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SPACING ROUGHNESS PARAMETERS STUDY ON THE DRY MACHINING OF AN AL-CU ALLOY

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ABSTRACT
The measurement and characterization of surface properties represent one of the most interesting aspects in manufacturing processes due to the enormous importance that a good surface quality has on corrosion, fatigue and wear resistance of parts. In this work, a surface roughness study on the dry turning of a 2030 aluminium alloy, whose main alloying element is copper, has been carried out. The study has been made on two spacing roughness parameters i.e. Sm (mean spacing of profile irregularities) and Pc (peak count or peak density). One of the innovations in this work is the roughness parameters selected, Sm and Pc, as against some other much more commonly used ones such as Ra, Rq or Rt. The models of Sm and Pc will be obtained in function of the following design factors: depth of cut (a_p), cutting speed (V_c), feed rate (F) and tool radius (R). Basically, this will be done by using the technique of design of experiments (DOE), which allows us to carry out the earlier analysis by performing a relatively small number of experiments. The design finally selected was a factorial design of type 2^4 with four central points to see if a second order model is necessary. The material employed for the experiments was a 2030-T4 aluminium alloy because of the growing interest of manufacturers in the advantages that materials that can be easily dry machined present.
Keywords: Surface Roughness, Design of Experiments, Turning

1. INTRODUCTION
Surface finish is a very important aspect to consider when designing mechanical elements and it is always presented as a quality and precision indicator of manufacturing processes, where a proper knowledge of the geometry of the part that involves, not only its macrogeometry, but also where its microgeometry is necessary [1].
In order to know in advance the surface quality of machined parts, it is necessary to employ experimental models that make it feasible to predict surface roughness in function of operation conditions such as cutting speed, rotating speed of the spindle, feed rate, depth of cut and nose radius of the cutting tool, among others [2].
These mathematical models should be assessed using an adequate methodology which allows us to evaluate both main and interaction factors. In this work, this will be carried out by employing statistical techniques such as Design Of Experiments (DOE) and multiple linear regression analysis. The design finally selected was a 2^4 factorial design with four central points [3]. These central points are useful to do lack-of-fit tests for the fitted models. The design factors are as follows: depth of cut (a_p), cutting speed (V_c), feed rate (F) and tool radius (R). The study will be focused on the influence of the above-mentioned factors over two surface roughness parameters: Sm (mean spacing of profile irregularities) and Pc (peak count or peak density), which are both spacing roughness parameters, as against some other much more commonly used ones such as: Ra (arithmetic mean deviation), Rq (quadratic mean deviation) or Rt (total height of roughness profile) [1].

2. DESIGN OF THE EXPERIMENTATION

2.1. Aluminium alloy selected and machine-tool and cutting tools used

The material selected for the experiments was a 2030-T4 aluminium alloy because of the growing interest of manufacturers in the advantages that materials that can be easily dry-machined present: non-cleaning of the parts, absence of health problems for the machinists, no environmental impact associated with the use of coolants, lower energy consumption and less complex machine-tools due to the non-existence of cooling system, among others.

The machine-tool used was a numerically controlled lathe Danobat (Danobar-65). The power and maximum speed of its spindle are 19,5 kW and 5500 rpm, respectively. The maximum diameter which is possible to machine (swing) is 180 mm and the maximum length is 500 mm.

The cutting tools employed in the turning experiments were typical inserts made of hard metal with a coating of titanium nitride (TiN). The specific Sandvik Coromant codes™ were CNMG 12 04 04-PM, CNMG 12 04 08-PM and CNMG 12 04 12-PM, depending on the radius of the tool.

2.2. Measurement of surface roughness

The surface roughness of machined parts depends on the manufacturing conditions used in the process. A complete modelling of surface roughness should involve all of them. Nevertheless, it can be stated that the most influential factors in a turning process are the depth of cut (a_p), the cutting speed (V_c), the feed rate (F) and the radius of tool nose (R).

With the aim of measuring the surface roughness of the machined parts, an electronic rugosimeter with a mobile stylus (ALPA RT-70) was used. In this work, a phase-corrected 2CR filter was employed because, as quoted in the UNE-EN-ISO 11562: 1998 norm [4], this filter does not produce phase differences or asymmetric distortions of the roughness profile. The advance speed of the unit when performing the measurement was 1 mm/s, whereas the return speed was 2 mm/s. Furthermore, a stylus tip with a diamond cone whose angle and tip radius are 90º and 3 μm, respectively, was employed, the force exerted by the stylus being $12 \cdot 15^{-5}$ N.

