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SIMULATION OF ELECTRICAL DISCHARGE MACHINING OF DISSIMILAR MATERIALS

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ABSTRACT

Mathematical model of wear pattern of tool electrode (TE) upon processing of dissimilar materials enables forecasting of output processing parameters and provides preset precision indices. At present simulation of TE wear upon processing of dissimilar materials is not sufficiently studied. In the course of electrical discharge machining (EDM) of dissimilar materials physical processes at interface between two materials differ from those peculiar upon processing of uniform material. Taking into account that electrical discharge resistance of bimetal components is different, TE is exposed to heterogeneous wear upon electrical discharge machining. We developed theoretical model facilitating estimation of EDM rate of steel-copper bimetal. On the basis of theoretical and experimental studies it is established that during processing of steel-copper bimetal maximum heterogeneity is achieved in min mode and equals to 2.44 mm. Taking in account that electrical discharge resistance of copper exceeds similar properties of Dural electrode, intensive wear of electrode is observed upon processing of copper. Minimum processing heterogeneity has been detected for med mode. Intensive TE wear is observed upon processing of item in maximum mode. Upon processing by copper electrode maximum heterogeneity has been achieved in min mode equaling to 0.89 mm. Minimum heterogeneity in med mode is 0.11 mm. It would be reasonable to process bimetal alloy in med mode with minimum processing heterogeneity. Experimental data confirm satisfactory agreement with theoretical calculations concerning occurrence of step on bimetal surface after processing. It is demonstrated that the amount of material removed per one pulse depends on pulse energy as well as on thermophysical constants of processed material.

Keywords: electrical discharge machining, tool electrode, bimetal, wear, precision, structure, simulation.

INTRODUCTION

Engineering development requires for necessity to create materials characterized by numerous properties providing high strength, corrosion resistance, heat conductance, wear resistance and others. Quite often individual metals and alloys cannot provide the required range of properties. Thus, layered metal composition is widely applied. Such materials can be produced by joining of dissimilar materials into solid composition preserving reliable connection of constituents upon subsequent engineering processing and operation [1-3]. Such materials include bimetals.

Electrical discharge workability of materials depends on their physicochemical properties. It is demonstrated in [4-6] that, assigning electrical discharge processability of steel to unity, electrical discharge workability of other metals (other conditions being equal) can be presented in the following relative units: tungsten - 0.3; solid carbide - 0.5; titanium - 0.6; nickel - 0.8; copper - 1.1; brass - 1.6; aluminum - 4; magnesium - 6. Thus, EDM of bimetals characterized by different electrical discharge machinability will run in heterogeneous manner.

In [6-12] interrelation between wear of tool electrode (TE) and error of shape of processed surface upon processing of similar materials is described.

The TE material is one of major elements participating in electrical discharge. Efficiency and quality of EDM depend on TE material. TE should be made of erosion resistant material, provide steady operation in overall range of EDM operation modes, and maximum efficiency with minor wear. Amount of thermal energy evolved at each electrode upon pulse discharge is different; as well as the amount of removed material from electrode surfaces.

Less intensive electric erosion will be peculiar for materials characterized by high melting points. Materials used for production of TEs in ascending order of their erosion resistance are as follows: aluminum and its alloys, gray cast iron, brass, copper, tungsten, graphitized materials [3, 4, 6].

It is demonstrated in [3] that upon processing of steel-copper bimetal by brass electrode the TE wear is heterogeneous: in copper processing point the electrode is worn more intensively than in steel processing point. Maximum difference in the electrode wear is 3.24 mm. It is established that upon processing by copper electrode in med, max modes the electrode wear is minimum and equals to 0.06 mm and 0.03 mm, respectively. It is demonstrated that upon processing of steel–copper bimetal by Dural electrode the TE wear is heterogeneous: in copper processing point the electrode is worn more intensively than in steel processing point. Maximum difference in the electrode wear is 2.64 mm. It is demonstrated that upon processing of steel-copper bimetal by steel electrode the TE wear is heterogeneous: in copper processing point the electrode is worn more intensively than in steel processing point. Maximum difference in the electrode wear is 1.82 mm.

