G. KROLCZYK, S. LEGUTKO, M. GAJEK

ISSN 0543-5846
METABK 52(2) 259-262 (2013)
UDC – UDK 669.15:621.773:621.9.015=111

PREDICTING THE SURFACE ROUGHNESS IN THE DRY MACHINING OF DUPLEX STAINLESS STEEL (DSS)

Received – Prispjelo: 2012-06-17
Accepted – Prihvaćeno: 2012-10-25
Preliminary note – Prethodno priopćenje

This paper examines the influence of cutting parameters, namely cutting speed, feed and depth of cut onto surface roughness after DSS turning process. The study included developing a mathematical model to determine the surface roughness. Verification research has been carried out on CNC lathe; hence the test plan has been adjusted to the possibility of programmable machines controlling GE Fanuc Series 0-T. The comparison of results obtained by given experimental plan was performed in industrial company.

Key words: Duplex Stainless Steel, dry machining, surface roughness, response surface method (RSM)

INTRODUCTION

Duplex stainless steel is gaining importance according to companies producing construction materials. It is reflected in the wide range of these products available in the market. According Olszak [1] DSS is classified as almost unworkable. The wear process of tool wedges, which is largely dependent on cutting parameters, is an important factor. Investigation performed by Alauddin et al. [2] has revealed that when the cutting speed is increased, productivity can be maximised and surface quality can be improved. The wear of the cutting tool wedge leads to a deterioration in quality of the machined surface, and in the most commonly used surface roughness parameter in production which is the arithmetic average deviation from the average line profile. Surface finish can be characterised by various parameters and mostly such as surface roughness *Ra* [3]. The basic requirement in the application of indexable tool inserts in industrial conditions is the total increase in production; not the precision performance of its particular machine parts. According to Smith [4], where the equipment stocks are consolidated and the materials used in cutting tools are more universal, we can, in industrial conditions, use a smaller number of types and geometry of the cutting tool. Smaller stocks of indexable tool inserts allow us to more effectively optimize the production process. The above-mentioned aspects, combined with the optimization of the cutting speed, feed and depth of cut, allow the desired production targets to be met. Due to an optimization of the cutting parameters, it is possible to take full advantage of the basic equipment; as a result you can expect a large increase in overall production efficiency. In order to know surface quality and dimensional properties is necessary to employ theoretical models making it feasible to do predictions in function

Table 1 **Chemical composition of 1.4462 duplex stainless steel /wt %**

C_{max}	Si_{max}	Mn_{max}	P_{max}	S_{max}	Cr	Ni	Mo	N
0,03	1	2	0,03	0,02	21 - 23	4,5 - 6,5	2,5 - 3,5	0,1 -0,22

Table 2 **Cutting tool specification**

Tool	Substrate	Others
T1	Hardness: 1 350 HV3 Grade: M25, P35	Coatings: Ti(C,N) - (2 μm) (top layer) Al_2O_3 - (1,5 μm) (middle layer) TiN - (2 μm) (bottom layer) Coating technique: CVD

Table 3 **Coded indication of the study plan**

Test No.	Coded factors			Decoded real value		
	x_1	x_2	x_3	v_C	f	a_p
1	-1	-1	-1	70	0,24	1,4
2	-1	-1	+1	70	0,24	2,6
3	-1	+1	-1	70	0,36	1,4
4	-1	+1	+1	70	0,36	2,6
5	+1	-1	-1	130	0,24	1,4
6	+1	-1	+1	130	0,24	2,6
7	+1	+1	-1	130	0,36	1,4
8	+1	+1	+1	130	0,36	2,6
9	-1,682	0	0	50	0,3	2
10	1,682	0	0	150	0,3	2
11	0	-1,682	0	100	0,2	2
12	0	1,682	0	100	0,4	2
13	0	0	-1,682	100	0,3	1
14	0	0	1,682	100	0,3	3
15	0	0	0	100	0,3	2
16	0	0	0	100	0,3	2
17	0	0	0	100	0,3	2
18	0	0	0	100	0,3	2
19	0	0	0	100	0,3	2
20	0	0	0	100	0,3	2