The response variables used to accomplish this study were Sm (mean spacing of profile irregularities) and Pc (peak count or peak density). The selected parameters are defined in accordance with UNE-EN-ISO 4287: 1997 [5] as follows: Sm (μm) is the mean spacing between peaks, with a peak defined relative to the mean line (a peak must cross above the mean line and then return back below it); and Pc (cm^{-1}) is the number of peaks in the evaluation length divided by the evaluation length.

In all cases, an evaluation length of 4 mm (5*0,8 mm) was employed, the number of sampling lengths being 5 and 0,8 mm the value of the cut-off (λc) used. The values of the roughness parameters for each experiment were obtained from the arithmetical mean of the values of the measurements performed following three generatrices of the machined cylinders, equally distributed approximately at 120º.

A more complex study considering the uncertainty due to the standard deviation of the roughness measurements will be published in a future work [6].

2.3. Design of experiment selected

The design finally selected in this work was a factorial design of type 2^4 with four central points. The addition of these central points allows us to perform lack-of-fit tests for the first order models proposed, which consist of a total of 20 experiments. If the first order model turns out to be inadequate for the observations of Sm or Pc, this will be augmented with the addition of 8 new experiments, which are called star points, thus providing a central composite design with the axial or star points located in the centres of the faces.

Table 1 shows the standard design matrix for the first and second order models of Sm and Pc, as well as the experimental values obtained for each of them. Table 2 shows the values of the R-squared (R^2) and adjusted R-squared ($\overline{R}^2$) statistics obtained for the first and second order models. These models have been assessed both considering all the possible effects as well as excluding some effects in order to obtain the model with the highest value for the adjusted R-squared statistic. Furthermore, Table 2 presents the P-Values obtained for the adequacy or lack-of-fit tests of the different models.

In this study, no kind of simplification in the models is to be made in order to consider all the possible effects. Therefore, taking all the values shown in Table 2 into account, the first order model (adequate at a confidence level of 95 % as its P-Value = 0,1708 is higher than α = 0,05) was selected to analyse the behaviour of Sm and the second order model (adequate at a confidence level of 99 % as its P-Value = 0,0488 is higher than α = 0,01) was selected for Pc.

Table 1. Design matrix for the 1st and 2nd order models of Sm and Pc

	a_p [mm]	V_c [m/min]	F [mm/rev]	R [mm]	Sm [µm]	Pc [cm^{-1}]
1	0,5	50	0,05	0,4	45	222
2	1,5	50	0,05	0,4	68	150
3	0,5	100	0,05	0,4	53	187
4	1,5	100	0,05	0,4	63	158
5	0,5	50	0,25	0,4	163	63
6	1,5	50	0,25	0,4	141	74
7	0,5	100	0,25	0,4	120	82
8	1,5	100	0,25	0,4	202	46
9	0,5	50	0,05	1,2	36	275
10	1,5	50	0,05	1,2	42	242
11	0,5	100	0,05	1,2	48	206
12	1,5	100	0,05	1,2	48	207
13	0,5	50	0,25	1,2	211	51
14	1,5	50	0,25	1,2	180	68
15	0,5	100	0,25	1,2	221	46
16	1,5	100	0,25	1,2	209	48
17	0,5	75	0,15	0,8	146	68
18	1,5	75	0,15	0,8	90	112
19	1,0	50	0,15	0,8	119	86
20	1,0	100	0,15	0,8	93	108
21	1,0	75	0,05	0,8	46	220
22	1,0	75	0,25	0,8	199	51
23	1,0	75	0,15	0,4	104	97
24	1,0	75	0,15	1,2	115	83
25	1,0	75	0,15	0,8	133	77
26	1,0	75	0,15	0,8	117	88
27	1,0	75	0,15	0,8	108	94
28	1,0	75	0,15	0,8	111	91

Table 2. R^2 and $\overline{R}^2$ statistics of the models as well as P-Values for their lack-of-fit tests

			1st order	2nd order
Sm	All the effects	R^2	0,9630	0,9406
		$\overline{R}^2$	0,9218	0,8765
		LOF	0,1708	0,1348
	Effects excluded for highest $\overline{R}^2$	R^2	0,9580	0,9331
		$\overline{R}^2$	0,9386	0,9179
		LOF	0,2601	0,2724
Pc	All the effects	R^2	0,9209	0,9598
		$\overline{R}^2$	0,8331	0,9166
		LOF	0,0119	0,0488
	Effects excluded for highest $\overline{R}^2$	R^2	0,9101	0,9592
		$\overline{R}^2$	0,8577	0,9352
		LOF	0,0171	0,0747