Despite the performed experimental tests, the problem of simulation of bimetal processing is still urgent. Development of mathematical model enabling description of wear pattern of TE makes it possible to forecast output

processing parameters and to provide preset precisions. At present simulation of TE wear upon processing of dissimilar materials is not sufficiently studied.

MATERIALS AND METHODS

Steel-copper bimetal has been selected as experimental material. Steel: grade 09G2S according to Russian Standard GOST 19281 - 89. Copper: grade M1 according to Russian Standard GOST 859-2001.

A billet was processed with Electronica Smart CNC punching machine.

Processing modes are summarized in Table-1.

Table-1. Processing modes.

Processing modes	Min	med	max
Ton, µs	1	100	750
Ip, A	0.5	3	20
U, B	50	50	50
Depth of processing, mm	5	5	5
Processing modes in codes of Smart CNC machine	E13	E55	E96

TEs were as follows: steel 20, Russian Standard GOST 1050-8; Dural, grade D16, Russian Standard GOST 4784-74; copper M2, Russian Standard GOST 859-2001. Electrode diameter: 8 mm. Operating fluid: EDM Oil - IPOL SEO 450.

Simulation of EDM of item with fused coating

The following assumptions were made for theoretical study:

a) No diffusion layer exists at material interface.

b) TE consists of homogeneous material.

c) TE moves only progressively upon processing.

d) Properties of operating fluid are uniform along overall length of inter-electrode gap.

e) Electrode surfaces are parallel at the start of processing.

The inter-electrode gap is uniform over total surface of processing at initial time. When operating pulse is fed, the breakage occurs in any point of operating region. Removal of material will vary depending on its thermomechanical properties. Components of bimetal items are usually characterized by significantly different properties, that is, by their electrical discharge machinability.

In the course of time some material is removed from each billet part. Minimum value of inter-electrode gap on one of the materials will exceed the value required for breakage which leads to heterogeneous wear of TE [3].

Since the electrode surfaces are worn equally, the inter-electrode gap above one of the bimetal materials will be lower. Hence, this material will be processed first. Step by step distribution of the inter-electrode gap will vary, and material will be removed from the second bimetal part.

In the course of processing the electrode surfaces will obtain more and more pronounced step-like shape with rounded profile edges.

Further on, let us denote the parameters using the following postscripts: 1 - relating to EDM, 2 - relating to TE, 3 - relating to billet.

In general case the surfaces of TE and billet can be described by the following implicit functions:

$$\Phi_2(x, y, z + h, h) = 0,$$
$$\Phi_3(x, y, z, h) = 0, \tag{1}$$

where x, y, z are the Cartesian coordinates of points located on the surface of TE and billet; $h = \int_0^t V_2(\tau)d\tau$ is the distance passed by TE along z axis; $V_2(\tau)$ is the motion speed of TE upon processing; t is the time.

Assuming that metal is removed flatwise from TE and billet, on the basis of equation (1) it is possible to derive equation of surface evolution of TE and billet upon processing [12-15]:

$$-k_v k V_1 |\text{grad } \Phi_2| + \frac{\partial \Phi_2}{\partial h} + \frac{\partial \Phi_2}{\partial(z+h)} = 0,$$
$$-V_{ээо} |\text{grad } \Phi_3| + \frac{\partial \Phi_3}{\partial h} = 0, \tag{2}$$

where k_v is the relative bulk wear of TE; k is the coefficient considering for heterogeneity of electric field in inter-electrode gap (TE surface curvature); V_1 is the rate of metal removal upon EDM. These equations are illustrated in Figure-1, for billet of homogeneous material. Substituting the variables:

$$T_2(x, y, z + h) = \Phi_2(x, y, z + h, h) - h,$$
$$T_3(x, y, z) = \Phi_3(x, y, z, h) - h, \tag{3}$$

