
12		800	0.29	4.5	9	0.698	0.279
13		950	0.05	7.5	9	0.148	0.075
14		950	0.13	6	12	0.312	0.247
15		950	0.21	4.5	6	0.535	0.446
16		950	0.29	3	15	1.395	0.781
Milling roughness	K1	1.303	0.622	2.061	0.985		
	K2	0.978	0.866	1.662	1.260		
	K3	1.559	1.832	1.125	1.466		
	K4	2.390	2.910	1.382	2.519		
	K1	0.326	0.156	0.515	0.246		
	K2	0.245	0.217	0.416	0.315		
	K3	0.390	0.458	0.281	0.367		
	K4	0.598	0.728	0.346	0.630		
	Range	0.353	0.572	0.234	0.384		
	Factors	Order	B, D, A, C				
Inverse milling roughness	K1	1.109	0.371	1.309	0.759		
	K2	0.596	0.592	0.970	0.732		
	K3	0.845	1.375	0.790	1.249		
	K4	1.549	1.761	1.030	1.359		
	K1	0.277	0.093	0.327	0.190		
	K2	0.149	0.148	0.243	0.183		
	K3	0.211	0.344	0.198	0.312		
	K4	0.387	0.440	0.258	0.340		
	Range	0.238	0.348	0.130	0.150		
	Factors	Order	B, A, D, C				

Table 5. Variance analysis of milling roughness

Source	SS	df	MS	F	Sig.
Cutting speed (A)	0.273	3	0.091	3.657	*
Feed rate (B)	0.814	3	0.271	10.894	**
Axial depth of cut(C)	0.121	3	0.040	1.613	
Radial depth of cut(D)	0.337	3	0.112	4.511	*
Error (e)	0.075	3			
Total	1.620	15			

Table 6. Variance analysis of inverse milling roughness

Source	SS	df	MS	F	Sig.
Cutting speed (A)	0.125	3	0.042	2.500	
Feed rate (B)	0.320	3	0.107	6.422	**
Axial depth of cut(C)	0.035	3	0.012	0.697	
Radial depth of cut(D)	0.080	3	0.027	1.598	
Error (e)	0.050	3			
Total	1.620	15			

The variance analysis of milling and inverse milling roughness are shown in Table 5 and Table 6 respectively. When the confidence degree were 95% and 99% and degree of freedom were 3 and 15, the critical values $F_{0.05}$ (3, 15) =3.29, $F_{0.01}$ (3, 15) =5.42. The F values in the table indicated the influence of responding factor on roughness. In milling and inverse milling processes, feed rate had the largest influence but axial depth of cut smallest, and influence of cutting speed and radial depth of cut was different in the two milling processes, consistent with the result of range analysis.

4.3. Establishment of surface roughness model

Surface roughness exponential regression model as follows was the relationship between roughness and cutting parameters when the machine system and tool geometry parameters were determined.

$$Ra = C_0 {v_c}^{b_1} f_z^{b_2} a_p^{b_3} a_e^{b_4} \tag{1}$$

In the formula, C_0 was coefficient determined by work piece materials and cutting condition. b_1, b_2, b_3 and b_4 were indexes.

Roughness experimental formula could be established after exponential transformation to formula 2.

$$Ra = e^{\beta_0} {v_c}^{\beta_1} f_z^{\beta_2} a_p^{\beta_3} a_e^{\beta_4} \tag{2}$$

Significance test was carried on and measured values obtained in verifying tests were compared to predicted values obtained by experimental formula to test the accuracy of the formula.

Significance test results of regression formula and its coefficients of milling roughness are listed in Table 7 and Table8. In the test for regression formula, the confidence degree was 99% and number of independent variables m=4 and number of experiment n=16, so the critical value F_α(m,n-1)= $F_{0.01}$(4,15)=4.89 from checking upper quantile table of F, smaller than that 11.308 in table 3.7. Linear correlation coefficient critical value R_α(m,n-m-1)=$R_{0.01}$(4,11)=0.821 was obtained by checking table on the conditions α=0.01,m=4,n=16. The value 0.897 resulted in tests was bigger than critical value 0.821. The values of R and F indicated that the regression formula had high significance.

