ENERGY CONSUMPTIONS EVALUATION AT ELECTRO DISCHARGE MACHINING OF POLYCRYSTALLINE DIAMOND

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Abstract: This paper presents some comparative considerations over the possibilities of electro discharge machining for two groups of materials. The first taken in discussion are common materials like steel alloy that, from EDM point of view, is considered a homogeneous material. The second type is a relatively new material, from the group of heterogeneous materials. The analysis is made using energetic phenomenon as reference and, as well, the evolution of erosive process.

Keywords: EDM, polycrystalline diamond, removal mechanism, energy comparison analysis

1. INTRODUCTION

In scientific literature, aspects related to machining of heterogeneous materials like ceramics or polycrystalline diamond (PCD) are relatively few, which could be explained by the fact that the usage of such materials is relatively new. More numerous are those related to the processing of ceramics and in the case of polycrystalline diamond, mostly pertain to the processing through wire EDM.

Several experiments in this area have been conducted at lower currents values, because in some papers reports that die sinking EDM of PCD with currents over approximately 8 A is very cumbersome and inefficient [1]. In addition, all other reference data are presented for wire electrode EDM and were conducted by Professor Spur in several research papers [2, 3].

In this article, are presented and analysed some experimental researches made at (WZL der RWTH, Aachen [4] and Transilvania University Brasov [5], which particularised the die sinking electro discharge machining of polycrystalline diamond.

2. THE PROCESS EVALUATION

Most of modern sintered materials are including at least one phase that is non-metallic. In order to assure the machinability through EDM, this phase, which is electrical and thermo isolator, a metallic phase is used as a binder. In this way is assured a minimal specific electrical conductivity (above 10^{-2} S/cm).

One of the possibilities to investigate the EDM effectiveness of such materials is comparing the use of pulse for processing, the lost pulses, and short-circuit ones.

In all analysed cases, electro - technological parameters were:

- sparking voltage	80 V
- working voltage	21 – 23 V
- maximum current	2,4 and 4,8 A
- pulse on time	40 to 160 μs
- pulse off time	160 and 200 μs

A first analysis was done comparing the die sinking EDM of homogeneous materials (steel alloy with Cr and V) and a sample of PCD 0.025. Initially, researches were conducted by counting the short circuit pulses in for different pulse on and off durations and for several machining times (hence different depths of erosion). The outcomes presented in Table 1 and 2 were resulted after 1 - 5 min. erosion time, using a cooper sheet of 1 mm width as a tool electrode. In all cases, pulse off duration was 160 μs or 200 μs. The graphical expression of data presented in Table 1 and 2 is illustrated in figure 1 and 2.

The diagrams present the evolution of *zk* (number of short circuit pulses) for different machining times, more exactly after every one minute until five (without addition of previous).

The first notice resulted is that the depth has a great influence over short circuit pulse at EDM of PCD. Thus, depending to fill factor v, the ratio *zk%* (ratio between *zk* and total number of pulses) is increasing by 32 for machining at 5 mm depth related to 1 mm depth for v equals to 0.27. For $v = 0.43$ and a pulse off duration of 120 μs the increasing is only about five times.

Table 1. Number of short circuit pulses at pulse off tp = 160 μs

ti	T	zk	zk %	zk	zk %
μs	min	steel alloy		PCD	
60	1	9209	3.37	2445	0.89
	2	10211	3.75	13614	4.99
	3	14956	5.49	34479	12.64
	4	18222	6.69	64468	23.63
	5	24241	8.90	76785	28.15
80	1	6191	2.49	3210	1.28
	2	6796	2.72	12118	4.85
	3	6933	2.83	22602	8.82
	4	11254	4.50	33909	13.56
	5	12942	5.18	52317	20.91
120	1	8368	3.91	12486	5.82
	2	12558	5.86	19115	8.91
	3	14308	6.69	30592	14.26
	4	17422	8.62	41632	19.43
	5	23393	10.85	68574	31.51

Table 2. Number of short circuit pulses at pulse off tp = 200 μs

ti	T	zk	zk %	zk	zk %
μs	min	steel alloy		PCD	
60	1	8709	3.77	1022	0.45
	2	12058	5.22	3514	1.52
	3	17888	8.05	5875	2.55
	4	23989	10.41	8046	3.54
	5	29269	13.28	13704	6.03
80	1	6597	4.12	2168	1.01
	2	9134	5.62	7839	3.66
	3	12598	7.76	11865	5.82
	4	15036	9.82	18140	8.48
	5	18806	11.57	29187	13.62
120	1	9057	4.83	8146	4.35
	2	11134	5.93	11530	6.16
	3	15183	8.10	17826	9.51
	4	16664	8.89	30173	16.11
	5	18950	10.11	45115	24.07