Equation (3) can be rewritten as eikonal equations:

$$|\text{grad } \Phi_2| = \frac{1}{k_v k V_1}\left(1 + \frac{\partial T_2}{\partial(z+h)}\right),$$
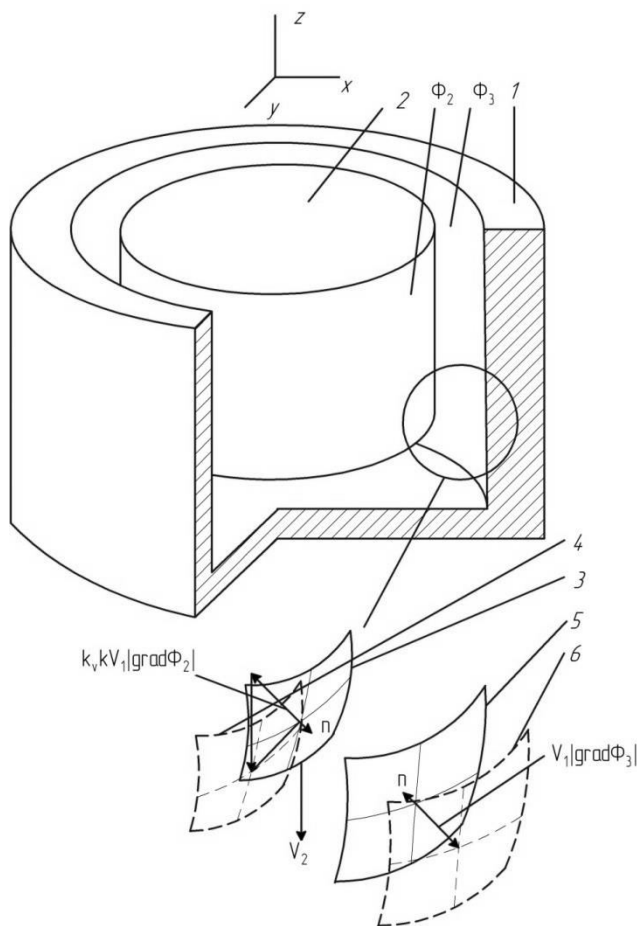$$|\text{grad } \Phi_3| = \frac{1}{V_1}, \tag{4}$$

Figure-1. Evolution of electrode surfaces: 1- billet; 2 - TE; 3 - element of TE initial surface; 4 - element of TE modified surface; 5 - element of billet initial surface; 6 - element of billet modified surface.

Proceeding to bimetal processing, considering for made assumptions, the model will be presented as a set of equations (4) for each billet part:

$$
\begin{cases}
\left|\operatorname{grad}\Phi_2^1\right| = \dfrac{1}{k_v^1 k V_1^1}\left(1 + \dfrac{\partial T_2^1}{\partial(z+h)}\right), \\[2mm]
\left|\operatorname{grad}\Phi_3^1\right| = \dfrac{1}{V_1^1} \\[2mm]
\left|\operatorname{grad}\Phi_2^2\right| = \dfrac{1}{k_v^2 k V_1^2}\left(1 + \dfrac{\partial T_2^2}{\partial(z+h)}\right), \\[2mm]
\left|\operatorname{grad}\Phi_3^2\right| = \dfrac{1}{V_1^2}
\end{cases}
\tag{5}
$$

where superscripts 1 and 2 relate to the billet regions of different materials and corresponding regions of TE.

The rate of EDM of billet can be calculated as follows:

$$V_1 = Cx\lambda T^2 W_p f, \tag{6}$$

where: W_p is the pulse energy; f is the pulse repetition rate; C is the heat capacity of the processed material; x is the density; λ is the coefficient of heat conductivity; T is the melting point.

According to equation (6) the amount of metal removed per one pulse depends on pulse energy as well as on thermophysical constants of processed materials, that is, its melting point, thermal conductivity, thermal capacity and density. Knowing thermophysical properties of bimetal components, it is possible to calculate the rate of EDM for each component.

Table-2 summarizes calculated ratios of erosion rates TEs upon processing of steel–copper bimetal. For the sake of simplicity let us denote the TE segment corresponding to steel part of the billet as segment 1 (rate V_1^1); TE segment corresponding to copper part of the billet - as segment 2 (rate V_1^2).