3. RESULTS ANALYSIS

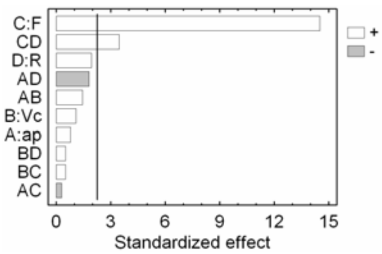

Figure 1. Pareto chart for Sm

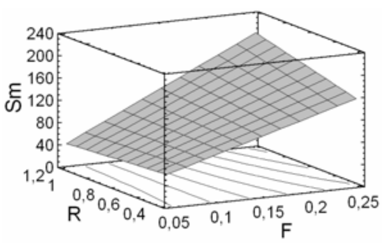

Figure 2. Sm versus F and R

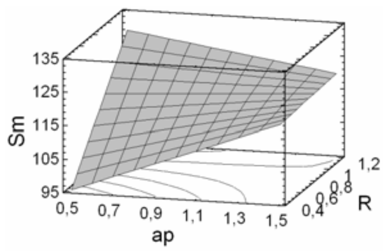

Figure 3. Sm versus a_p and R

With respect to Sm, the analysis of variance shows that the only influential factor is feed rate and that there is a significant interaction between this factor and tool radius, for a confidence level of 95 %, as can be observed in Figure 1.

Figures 2 and 3 show the proposed first order model for Sm versus feed rate and tool radius and versus depth of cut and tool radius. As can be observed in Figure 2, Sm greatly increases when feed rate is increased, where this behaviour is what was expected in advance as a higher value of feed implies a higher spacing distance between the irregularities or peaks in the surface roughness profile.

Furthermore, one can observe in Figure 2 the strong interaction between feed rate and tool radius as Sm tends to increase when tool radius is increased, except for low values of feed where this tendency is reversed. Again, there seems to be an interaction effect between depth of cut and tool radius (in this case, not significant for $\alpha = 0{,}05$), as can be observed in Figure 3.

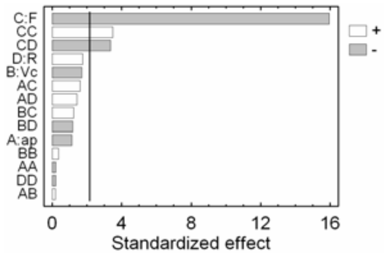

Figure 4. Pc Pareto chart for Pc

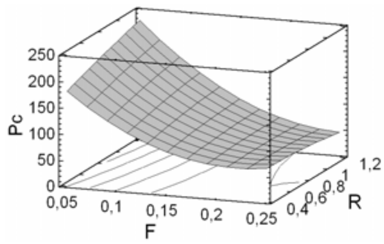

Figure 5. Pc versus F and R

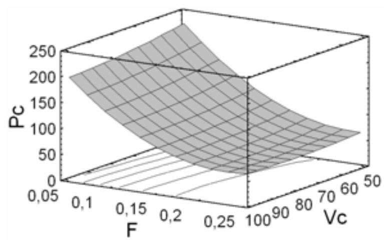

Figure 6. Pc versus F and V_c

Figure 4 shows the standardised Pareto chart of the estimated effects (arranged in decreasing order) for Pc, where now there are three significant effects at a confidence level of 95 %: feed rate, its pure quadratic effect and the interaction of the former with tool radius.

Figure 5 and Figure 6 show the estimated response surfaces of Pc in function of feed rate and tool radius and cutting speed and feed rate, respectively. As can be observed in both figures, Pc decreases when feed rate is increased within the work interval considered, where this tendency can be explained because of the fact that irregularities of greater size in the roughness profile mean a lesser number of them and therefore a lower number of peaks.

Regarding the influence of tool radius, although it is not statistically significant, the number of peaks tends to increase slightly when this factor is increased, except for high values of feed rate, as can be seen in Figure 5, where this variation tendency does not coincide with the behaviour obtained for Sm.

4. CONCLUSIONS

This present work is focused on the modelling of two spacing roughness parameters (Sm and Pc) in the case of the turning of a 2030 aluminium alloy, as it can be easily machined with non-use of coolant.

The design of experiments finally selected was a central composite one on the basis of a 2^4 factorial design. In the end, it was necessary to use a first order model for Sm and a second order one for Pc. Nevertheless, it should be pointed out that a more complex analysis, which considers the uncertainty in the measurements, should be carried out in order to reach more accurate conclusions. This will be made in a future work that will be published later on.

In both cases, the only influential factor was feed rate by far, whereas the rest of the factors (depth of cut, cutting speed and tool radius) did not turn out to be statistically significant for a confidence level of 95 %. With respect to the behaviour observed for Sm and Pc when varying feed rate from 0,05 to 0,25 mm / rev, these parameters were obtained to increase and to decrease, respectively. It was logical to expect this as higher values of feed produce irregularities on the surface of greater size, which is translated into a higher mean spacing distance between them.

5. REFERENCES

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