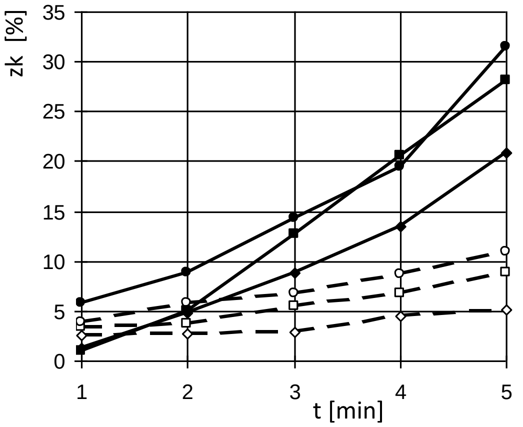
Significance of notations:

zk – number of short circuit pulses

zk% – ratio between zk and total number of pulses

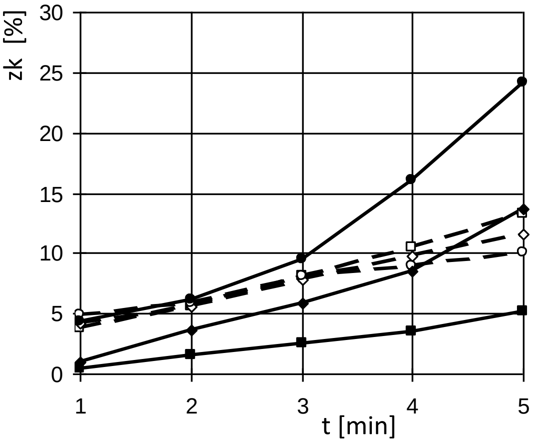
The phenomenon explication is that with the depth increasing, the possibilities for removal of eroded material are decreasing and therefore a great number of short circuits.

On the other hand there are two kinds of residues, some quite large (crystals) that by depositing a metal film on their surface become somewhat conductive, leading to hinder their removal, thus constituting a further explanation on absolute and relative increase of short circuit. In this case, particles, which theoretically are electrical non-conductive, are causing more short circuits.



Legend: PCD ■ ● ♦ and steel alloy □ ○ ◊

Fig.1. Variation of zk % for tp = 160 μs



Legend: PCD ■ ● ♦ and steel alloy □ ○ ◊

Fig.2. Variation of zk % for tp = 200 μs

For 200 μs duration of pulse off, phenomenon is also very relevant to the process and confirms those presented above. In this case, the explanation is logical since there is more time between successive discharges hence is more time to evacuate the residues.

Finally, the above becomes even more interesting if we follow the evolution of values for steel, which is relatively constant however, with a growth rate lower than that of the depth of erosion, which is visible from almost linear evolution of the curve (variation is between 2 ~ 3 times for five times depth increasing).

It is assumed that in this case, the eroded particle size being approximately constant discharge conditions do not change too much even at higher depths of machining.

2. ENERGY ASSESSMENTS

Electro discharge machining stages are the same in the case of two kinds of materials taking in discussion. Most important is energy transforming phase from electric to heat form, based on Joule effect, because the transfer of the heat in electrodes bodies is under the influence of different physical properties.

The last phase of electro discharging is considerably different relating to types of material. The plasma channel and gas bubbles are blasting away following the high pressures and temperatures. Material in a liquid and/or vapours phases (steel or binding material) or in a solid shape (PCD crystals in this case) are ejected from discharge zone. If metallic discharging components are smaller, that is not the case of PCD. Being bigger than metallic spheres, the diamond may remain in the area. In that case, this is the cause of some thermic and electric dysfunctions. At the same time, the polycrystal may join the surface of two electrodes, which means smaller amount of material removed, from that the one produced by individuals discharges.

