Analysis of Surface Roughness Parameters in Aluminium Fine Turning with Diamond Tool

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Abstract. *Machining of aluminium parts has become particularly important in recent years. Aluminium alloys are increasingly used in automotive, aerospace and defence industries due to the advantageous mechanical and chemical properties. In technology planning, the average surface roughness is as important criterion as geometrical size or tolerance. In this paper, machinability of an AlMgSi alloy with a diamond tool is examined by design of experiments. An empirical relation is established between the surface roughness and the cutting parameters.*

Keywords: Fine Turning, Surface Roughness Measurement, Design of Experiments, RSM Method

1. Introduction

Surface roughness measurements are essential in characterization of the features of a machined surface. To examine the effect of cutting parameters on surface roughness thoroughly, a huge number of experiments are needed, depending on the number of parameters. By utilizing the method of design of experiments (DoE), the number of experiments can be reduced in such a way that the effect of parameters could be assessed appropriately. If linear effects of cutting parameters are considered, then fractional factorial design is sufficient, but to examine the quadratic term, RSM method has to be utilized [1].

DoEs are often employed in cutting research. Aouchi et al. [2] and M. Y. Noordin et al.[3] examined hard turning with a CBN and hard metal tool and the resulting surface with the help of DoE. Asiltürk et al. [4] examined stainless steel turning with coated hard metal tools. Dry, wet, and MQL turning was examined with the help of DoE by Young Kug Hwang [5]. M. Harničárová et al. studied the topography of laser-cut surfaces [6]. Lazarevic, D. et al. examined the surface roughness of engineering polymers by using Taguchi method [7].

In this study, cutting parameters and surface roughness parameters were correlated to determine the relationship between them in case of aluminium fine turning. Our goal was to create a mathematical model that can be easily used in technology planning to estimate the expected values of surface roughness. In this paper, the dependence of the *Ra* parameter on cutting parameters will be described.

2. Subject and Methods

Workpiece and tool materials

Turning experiments were performed in dry conditions using CNC lathe type NCT EUROTURN 12B, with 7 kW spindle power and 6000 1/min rotation speed. The workpiece material was AS17, frequently used in automotive, aerospace and defence industries. The chemical composition (in wt.%) is: Al = 74.35 %; Si = 20.03 %; Cu = 4.57 %; Fe = 1.06%. The hardness of the workpiece was 114 $HB_{2,5/62,5/30}$. The examined part was a cylinder with a diameter of 110 mm. The experimental runs were made every 10 mm.

The standard designation of the used tool was DCGW 11T304 FN (CVD-D) and it was manufactured by TiroTool. The holder of the tool was codified as SDJCR 1616H 11. The average surface roughness value (*Ra*) was measured by a Mitutoyo SJ-301 surface roughness tester. Parameters related to surface roughness measurement were: $l=4$ *mm*, $\lambda_c=0.8$, $N=5$. The measurements were repeated three times at three reference lines equally positioned at 120° and the result was the average of these values.

Experimental design

Response surface methodology (RSM) is a procedure which is able to determine a relationship between independent input process parameters (e.g. cutting parameters) and output data (process response, e.g. *Ra*). In the current study, the relationship between the input parameters, as the cutting conditions (cutting speed (v_c, m/min), feed rate (f, mm), depth of cut (a, mm), and the output parameters, defined as the machinability aspect (*Ra*) which is given as:

$$Ra = \Omega(v_c, f, a) \tag{1}$$

where Ω is the response function.

The approximation of *Ra* is proposed by using the following equation which consist of linear and quadratic effects of the input parameters and their interactions as well:

$$Ra = b_0 + b_1 \cdot v_c + b_2 \cdot f + b_3 \cdot a + b_{11} \cdot v_c^2 + b_{22} \cdot f^2 + b_{33} \cdot a^2 + b_{12} \cdot v_c \cdot f + b_{13} \cdot v_c \cdot a + b_{23} \cdot f \cdot a + \varepsilon \tag{2}$$

where $b_i s$ are the calculated coefficients, v_c, f and a are input parameters, and ε is the experimental error.

In the course of design of experiments, a response surface method was chosen, the central composite design (CCD) method. CCD was set up for three controllable factors: cutting speed (v_c), feed rate (f) and depth of cut (a). Each factor had 5 different levels. The number of experimental runs was 16, in which two trials were examined in the centre of the design.

The limits of the studied cutting parameters are set so that they meet the values used by industries currently and so that they should meet the requirement of high speed cutting (HSC) applications as well. Taking these into consideration the chosen limits of cutting parameters are summarized in Table 1.

Table 1. The limits of used cutting parameters.

v_{cmin} =500 m/min	v_{cmax} = 2000 m/min
f_{min}= 0.05 mm	f_{max} = 0.12 mm
a_{min} = 0.2 mm	a_{max}= 0.8 mm

3. Results

Values of input parameters and the response factor, as a surface roughness component are shown in Table 2. Surface roughness was obtained in the range of 0.47 and 1.77 µm. The calculated standard deviation of *Ra* related to measurement error and inhomogeneity of the surface of the examined part was 0.126 µm.

Table 2. Input parameters of experimental runs and the measured surface roughness values.