G. Krolczyk, M. Gajek, Opole University of Technology, Department of Technology and Work Environment Engineering, Opole, Poland, S. Legutko, Poznan University of Technology, Institute of Mechanical Technology, Poznan, Poland

of operation conditions. The response surface method (RSM) is practical, economical and relatively easy for use [5]. The experimental data was utilized to build mathematical model for second-order model. This method has been used by some researchers for determination of tool life and surface roughness [3, 6–10]. Taraman [6], Hasegawa et al. [3], Sundaram and Lambert [7] used the RSM for predicting surface roughness. Baradie [8], Mital and Mehta [9], Kopac et al. [10] investigated the use of RSM in developing a surface roughness prediction model.

EXPERIMENTAL TECHNIQUES

Workpiece and cutting tool materials

Machined material was 1.4462 (DIN EN 10088-1) steel with a ferritic-austenitic structure containing about 50 % of austenite. The ultimate tensile strength R_m = 700 MPa, Brinell hardness - 293 HB. The elemental composition of the machined material and technical details of the cutting tools are given in Tables 1 and 2 respectively. Cutting tool inserts of TNMG 160408 designation clamped in the tool shank of ISO-MTGNL 2020-16 type were employed. Based on the industry recommendations a range of cutting parameters T1: v_c = 50 - 150 m/min, f = 0,2 - 4 mm/rev, a_p = 1 - 3 mm was selected. The study was conducted within a production facility. The research program was carried out on a lathe CNC 400 Famot – Pleszew.

Research plan

The static determined selective-multivariate uniform static - rotatable PS/DS-P:λ program as the method of optimization for DSS cutting parameters has been selected [11]. A choice of the PS/DS-P:λ program was dictated with the assumption that the second-degree polynomial function model will be a nonlinear model which can be reduced to a linear model. The second-degree polynomial function has been chosen because there are no restrictions in research related to the measurement technique. The required number of experimental points is $N = 2^3 + 6 + 6 = 20$ (Table 3). There are eight factorial experiments (3 factors on two levels, 2^3) with added 6 star points and centre point (average level) repeated 6 times to calculate the pure error [12].

Table 4 **Verified research parameters of the model of surface roughness**

Cutting parameters			Average value of research *Ra* /µm	Calculation results *Ra* /µm
v_C/ m/min	f/mm/rev	a_p/mm		
150	0,2	2	1,92	0,90
150	0,4	2	6,49	6,50
50	0,2	2	1,65	1,47
50	0,4	2	5,89	6,11

MODELING OF SURFACE ROUGHNESS AND ITS VERIFICATION

The aim of this study was an attempt to verify, in industrial conditions, the calculated value of the function describing surface roughness after turning DSS. The study was conducted in industrial conditions. Chosen results are presented in Table 4.

Surface roughness model

Based on the PS/DS-P:λ program and the experimental data the polynomial function of surface roughness has been elaborated:

$$
\begin{aligned}
Ra = &- 1{,}7163 - 0{,}013259 \cdot v_C + 27{,}5189 \cdot f - \\
&- 1{,}4311 \cdot a_p - 0{,}000056162 \cdot v_C^2 - \\
&- 15{,}9793 \cdot f^2 + 0{,}11521 \cdot a_p^2 + \\
&+ 0{,}047667\, v_C \cdot f + 0{,}0046265\, v_C \cdot a_p + \\
&+ 1{,}4583\, f \cdot a_p. \qquad (1)
\end{aligned}
$$

Verification study of model

The evaluation of the mathematical model was performed using the Student's *t* test to compare two mean values of populations with normal distributions and homogeneous variances. Statistical calculations were performed with the Statistica 9.0 program [13].

The assumptions of normality were examined using the Shapiro - Wilk test for the model of surface roughness (Table 5).