Table 7. Significance test for milling roughness regression formula

R2	F	P	Critical value of F	Critical value of R
0.804	11.308	0.001	$F_{0.01}$(4,15)=4.89	$R_{0.01}$(4,11)=0.821

Table 8. Significance test for milling roughness regression formula coefficients

Model	Coefficient	Std. error	t	Sig.
Constant	-7.091	2.903	-2.443	0.033
lnv_c	0.821	0.422	1.947	0.078
lnf_z	0.839	0.152	5.511	0.000
lna_p	-0.077	0.295	-0.262	0.798
lna_e	0.978	0.295	3.317	0.007

In the significance test for regression formula coefficient, t meant partial regression coefficient, the bigger the absolute values were, the more significant the corresponding partial regression coefficients were, and corresponding factors were more influent. In Table 8, it could be found that the order of cutting parameters' influence on roughness was feed rate, radial depth of cut, cutting speed, axial depth of cut, which matched the results of range analysis and variance analysis, indicating the regression analysis was reliable.

Milling roughness predicting formula was resulted from content above.

$$Ra = e^{-7.091} v_c^{\ 0.821} f_z^{\ 0.839} a_p^{-0.077} a_e^{0.978} \qquad R^2 = 0.804 \tag{3}$$

Table 9 and Table 10 are listed the significance test for inverse milling roughness regression formula and its coefficients.

Table 9. Significance test for inverse milling roughness regression formula

R^2	F	P	Critical value of F	Critical value of R
0.852	7.274	0.004	$F_{0.01}(4,15)=4.89$	$R_{0.01}(4,11)=0.821$

Table 10. Significance test for inverse milling roughness regression formula coefficients

Model	Coefficient	Std. error	t	Sig.
Constant	-3.986	3.288	-1.212	0.251
lnvc	0.410	0.478	0.859	0.409
lnfz	0.838	0.172	4.859	0.001
lnap	-0.189	0.334	-0.566	0.583
lnae	0.703	0.334	2.105	0.059

Roughness predicting formula:

$$Ra = e^{-3.986} v_c^{\ 0.410} f_z^{\ 0.838} a_p^{-0.189} a_e^{0.703} \qquad R^2 = 0.852 \tag{4}$$

Critical value of F 4.89 was smaller than that 7.274 obtained in the test and critical value of R 0.821 was smaller than that 0.923 in table 3.9, resulting that the regression had high significance. In Table 10, it could be found that the order of cutting parameters' influence on roughness was feed rate, radial depth of cut, cutting speed, axial depth of cut.

5. Conclusion

Orthogonal test for milling MgCa0.8 alloy was carried in this chapter and surface roughness data obtained by milling and inverse milling processes was dealt and summarized, conclusions were as follows:

(1) Roughness obtained in inverse milling process was smaller in the same cutting parameters.

(2) Partial regression coefficients in range analysis and variance analysis were compared and the orders of cutting parameters influence on roughness were feed rate, radial depth of cut, cutting speed, axial depth of cut in milling process and feed rate, cutting speed, radial depth of cut, axial depth of cut in inverse milling process.

(3) Linear regression method was used to fit the formula of influence of cutting parameters on roughness, and exponential models were established and significance tested. Measured values in verifying test were similar to real roughness. To a certain extent, exponential regression model could predict roughness.

Acknowledgments

This work was supported by Taishan Scholar Engineering Special Funding, the Development Program of Science and Technology of Shandong (2017GGX30143), and Shandong Natural Science Foundation of China (ZR2017LEE015).

IOP Conf. Series: Materials Science and Engineering **397** (2018) 012114 doi:10.1088/1757-899X/397/1/012114

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