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"Politehnica" University of Bucharest, Machine and Manufacturing Systems Department
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METAL SPRAYED ALUMINUM ALLOY – STATISTICAL MODEL OF SURFACE ROUGHNESS IN TURNING

Mihaiela ILIESCU, Marian GHEORGHE

Abstract: *Thermal spray process is widely used in order to obtain surfaces with very good corrosion resistance and mechanical characteristics. Often, after spraying there is the need of machining, so as to get the prescribed surfaces' geometrical tolerances and roughness. This paper presents statistical models of surface roughness, R_a parameter, determined so as to evidence machining (turning) parameters' influence and obtain its optimum value.*

Key words: *thermal sprayed, aluminium alloy, regression analysis, surface roughness.*

1. INTRODUCTION

The metal spraying or metallizing [1] is the process of spraying molten metal onto a surface to form a coating. Because the molten metal is accompanied by a large amount of air, the object being sprayed does not heat up too much.

An excellent mean of protecting iron and steel from corrosion is represented by metallizing zinc or aluminium. Thus, could be obtained either heavy coatings or, thin undercoating for organic materials, such as paint or plastic finishes.

Aluminium is one highly recommended material for atmospheric protection of iron and steel and, also, for protection to salt or fresh water immersion.

In order to obtain prescribed characteristics, metallized coating often need machining and, the commonly used procedure – specially for aluminium sprayed coatings – is turning.

The References present only general information on machining procedures and very few dependence mathematical relations (quantitative data) of surface roughness on machining parameters. As for aluminium alloys metallized coatings, there are no such above mentioned relations.

So, it was considered of interest a study on turning parameters influence on surface roughness so as to enable setting optimum parameters' value as to get smallest R_a (surface roughness parameter) values.

2. RESEARCH METHODOLOGY

The variables of a technological process should be "connected" [2] by relation:

$$Y = \Gamma\left(z_1, z_2, ..., z_j, ...z_n\right) \qquad (1)$$

called process function, where:

z_j , j = 1, 2, …., k represents the process independent variables (inputs); Y - process dependent variable (output); Γ - type of dependence relation.

In order to determine optimum Γ type, one has to establish the values – both real z_j and coded x_j – and variation field of each input, as well as the experiment design that fits best.

Considering the number of independent variables studied and the dependence relations type, to be determined, several experiment designs have been applied, as follows:

– Fractional Factorial Design, P2.1 [2, 3] – a three level design for four independent variables, 12 runs and 3 replicates;

– Full Factorial Design, P3 [2, 3] – a three level design for five independent variables, 20 runs and 3 replicates

– Full Factorial Design, FFD [4, 5] – a two level design for three independent variables, 8 runs and 3 replicates;

For statistical modeling, two software types have been used:

– REGS, for P2.1 and P3 experiment designs – determines polynomial regression function, regression coefficients, standard errors and all other values required by a multiple regression analysis.

– *DOE KISS* (Student Version), for FFD experiment design – computes regression coefficients, standard errors, prediction interval, etc. The DOE KISS also provides the *Pareto Chart of Coefficients* – a graph that points out how much the influence of each input (as well as its interactions) on the output is and an *Expert Optimizer* – which sets the inputs values, in order to optimize the output.

The structure of experimental programs is presented in Table 1, and the regression functions type are shown by relations (2), (3), and (4) respectively:

$$Y = A_0\, v^{A_1}\, s^{A_2}\, t^{A_3}\, A_4^{r}, \qquad (2)$$

$$Y = A_0\, v^{A_1}\, s^{A_2}\, t^{A_3}\, A_4^{r} \cdot A_5^{VB}, \qquad (3)$$

$$Y = a_0 + a_1 \cdot z_1 + a_1 \cdot z_1 + a_1 \cdot z_1 + a_{12} \cdot z_1 z_2 + + a_{13} \cdot z_1 z_3 + a_{23} \cdot z_2 z_3 + a_{123} \cdot z_1 z_2 z_3. \qquad (4)$$