Table 5 **Tests of normality for the model of surface roughness**

Variable	n	W	p
Average value of research	4	0,8100	0,1215
Calculation results	4	0,8070	0,1154

As the level of significance of p is greater than 0,05 for the test case, there is no reason to reject the hypothesis of normal distribution.

Homogeneity of variances was checked by Fisher test. Two general populations has been examined with normal distributions $N(m_1, \sigma_1)$ and $N(m_2, \sigma_2)$, where the parameters of these distributions are unknown. There were two sample sizes $n_1 = 4$ and $n_2 = 4$. On the basis of test results the hypothesis was tested H_0: $\sigma_1^2 = \sigma_2^2$, against the alternative hypothesis H_1: $\sigma_1^2 \neq \sigma_2^2$. The results of the calculations for the model of surface roughness are presented in Table 6.

Table 6 **The results of F-statistic model calculation for surface roughness**

F	1,3482
p	0,8118

Because p is greater than 0,05 there is no reason to reject the hypothesis of homogeneity of variances for each of the cases.

We subsequently studied two populations having normal distributions $N(m_1, \sigma_1)$ and $N(m_2, \sigma_2)$, standard deviations are unknown, but equal, i.e. there is $\sigma_1 = \sigma_2$. Based on two sample sizes $n_1 = 4$ and $n_2 = 4$ we verified the hypothesis H_0: $m_1 = m_2$ against the alternative hypothesis H_1: $m_1 \neq m_2$. We calculated the average values from both samples $\overline{x_1}$ and $\overline{x_1}$ and variances s_1^2 and s_2^2, then the value of t statistics according to the following formula:

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{n_1 s_1^2 + n_2 s_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \qquad (2),$$

The calculation results are presented in Table 7.

Table 7 **The results of t-statistic model calculations for surface roughness**

t	0,1237
p	0,9055

The significance level of p for the tested models is greater than 0,05 which means there is no reason to reject the hypothesis of equal averages. Therefore, it is shown on the significance level of 0,05, that the average value of research and the model are not significantly different. It can therefore be concluded that the designated model reflects changes in surface roughness represented by the empirical values.

CONCLUSIONS

The purpose of this article was to develop a methodology which can offer the possibility of predicting the surface roughness in the turning process of duplex stainless steel. Predicting the required parameter of surface roughness *Ra* in the process of dry machining is an important part of the process and impact of such conditions on the technological properties of the surface layer. Tables 8 - 10 shows results (values) of the surface roughness of *Ra*, depending on the technological cutting parameters in the turning process of duplex stainless steel.

Factorial design of an experiment can be successfully employed using coated carbide cutting tools in turning the DSS. The following conclusions have been drawn:

Table 8 **Values of surface roughness according to *Ra* for *Ra* = *f*(a_p) for v_c = 50 - 150 m/min and *f* = 0,2 - 0,4 mm/rev obtained for the depths of cutting a_p = 1 mm, a_p = 2 mm, a_p = 3 mm**

No	v_c	*f*	*Ra*(a_p=1)	*Ra*(a_p=2)	*Ra*(a_p=3)
1	50	0,2	2,029	1,466	1,134
2		0,3	4,366	3,949	3,763
3		0,4	6,383	6,112	6,072
4	100	0,2	1,653	1,321	1,221
5		0,3	4,228	4,043	4,088
6		0,4	6,484	6,444	6,635
7	150	0,2	0,996	0,896	1,026
8		0,3	3,809	3,855	4,132
9		0,4	6,304	6,495	6,918

Table 9 **Values of surface roughness according to *Ra* for *Ra* = *f*(v_c) for *f* = 0,2 - 0,4 mm/rev and a_p = 1 - 3 mm obtained for the cutting speed v_c = 50 m/min, v_c = 100 m/min, v_c = 150 m/min**

