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INFLUENCE OF RAM EDM PARAMETERS ON 3D SURFACE ROUGHNESS OF THE QUENCHED AND TEMPERED VC-131 TOOL STEEL

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Abstract. *Tool steels are widely used as die components due to their properties. Despite the high hardness that can be achieved after heat treatment, further machining processes are always required to reach a desired geometry. These processes greatly affect the surface characteristics and this may lead to an early failure. The EDM process is broadly applied to the construction of those die components because any conductor material can be machined by this process, regardless its hardness. This study aims to establish correlations between the main control variables during the Ram EDM process – pulse current, pulse on-time, pulse off-time and sequential pulse time – and 3D roughness parameters – Sq, Sdq and Sds – evaluated in a Taylor Hobson CCI Lite non-contact 3D optical profiler. The machined material was a quenched and tempered VC-131 tool steel and the electrodes were made of electrolytic copper. To carry out the experiments and analyse the results a factorial planning at two levels was used. This showed that the surface roughness was most affected by pulse current, pulse on-time and sequential pulse time.*

Keywords: *EDM, tool steel, heat treatment, surface properties, 3D roughness.*

1. INTRODUCTION

Surface integrity is a very relevant aspect for machining processes. Within the possible evaluated factors the surface roughness receives a special attention because several components depend on this characteristic to their better working (Jawahir, et al., 2011). An example is the use of tool steels for plastic injection moulds (Altan, et al., 2001). During the manufacturing of moulds, the electrical discharge machining (EDM) is largely employed to achieve the final forms, and it is possible to affirm that the better the control of surface roughness, the better the performance of the tool (Zeid, 1997).

Some investigations are very focused on the effect of EDM variables on roughness parameters for tool steels (Ramasawmy and Blunt, 2004; Guu, 2005; Sahoo, et al., 2009). Nonetheless, the VC-131 steel can be considered a typical material used in Brazilian industries, and in this way this kind of study is more uncommon to find in the literature.

Considering the abovementioned arguments, this investigation aims to study the influence of some variables in Ram EDM process – pulse current, pulse-on time, pulse-off time and sequential pulse time – on the 3D roughness parameters

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– Sq, Sdq and Sds – in the machined VC-131 steel.

2. EXPERIMENTAL PROCEDURE

For studying the main control variables' influence on the surface quality after the EDM process, controlled experiments were carried out using a IBH – Hidro-matic 50.A machine and the parameters determination before and after the experiments were made by a Taylor Hobson non-contact 3D optical profiler through the 3D Talysurf CCI Lite software.

A complete 2^4 factorial planning at two levels was used to execute the parameters and levels combination so that posterior statistical analyses could be done. The studied factors, as well their levels, are presented in Tab. 1. Each factor's levels were determined according to experiments carried out by the used EDM machine's supplier.

Table 1. Factors and levels for the complete 2^4 factorial planning.

Factor	Variable	Description	Level -1	Level +1
A	Current (A)	Pulse-peak current	2.5	10
B	ton (µs)	Pulse-on time	80	200
C	toff (µs)	Pulse-off time	24	60
D	tds (s)	Sequential pulse time	1.0	2.5

Aiming to reduce the unknown variables, which could disturb posterior analyses, operation conditions were set as the cleaning of the work slot (lateral stream), fluid level in the Ram EDM machine's bowl, electrode ram depth (0.2 mm) and electrode's movement recess (2.0 s).

For portraying in the most complete way the evaluated surfaces, one parameter was selected from each category of three-dimensional roughness parameters: mean (Sq), hybrid (Sdq) and spacing (Sds). The definitions for these parameters can be found in Blunt and Stout (2000).

The proof body was made of the VC-131 tool steel (2.1 %C, 11.5 %Cr, 0.7 %W, and 0.15 %V nominal chemical composition), supplied by Villares Metals S.A.

After being milled, the proof body undertook quenching and tempering heat treatments. The quenching treatment was carried out at 960°C with oil cooling followed by double temper wherein the material heating occurred at 200°C during two hours in each repetition. After the heat treatments it was grinded and the work surface hardness was measured. The hardness was randomly assessed and the mean value found was 64.3 ± 0.5 HRC for a 95% significance level.

General topographic characteristics on the work surface are shown in Fig. 1 and the evaluated roughness parameters are presented in Tab. 2.

Table 2. Sq, Sdq e Sds roughness parameters measured on the work surface(1).