Table 1

Structure of experimental programs

Experiment Design	Coded values												
P 2.1	**Run**	1	2	3	4	5	6	7	8	9	10	11	12
	x_1	-1	+1	-1	+1	-1	+1	-1	+1	0	0	0	0
	x_2	-1	-1	+1	+1	-1	-1	+1	+1	0	0	0	0
	x_3	-1	-1	-1	-1	+1	+1	+1	+1	0	0	0	0
	x_4	-1	+1	+1	-1	+1	-1	-1	+1	0	0	0	0
P 3	**Run**	1	2	3	4	5	6	7	8	9	10		
	x_1	-1	+1	-1	+1	-1	+1	-1	+1	-1	+1		
	x_2	-1	-1	+1	+1	-1	-1	+1	+1	-1	-1		
	x_3	-1	-1	-1	-1	+1	+1	+1	+1	-1	-1		
	x_4	-1	-1	-1	-1	-1	-1	-1	-1	+1	+1		
	x_5	-1	+1	+1	-1	+1	-1	-1	+1	+1	-1		
	Run	11	12	13	14	15	16	17	18	19	20		
	x_1	-1	+1	-1	+1	-1	+1	0	0	0	0		
	x_2	+1	+1	-1	-1	+1	+1	0	0	0	0		
	x_3	-1	-1	+1	+1	+1	+1	0	0	0	0		
	x_4	+1	+1	+1	+1	+1	+1	0	0	0	0		
	x_5	-1	+1	-1	+1	+1	-1	0	0	0	0		
FFD	**Run**	1	2	3	4	5	6	7	8				
	x_1	-1	-1	-1	-1	+1	+1	+1	+1				
	x_2	-1	-1	+1	+1	-1	-1	+1	+1				
	x_3	-1	+1	-1	+1	-1	+1	-1	+1				

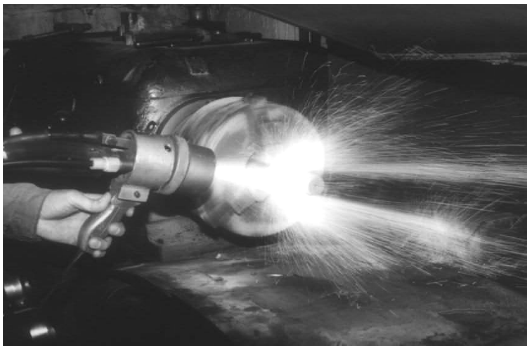

Fig. 1. Metallizing process.

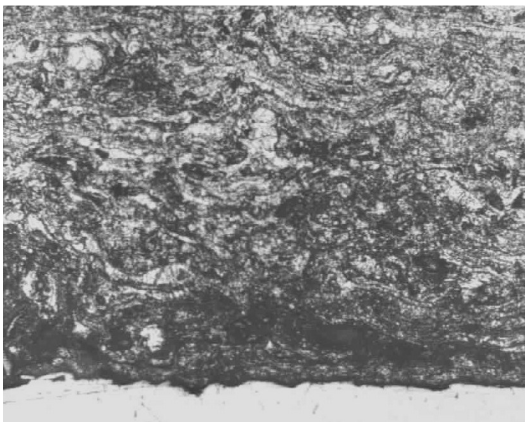

Fig. 2. Metallographic structure of thermal sprayed Al (99,5%)-S10Mn1Ni2.

3. EXPERIMENTS

The research was carried out on the electric arc thermal spray aluminium alloy [Al (99.5%)-S10Mn1Ni2] coatings. The samples were exterior cylindrical ones and the depth of sprayed coatings was about 2.5 mm.

The studied variables [3] were as follows.

Controllable independent variables (inputs) z_j:

• *cutting tool (SA)* - metallic carbides Romanian tools, conventionally called K10, characterized by nose radius *r* [mm] and wear *VB* [mm] parameter;

• *cutting parameters* - cutting speed *v* [m/min]; cutting feed *s* [mm/rev]; cutting depth *t* [mm].