No	*f*	a_p	*Ra*(v_c=50)	*Ra*(v_c=100)	*Ra*(v_c=150)
1	0,2	1	2,029	1,653	0,996
2		2	1,466	1,321	0,896
3		3	1,134	1,221	1,026
4	0,3	1	4,366	4,228	3,809
5		2	3,949	4,043	3,855
6		3	3,763	4,088	4,132
7	0,4	1	6,383	6,484	6,304
8		2	6,112	6,444	6,495
9		3	6,072	6,635	6,918

Table 10 **Values of surface roughness according to *Ra* for *Ra* = *f*(*f*) for v_c = 50 - 150 m/min and a_p = 1 - 3 mm obtained for the feed *f* = 0,2 mm/rev, *f* = 0,3 mm/rev, *f* = 0,4 mm/rev**

No	v_c	a_p	*Ra*(*f*=0,2)	*Ra*(*f*=0,3)	*Ra*(*f*=0,4)
1	50	1	2,029	4,366	6,383
2		2	1,466	3,949	6,112
3		3	1,134	3,763	6,072
4	100	1	1,653	4,228	6,484
5		2	1,321	4,043	6,444
6		3	1,221	4,088	6,635
7	150	1	0,996	3,809	6,304
8		2	0,896	3,855	6,495
9		3	1,026	4,132	6,918

1. Second-order model predicting equations for surface roughness have been developed using response surface methodology for turning the DSS with coated tools.
2. The established equations clearly show that the feed rate was main influencing factor on the surface roughness. Surface roughness increased with increasing the feed rate.
3. The predicted values and measured values are fairly close which indicates that the developed surface roughness prediction model can be effectively used to predict the surface roughness for the turning process. Using such models, a remarkable cost saving has been obtained.

Nomenclature

a_p – depth of cut in mm
f – feed rate in mm/rev
v_c – cutting speed in m/min
Ra – average of surface roughness in μm
DSS – Duplex Stainless Steel

REFERENCES

[1] W. Olszak: Obróbka skrawaniem, WNT, Warszawa 2008.

[2] M. Alauddin, M. A. El Baradie and M. S. J. Hashmi: Prediction of tool life in end milling by response surface methodology, Journal of Materials Processing and Technology, 71 (1997), 456-465.

[3] M. Hasegawa, A. Seireg and R. A. Lindberg:. Surface roughness model for turning, Tribology International, (December) (1976), 285–289.

[4] G. T. Smith: Cutting Tool Technology, Industrial Handbook, Springer - Verlag, London 2008.

[5] Y. Sahin, A. Riza Motorcu: Surface roughness model for machining mild steel with coated carbide tool, Materials & Design, 26 (2005), 321–326.

[6] K. Taraman: Multi-machining output-multi independent variable turning research by response surface methodology, Int. J. Prod. Res., 12 (1974) 2, 233–245.

[7] R. M. Sundaram, B. K. Lambert: Mathematical models to predict surface finish in fine turning of steel, Int. J. Prod. Res., 19 (1981), 557–564.

[8] M. A. El Baradie: Surface roughness prediction in the turning of high strength steel by factorial design of experiments, J. Mater. Process. Tech., 67 (1997), 55–61.

[9] A. Mital, M. Mehta: Surface finish prediction models for fine turning, Int. J. Prod. Res., 26 (1998) 12, 1861–1876.

[10] J. Kopac, M. Bahor, M. Sokovic: Optimal machining parameters for achieving the desired surface roughness in fine turning cold pre-formed steel work processing, Int. Mach. Tool. Manuf., 42 (2002), 707–716.

[11] Z. Polański: Metody optymalizacji w technologii maszyn, PWN, Warszawa 1977.

[12] D. Montgomery: Design and Analysis of Experiments, 5th Edition, John Wiley & Sons Inc., New York, 2003.

[13] StatSoft, Inc., STATISTICA (data analysis software system), version 9.0. www.statsoft.com, 2009.

Note: The responsible translator for English language is lecturer from Faculty of Production Engineering and Logistics, Opole University of Technology, Poland