	Machining parameters			Response factor			
Runs	**v_c, m/min**	**f, mm**	**a, mm**	**Ra_1, µm**	**Ra_2, µm**	**Ra_3, µm**	**$Ra_{average}$, µm**
1	667	0.058	0.267	0.47	0.48	0.48	0.477
2	667	0.058	0.733	0.62	0.51	0.35	0.493
3	667	0.112	0.267	1.06	1	1.03	1.030
4	667	0.112	0.733	1.55	1.44	1.54	1.510
5	1833	0.058	0.267	0.41	0.51	0.6	0.507
6	1833	0.058	0.733	0.7	0.58	0.67	0.650
7	1833	0.112	0.267	0.96	1.01	1	0.990
8	1833	0.112	0.733	1.34	1.23	1.31	1.293
9	500	0.085	0.5	0.98	1.05	1.1	1.043
10	2000	0.085	0.5	0.8	1.01	1.03	0.947
11	1250	0.05	0.5	0.55	0.48	0.49	0.507
12	1250	0.12	0.5	1.72	1.75	1.85	1.773
13	1250	0.085	0.2	0.82	0.82	0.91	0.850
14	1250	0.085	0.8	0.84	0.85	0.85	0.847
15 (C)	1250	0.085	0.5	0.76	0.9	0.86	0.840
16 (C)	1250	0.085	0.5	0.83	0.83	0.85	0.837

4. Statistical analysis

Statistical analysis was employed to determine the relation between the individual measured values of surface roughness and the cutting parameters. Results of variance analysis are shown in Table 3. In the second column, the calculated coefficient (b_is) of Eq (2) are shown. It is obvious, that several factors have a large impact on the measurement results like f^2, a^2, v_c·f, and f·a. The estimated model describes well the measurement points since the value of R^2 is near 90%.

Table 3. Analysis of variance of the measuring points

```
Term                               Coef  SECoef       T      P
Constant                         -0.067  0.4537  -0.147  0.884
Vc [m/perc]                       0.000  0.0003   1.311  0.198
f [mm]                           -5.007  8.0181  -0.624  0.536
a [mm]                            1.223  0.7374   1.659  0.105
Vc [m/perc]*Vc [m/perc]          -0.000  0.0000  -0.398  0.693
f [mm]*f [mm]                   102.111 43.5245   2.346  0.024
a [mm]*a [mm]                    -1.862  0.5890  -3.162  0.003
Vc [m/perc]*f [mm]               -0.004  0.0017  -2.091  0.043
Vc [m/perc]*a [mm]               -0.000  0.0002  -0.236  0.815
f [mm]*a [mm]                    12.385  4.2124   2.940  0.006

S = 0.129823   PRESS = 1.00648
R-Sq = 89.90%  R-Sq(pred) = 84.13%  R-Sq(adj) = 87.51%
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The model can be simplified by only considering effects of the significant parameters. By keeping the main factors (v_c, f, a), the equation can be reduced by avoiding other non-significant parameters. This leads to the equation of the reduced model:

$$
\begin{aligned}
Ra_{predicted} &= 0.01236 + 0.0002698 \cdot v_c - 5.023 \cdot f + 1.166 \cdot a + \\
&+ 102.206 \cdot f^2 - 1.862 \cdot a^2 - 0.003521 \cdot v_c \cdot f + 12.385 \cdot f \cdot a
\end{aligned} \tag{3}
$$

The goodness of correlation is of the reduced model is R^2=89.84%. Residual analysis shows that the residuals are normally distributed and random, therefore the estimated model is adequate. The reduced model equation is plotted in Fig. 1. Dependence of Ra on cutting speed is quite small, but the feed rate has a great impact on the resulting roughness. With this method, a simple relationship can be established between the surface roughness and the cutting parameters within the examined parameter range, which is beneficial in planning of fine turning processes.

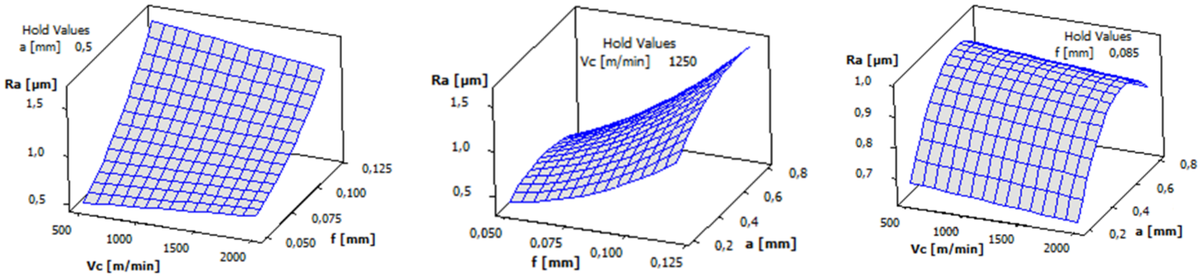

Fig. 1. Representation of built-up model plotted against cutting parameters.

5. Conclusions

In this paper, the influence of cutting parameters (v_c,f, a) were examined in case of fine turning of a cylinder of AS17 alloy with a CVD-D tool. A reduced empirical equation was built up to describe the examined function. In case of technology planning the equation obtained is suitable for estimating the required average surface roughness easily, and for specifying the ranges of optimal cutting parameters. To compare the estimated values with the measured values, it can be stated that a good agreement has been achieved. Additionally, this study shows which factors (cutting parameters) have a significant effect on average surface roughness. Further examinations of the other surface roughness parameters as well as those of different tool materials and geometries are needed to examine their machinability.

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