Sq (µm)	Sdq	Sds(2) (m^{-2})
0.20 ± 0.02	0.093 ± 0.007	13,900 ± 600

(1) 95% significance level
(2) (x1000)

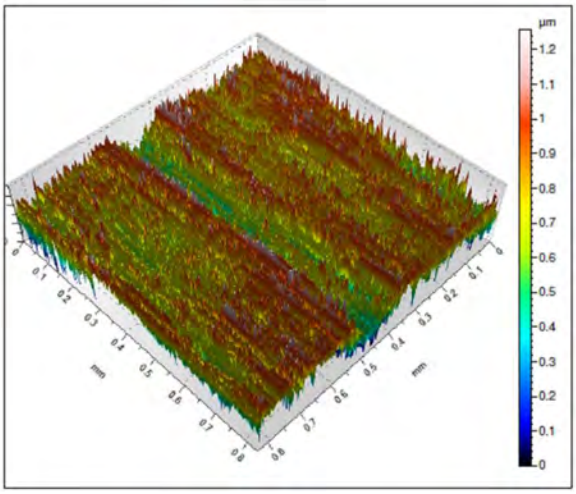

Figure 1. General topography on the work surface.

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The electrodes were made of electrolytic copper from the same wire drawn bar with hexagonal cross section of 9.525 mm (3/8") and the faces used for the experiments were milled. The main roughness characteristics are presented in Tab. 3 and general topographic characteristics in Fig. 2.

Table 3. Sq, Sdq e Sds roughness parameters measured on the electrodes' used faces(1).

Sq (µm)	Sdq	Sds(2) (m^{-2})
0.56 ± 0.08	0.17 ± 0.03	18,500 ± 800

(1) 95% significance level
(2) (x1000)

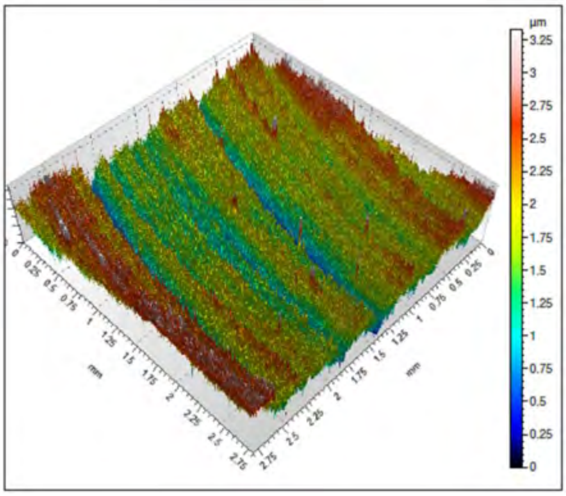

Figure 2. General topography on the electrodes' surfaces used in the experiments.

3. RESULTS AND DISCUSSION

For the statistical analyses the complete 2^4 factorial planning was used with 16 experiments randomly carried out and presented in Tab. 4.

According to Montgomery (2005), 2^k factorial plannings are more useful in the research's first phases, wherein there are several factors to investigate. On the other hand, this kind of planning must be avoided, unless the study of four or more factors is required. Another point to be considered is about the number of replications per combination. When there is only one observation, the results from the analysis of variance (ANOVA) can be seriously spoiled, due to that for certain square sums the freedom degrees number will be 0 (zero), what makes hard the decision-making.

Table 4. Complete 2^4 factorial planning with the measured values.

Test	Factors					Measured values		
	A	B	C	D	Contrasts	Sq	Sdq	Sds(x1000)
1	- 1	- 1	- 1	- 1	1	17.99	10.51	21,497
2	+1	- 1	+1	- 1	A	17.29	10.24	20,418
3	- 1	+1	+1	- 1	B	5.725	1.459	15,245
4	+1	+1	+1	- 1	AB	25.38	8.166	17,165
5	- 1	- 1	- 1	- 1	C	27.7	9.551	19,951
6	+1	- 1	- 1	- 1	AC	8.093	3.742	17,439
7	- 1	+1	- 1	- 1	BC	7.299	4.997	17,827
8	+1	+1	- 1	- 1	ABC	18.71	8.653	19,576
9	- 1	- 1	+1	+1	D	6.802	3.982	17,940
10	+1	- 1	+1	+1	AD	19.52	9.939	20,530
11	- 1	+1	+1	+1	BD	16.39	9.058	20,418
12	+1	+1	+1	+1	ABD	6.717	4.237	18,186
13	- 1	- 1	- 1	+1	CD	5.703	3.119	17,315
14	+1	- 1	- 1	+1	ACD	6.389	2.981	17,380
15	- 1	+1	- 1	+1	BCD	19.06	9.301	19,819
16	+1	+1	+1	+1	ABCD	6,727	2,884	16,766
					Totals	215.495	102.819	297,472

The results from the analysis of variance (ANOVA) for the roughness parameters Sq, Sdq and Sds are shown in Tab. 5 and the significant results highlighted.

Table 5. ANOVA for the Sq, Sdq and Sds roughness parameters.