Uncontrollable (noise) inputs:

• *Vickers micro-toughness* $HV_{0,05}$ = 150, of the electric arc thermal sprayed coating;

• *vibrations of the technological system,* at constant speed exterior cylindrical finish turning, on SN 500×1500 lathe.

Dependent variable (output):

• surface roughness, measured by R_a [μm].

An image of the metallizing process is shown in Fig. 1, while the metallographic structure of the sprayed coating is presented in Fig. 2.

The real and coded values of the independent variables are presented in Table 2.

Table 2

Structure of experimental programs

v (z₁) [m/min]			**s (z₂) [mm/rev]**			**t (z₃) [mm]**			**r (z₄) [mm]**			**VB (z₅) [mm]**		
(-1)	(0)	(1)	(-1)	(0)	(1)	(-1)	(0)	(1)	(-1)	(0)	(1)	(-1)	(0)	(1)
135	214	340	0.08	0.11	0.16	0.15	0.21	0.3	0.4	0.8	1.2	0	0.14	0.2.8

Experiments were carried out and image of the experimental stand, while machining the sample, is presented by Fig. 3. Surface roughness measurements were done with Rugomas instrument and an image of the stand, while measuring the surface roughness is shown in Fig. 4.

The medium values of surface roughness R_a [μm] obtained for each designed experiment type run are presented in Table 3.

The regression analysis, carried out with REGS program, provides the statistic models:

$$Y = 6.787 \cdot v^{-0.206} \cdot s^{0.508} \cdot t^{0.059} \cdot 0.472^{r}, \quad (5)$$

$$Y = 7.426 \cdot v^{-0.189} \cdot s^{0.476} \cdot t^{0.047} \cdot 0.490^{r} \cdot 2.875^{VB}. \quad (6)$$

Another regression analysis type has been considered useful, which should evidence the influence of most significant inputs (*r*, *s*, and *VB*), and their interactions, on cutting tool roughness (see Table 4).

The regression analysis results performed with DOE KISS are presented in Fig. 5 and consequently the statistic model obtained is:

$$Y = 5.126 - 1.411 \cdot r + 0.834 \cdot s + 0.709 \cdot VB - 0.209 \cdot rs - 0.134 \cdot rVB. \quad (7)$$

One can make the following hints:

*A factor is considered to have significant influence on the output as long as the P (*2 *Tail) value is less or equal to* 0.05.

This software also provides an Expert Optimizer which sets the input values as to minimize R_a values. The results are shown in Fig. 6.

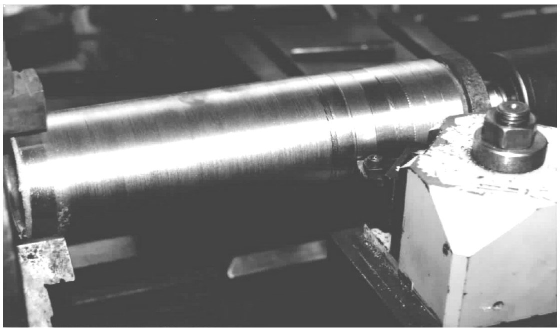

Fig. 3. Sample turning.

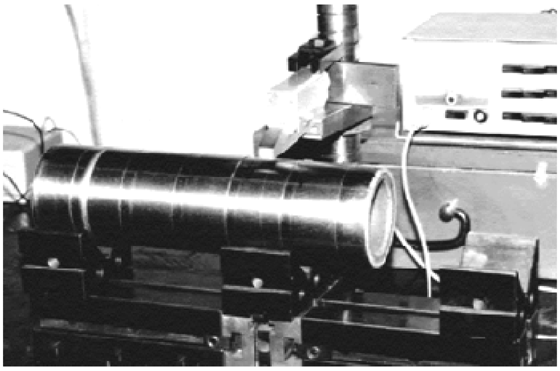

Fig. 4. Surface roughness measuring.

