Electrical discharge machining with graphene flakes in dielectric

Obróbka elektroerozyjna z płatkami grafenowymi w dielektryku

RAFAŁ ŚWIERCZ *

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The article presents statistical analysis of results experimental investigation of EDM process with graphene flakes in dielectric. The relations between surface roughness and process parameters have been determined.

KEYWORDS: electrical discharge machining (EDM), graphene flakes, surface roughness

Physics of material removal in electro-discharge machining (EDM) is essentially determined by the properties of medium, in which electrical discharges occur. Experimental investigations of the treatment process using additional powders in the dielectric [1-3] showed the possibility of reducing the roughness of treated surfaces. Molecules placed in the dielectric facilitate the initiation of electrical discharge while reducing its energy. Surface after machining is characterized by both a reduced roughness parameter R_a and structural changes occurring as a result of particle melting [5, 6]. Due to the properties of graphene flakes (high thermal conductivity 4840 ÷ 5300 W/m·K - and electric conductivity - 200 times greater than silicon) [4], there may be a different course of electrical discharge in kerosene.

Purpose of research

The purpose of the study was to determine the influence of selected parameters of electro-discharge machining and the type of applied dielectric (kerosene, kerosene with reduced graphene oxide flakes - RGO) on selected parameters of surface roughness.

Experimental

Experimental studies of electrical discharge machining process were carried out on the machine Charmilles Form 2 LZ ZNC. Grinded samples of hardened tool steel 1.2713 with dimensions of 12 x 12 mm were treated with cooper electrode. The study was conducted according to Hartley design of experiment two-stage, five-level. The following variables were adopted: pulse current I, pulse duration t_{on}, kerosene dielectric and kerosene with RGO (0.1%). Value of the constant parameter - discharge voltage U_c = 25 V. Time interval t_{off} was set as a pulse filling factor of σ = 0.7.

Analysis of the test results shows that there are significant differences in the topography of the treated surfaces depending on the pulse current and pulse duration values and dielectric properties. The arithmetic mean of the deviations from the mean S_a is in the range of 2.02 to 11.9 µm for kerosene dielectric and in the range of 0.96 to 8.89 µm for kerosene with RGO. These values correspond to the roughness of finishing and roughing. There is a noticeable decrease in the value of the roughness amplitude parameters when treated in RGO solution. The arithmetic mean curvature to the tops S_{sc} is in the range of 0.053 to 0.094 µm^{-1} for kerosene dielectric and from 0.053 to 0.084 µm^{-1} for kerosene with graphene flakes. The value of S_{sc} has a significant impact, among others, on abrasive wear of the surface, the possibility of surface coating and reflection. The higher the inclination and the smaller the rounding radius, the higher the roughness of the tops, the higher the friction coefficient, while increasing the surface adhesion. Tab. I presents results of measurements of selected surface roughness parameters.

TABLE I. Test results - surface roughness parameters

No.	Machining parameters		SGP parameters			
			kerosene		kerosene with RGO	
	I A	t_{on} µs	*Sa* µm	*Ssc* µm^{-1}	*Sa* µm	*Ssc* µm^{-1}
1	2,1	10	2,08	0,0665	0,263	0,0632
2	13,5	10	5,43	0,0885	0,379	0,0527
3	2,1	145	1,86	0,0531	0,180	0,0598
4	13,5	145	12,20	0,0943	0,513	0,0824
5	7,8	5	3,28	0,0839	0,353	0,0815
6	7,8	150	6,05	0,0715	0,342	0,0618
7	1,7	78	1,73	0,0670	0,201	0,0735
8	14,0	78	7,50	0,0914	0,481	0,0771
9	7,8	78	6,31	0,0858	0,428	0,0839
10	7,8	78	7,48	0,0874	0,442	0,0798

Based on experimental results, statistical mathematical models of the machining process were determined (tab. II).

* Dr inż. Rafał Świercz (rsw@meil.pw.edu.pl) – Instytut Technik Wytwarzania Politechniki Warszawskiej

TABLE II. Regression equations

Regression equations - machining in kerosene	R	F/F_{kr}
$Sa = 3{,}53 - 0{,}00019\ t_{on}^2 + 0{,}006\ I\ t_{on}$	0,96	47
$Ssc = 0{,}068 + 0{,}0014\ I - 0{,}000001\ t_{on}^2 + 0{,}000014\ I\ t_{on}$	0,96	24
Regression equations - machining in kerosene with RGO	R	F/F_{kr}
$Sa = -1{,}39 + 0{,}81\ I + 0{,}003\ I\ t_{on} - 0{,}00035\ t_{on}^2 + 0{,}046\ t_{on} - 0{,}033\ I^2$	0,99	40
$Ssc = 0{,}076 - 0{,}000001\ t_{on}^2 - 0{,}000117\ I^2 + 0{,}000028\ I\ t_{on}$	0,75	2,65