Table 3. Number of short circuit pulses for 0.5 mm tool electrode

ti	to = 160 μs		to = 200 μs	
μs	PCD	steel alloy	PCD	steel alloy
40	26289	2695		
60	39447	4471	32834	4254
80	28682	5253	40571	5229
100	42266	5505	41811	6032
120	52440	5195	43871	6053
160			43470	7703

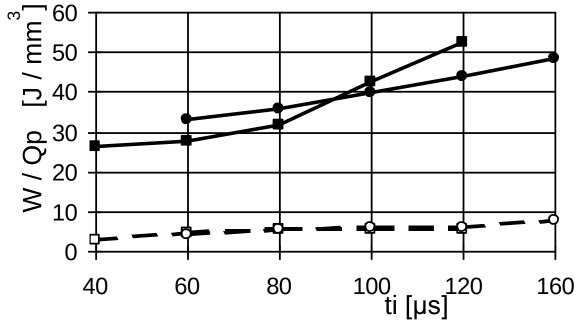
Table 4. Number of short circuit pulses for 1 mm tool electrode

ti	to = 160 μs		to = 200 μs	
μs	PCD	steel alloy	PCD	steel alloy
40	13721	3563		
60	20897	4714	15085	2939
80	26083	5362	20549	3251
100	28251	6521	25962	3947
120	27843	6998	25879	4436
160			24370	5042

Taking in consideration those presented above, another comparison quite convenient and simple can be made through energy assessments. However, since, the mathematical model of erosion processes for steel and PCD are not the same the comparison will be done through a concept, arbitrarily chosen, namely the fraction $\varepsilon = W / Qp$, respectively, the total amount of energy used (J) to remove a one mm^3 of material.

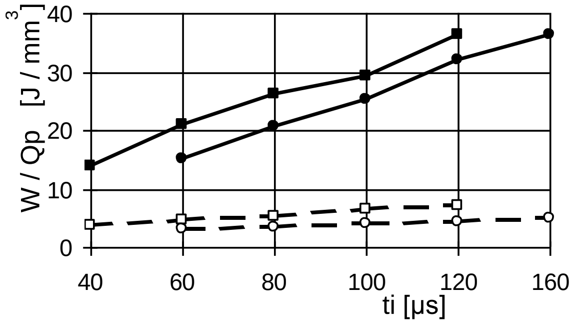
The results presented in table 3 and figure 3 corresponds to a tool electrode made by a cooper sheet of 0.5 mm width. Those presented in table 4 and figure 4 corresponds to a tool electrode made by a cooper sheet of 1 mm width.

In the tables and figures presented could be observed a general growing tendency but the evolution ratio is very different for polycrystalline diamond and steel alloy. For PCD the ratio W / Qp is 5 to 10 times higher than those for steel, and increasing is more rapidly. For steel, variation is approximately linear and relatively small.



Legend: PCD ■ ● ♦ and steel alloy □ ○ ◊

Fig.3. Variation of zk % for 0.5 mm tool electrode



Legend: PCD ■ ● ♦ and steel alloy □ ○ ◊

Fig.4. Variation of zk % for 1 mm tool electrode

3. CONCLUSIONS

These findings lead to an important conclusion, namely that the development of erosion process is largely different. Analogies and differences could be as follows.

In both processes is assumed the same initial mechanism for cracks (most probably due to mechanical factors), except that in the case of PCD, the development of such cracks is much easier and therefore more profound.

In PCD case, plasma action is more rigorous localized because of the material nature.

In this case, given the increase in losses through thermal conductivity, is presumably consumed a quantity of energy greater than that for dislocation of the same volume of steel.

At electrical erosion of polycrystalline diamond materials the share of energy related to melting and welding the base material is negligible. This is given to the finding that at the crystal surface displaced, or left the network after processing, there is only a film of metallic material, which ensures to crystal removed some electrical conductivity, leading to the increased number of short circuit pulses, and in this way to a final ratio of energy vs. quantity of removed material much higher.

Higher specific energy consumption (as shown by approximately five to ten times) in the case of polycrystalline diamond should be primarily put on account of the mechanical processes specific to this situation (for example, for particle transport from the area which have been displaced). As is known from scientific literature, the expulsion of eroded material is a result of pressure increases the discharge channel. In PCD case this is manifested in a lesser extent, due primarily to the much smaller amount of melted and vaporized material (binder), compared with the processing of steel where the entire displaced volume melts and in some extent even reach the gas phase.

The process of graphitisation may explain the high-energy consumptions, which is observable when diamonds are at higher temperatures (over 800 ^{o}C). This is the cause of more short circuits, reflected in increasing necessary energy, but who are not produced any material removals.

Exponential growth of ratio W / Qp depending on pulse off duration for PCD can be put into account of reduced time to evacuation of eroded material. In this way, could be explained why metallic materials, even with less homogeneity (metal carbides, for example) are better processed when the fill factor ti/T is smaller.

Energy balance model for homogeneous materials is based primarily on thermal model. This model could not be applied to PCD materials where erosive process presumably includes a series of mechanical phenomena which are particularly important. When the model was constructed for the erosion of steel, these aspects have been neglected.

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