Table 3

Experimental results – REGS regression analysis

Experiment Design	**Surface roughness R_a [μm]**												
P 2.1	**Run**	1	2	3	4	5	6	7	8	9	10	11	12
		4.33	2.95	3.37	7.35	2.25	5.02	6.07	3.92	3.85	3.95	3.98	4.07
P 3	**Run**	1	2	3	4	5	6	7	8	9	10		
		4.33	6.75	7.62	7.35	5.87	5.02	6.07	9.28	3.25	2.95		
	Run	11	12	13	14	15	16	17	18	19	20		
		3.37	5.22	2.25	3.99	4.77	3.92	4.38	4.26	4.64	4.81		

Table 4

Experimental results – DOE KISS regression analysis

Experiment Design	**Surface roughness R_a [μm]**								
FFD	**Run**	1	2	3	4	5	6	7	8
		4.68	6.31	6.71	8.45	2.60	3.58	3.65	5.00

Multiple Regression Analysis

Y-hat Model

Factor	Name	Coeff	P(2 Tail)	Tol	Active
Const		5,12625	0,0000		
A	nose radius, r	-1,41125	0,0000	1	X
B	feed, s	0,83375	0,0000	1	X
C	wear, VB	0,70875	0,0000	1	X
AB		-0,20875	0,0001	1	X
AC		-0,13375	0,0043	1	X
BC		0,05625	0,1818	1	X
ABC		0,02875	0,4859	1	X

Rsq	0,9921
Adj Rsq	0,9886
Std Error	0,1974
F	286,2977
Sig F	0,0000

Source	SS	df	MS
Regression	78,1	7	11,2
Error	0,6	16	0,0
Total	78,7	23	

Factor	Name	Low	High	Exper
A	nose radius, r	0,4	1,2	0,8
B	feed, s	0,08	0,16	0,12
C	wear, VB	0	0,28	0,14

Prediction

Y-hat	5,12625
S-hat	0,17078957

99% Prediction Interval

Lower Bound	4,6138813
Upper Bound	5,6386187

Fig. 5. DOE KISS Regression Analysis.

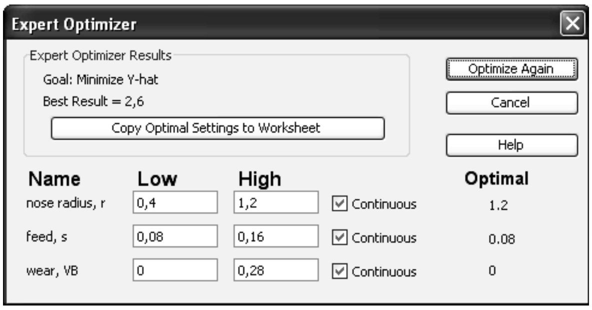

Fig. 6. DOE KISS Expert Optimizer.

4. CONCLUSIONS

Regression analysis, performed with REGS program, pointed out that all statistical models were adequate and the strongest influence on surface roughness was that of cutting tool nose radius *r*. The other considered independent variables: cutting feed *s*, cutting tool wear *VB*, and cuttings speed *v*, proved to be significant under the above mentioned order. The only variable that did not significantly influence the R_a parameter was the cutting depth *t*.

Regression analysis, performed with DOE KISS software, proved the adequacy of statistical obtained models and the influence on surface roughness of the considered variables, as well as of their interactions. So, it has been proved that the strongest influence was the same as in REGS analysis, meaning that of the cutting tool radius *r*. As it was expected, the cutting feed *s* and cutting tool wear VB, under the above mentioned order, are significant to R_a parameter.

One can notice that the factors interaction, *r-s* and *r-VB* do also influence R_a parameter (but less than the first order factors) as long as the *s-VB* and *r-s-VB* interactions are not significant to surface roughness.

Further researches should be developed on different process variables and with different statistical regression analysis software.

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Authors:

PhD, Mihaiela ILIESCU, Associated Professor, University “Politehnica” of Bucharest, Manufacturing Technology Department,
E-mail: iomi@clicknet.ro
PhD, Marian GHOERGHE, Professor, Vice rector,
University “Politehnica” of Bucharest, Manufacturing Technology Department,
E-mail: gheorghe@rectorat.pub.ro