Regression equations were described as a function of a second degree polynomial in the Statistica software. For each equation, the correlation coefficient R was used to reflect the variability of the feature to be tested. Validation of the regression equations was tested applying statistical tests (for $\alpha = 0.05$): F-Snedecor and t-Student. The obtained dependencies are shown in fig. 1 and fig. 2. The roughness parameters (e.g. S_a - fig. 1) are mainly dependent on the value of discharge current. The increase in the pulse current I and pulse duration t_{on}, corresponds to the increase in the amount of eroded material in a single impulse, leading to the generation of roughness of higher heights. At low currents (in the order of 1.7 A), increasing the discharge time (and therefore energy) does not result in a significant increase in the S_a parameter. This can be related to the amount of heat (depending on the current intensity) produced and delivered to the workpiece during the discharge process, which causes the material to melt and evaporate. Geometry of inequality described by the arithmetic mean curvature to the tops S_{sc}. Parameters S_{sc} depends both on the pulse current and the pulse duration. At the highest values of energy discharge, not only craters with the greatest depth are created, but also the vertices of inequality have the largest radius. This may be due to re-solidification of the melt microstructures that have not been eroded in the discharge process and re-solidified on the uneven surface. Change in the properties of medium, in which the electrical breakthrough takes place, significantly affects the values of roughness parameters (S_a) and the parameters describing their geometry (S_{sc}). Both for the largest and the smallest pulse current and pulse duration values, decrease in the analyzed values were observed during machining in kerosene with graphene flakes. This may be a direct result of the electrical discharge dispersion occurring on graphene flakes. Electrical discharge heating the surface being processed has lower energy.

The developed regression equations are characterized by a higher correlation coefficient R and less scattering of values in the electro-discharge machining in the kerosene with RGO. This may be due to the fact that better discharge stability is achieved throughout the area of electrical parameters tested.

Conclusions

Experimental studies have shown that the change in properties of the medium (adding conductive molecules) significantly affects the course of electrical discharge, and thus the effects of machining. Because of the properties of graphene flakes (high electrical and thermal conductivity), the course of electrical discharge and the final heat dissipation in the inter-electrode gap relative to the treatment in kerosene, are different. Facilitating the initiation of an electrical discharge (with an increased gap between standard electrodes) results in stable, low-energy electrical discharges.

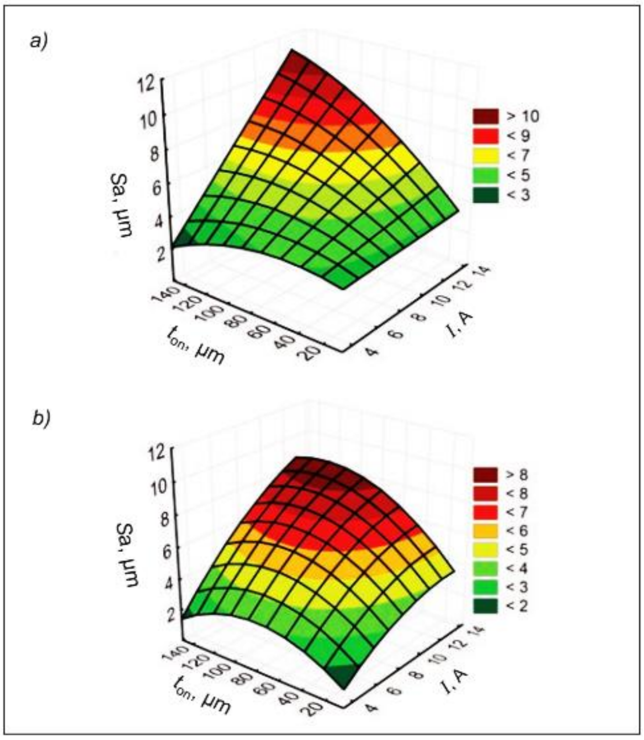

Fig. 1. Dependence of S_a parameter on the pulse current I, pulse duration t_{on}, a) machining in kerosene, b) machining in kerosene solution with RGO

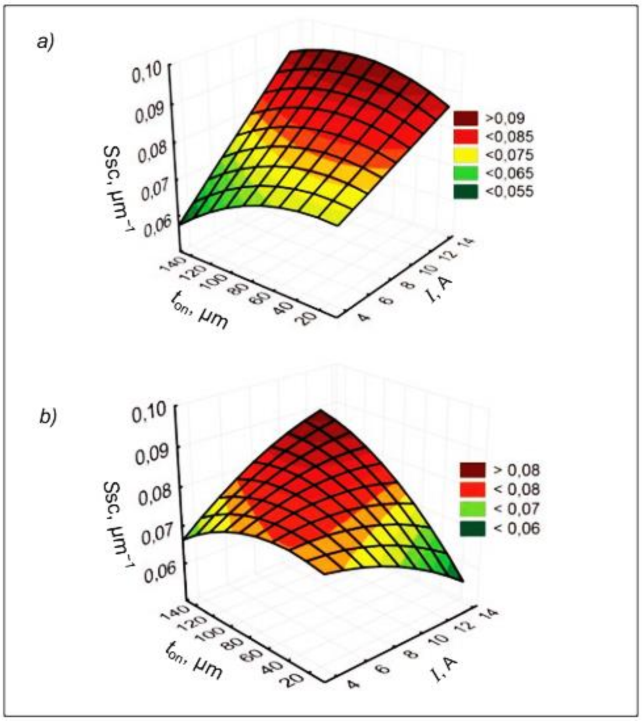

Fig. 2. Dependence of S_{sc} parameter on the pulse current I, pulse duration t_{on}: a) machining in kerosene, b) machining in kerosene with RGO

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