	Sq		Sdq		Sds	
Contrast	**Quadratic sum**	**%**	**Quadratic sum**	**%**	**Quadratic sum**	**%**
A	574.465	1.34013	5.153	0.05143	26.051	0.89734
B	580.424	1.35404	112.742	1.12530	223.084	**7.68427**
C	228.977	0.53417	611.375	**6.10225**	113.465	**3.90838**
D	181.010	0.42227	558.566	**5.57515**	2.335	0.08042
AB	150.602	0.35133	1.513	0.01510	1.850	0.06371
AC	4100.097	**9.56486**	1060.284	**10.58289**	98.010	**3.37602**
AD	3407.757	**7.94974**	376.593	**3.75884**	29.333	1.01040
BC	29.899	0.06975	1323.941	**13.21450**	508.412	**17.51258**
BD	4357.584	**10.16553**	1053.262	**10.51281**	530.473	**18.27248**
CD	965.220	2.25170	120.956	1.20728	156.851	**5.40282**
ABC	416.813	0.97236	195.273	1.94905	35.189	1.21209
ABD	23688.904	**55.26233**	4488.732	**44.80287**	924.160	**31.83327**
ACD	27.710	0.06464	3.233	0.03227	12.138	0.41811
BCD	3865.358	**9.01725**	91.050	0.90878	240.995	**8.30121**
ABCD	291.453	0.67991	16.176	0.16146	0.781	0.02692

The most significant results were defined as the factors with the major influence percentage from which the sum results in 90% from the whole observed influence.

The Sq parameter, whose objective is to depict the surface relating to the extent of its imperfections, was most influenced for the ABD interaction. This can be explained through the fact that the discharge energy depends on the pulse current and the pulse on-time. It is observed that the high the discharge energy, the more violent the process and higher the surface roughness (Amorin and Weingaertner, 2007). Similar results were found by Ramasawmy and Blunt (2004) and Guu (2005), apart from the sequential pulse time, which doesn't have any known influence in the discharge energy.

The Sdq parameter, used in the characterization of the imperfections' slopes on the surface, was influenced in a most significant way also by the ABD interaction so that the same factors – pulse current, pulse on-time and sequential pulse time – are those which most affected the surface quality during the Ram EDM process. However, it can be observed that this influence is lesser than the same influence on the Sq parameter, what implies on a major influence from the other parameters, even those ones being less significant.

Again, for the Sds parameter, whose objective is to depict the slopes in the surface's imperfections, the most influent factors were the pulse current, pulse on-time and the sequential pulse time through the ABD interaction. This influence was lesser significant than the same influence on the other parameters, however the interpretation for the Sds parameter isolated is difficult due to the EDM machined surface's nature which is shown in Fig. 3. The same influence was observed by Ramasawmy and Blunt (2004), unless for the sequential pulse time and it can be explained through the discharge energy concept.

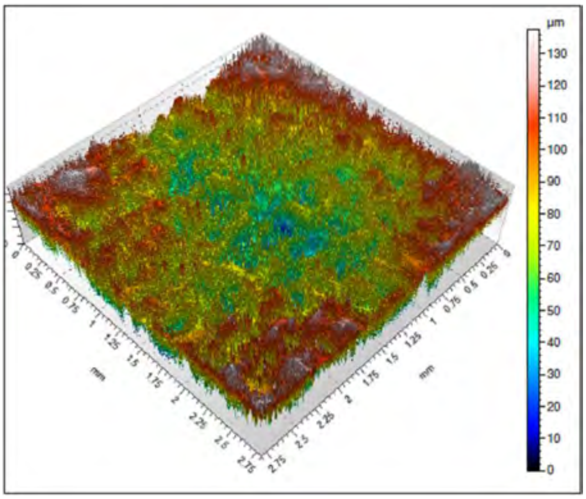

Figure 3. General topography on the EDM machine surfaces.

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4. CONCLUSIONS AND SUGESTIONS

Among all the factors and interactions studied the most significant interaction observed consists on the union of pulse current, pulse on-time and the sequential pulse time. The discharge energy, therefore, seems to be the most important physical quantity at the Ram EDM process assessment in the quenched and tempered VC-131 tool steel, insofar that the pulse current and the pulse on-time are critical factors in the quantity of energy transferred to the material during the process execution.

It is also observed that the sequential pulse time seems to influence the surface roughness. This fact can be a result from the cleaning deficit at the work slot while the electrode stays near the work surface for so long. This doesn't allow the fluid stream to flow in an efficient way and stop the material removal from the work slot.

It is possible that some factors have presented influence over the evaluated roughness parameters due to the large number of variables involved and to the difficult for controlling the process at this condition. It is suggested to assess the process with fewer variables involved and, specially, to study the influence of the cleaning method at the work slot on the surface characteristics to find out if this variable is really relevant.

5. AKNOWLEDGMENTS

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7. RESPONSIBILITY NOTICE

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