Table-2. Erosion rate ratio of TE regions upon various processing modes.

Processing mode	Dural TE V_1^1 / V_1^2	Steel TE V_1^1 / V_1^2	Copper TE V_1^1 / V_1^2
Min	0.08	0.4	0.1
Med	0.53	0.53	0.02
Max	0.4	0.33	0.06

Knowing the rate of EDM of segments of TEs of dissimilar materials and assuming the processing time being constant, it is possible to calculate the distance passed by electrode for each segment [3]:

$$h = \int_0^t V_1(\tau)d\tau \tag{7}$$

Table-3 summarizes calculations of bimetal processing. Processing heterogeneity was calculated as the difference between distance passed by TE upon processing of bimetal steel part (h_{steel}) and distance passed by TE upon processing of bimetal copper part (h_{copper}).

Table-3. Calculated bimetal processing heterogeneities.

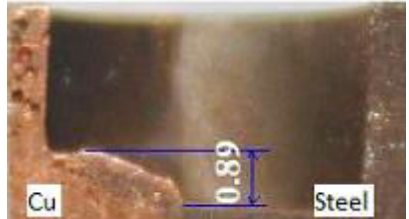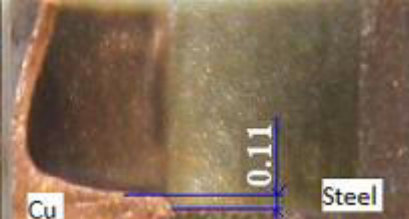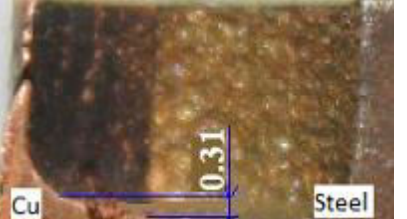| Processing mode	Dural TE h_{steel} - h_{copper}	Steel TE h_{steel} - h_{copper}	Copper TE h_{steel} - h_{copper}
Min	2.1	1.3	0.6
Med	1.8	1.2	0.3
Max	0.9	1.1	0.1
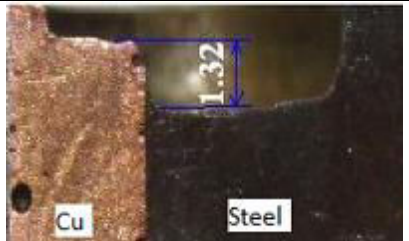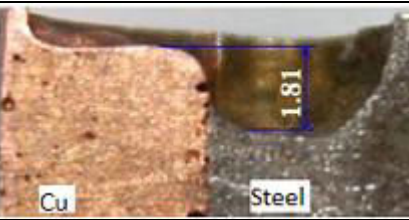
It is demonstrated that upon processing by copper TE the processing heterogeneity will be minimum in comparison with TE made of steel and aluminum.

Experimental studies of EDM of item with fused coating

Table-4 summarizes experimental results of processing heterogeneity of bimetal using electrodes with different physicomechanical properties in minimum, medium and maximum modes.

Table-4. Bimetal processing heterogeneity.

Upon processing of steel–copper bimetal by Dural electrode maximum heterogeneity was achieved in min processing mode equaling to 2.44 mm. Taking into account that electrical discharge resistance of copper exceeds similar properties of Dural electrode, intensive wear of electrode can be observed upon processing of copper. Minimum processing heterogeneity was detected for med mode. Intensive TE wear occurs upon processing in maximum mode.

Upon processing of experimental specimen by steel electrode maximum heterogeneity was achieved in med processing mode equaling to 1.81 mm. Minimum processing heterogeneity was detected for min mode equaling to 1.55 mm. This can be attributed to the fact that upon processing of materials it would be reasonable to select minimum processing mode. Heat is distributed uniformly over the processed item without overheating.

Upon processing of experimental specimen by copper electrode maximum heterogeneity was achieved in min processing mode equaling to 0.89 mm. Minimum processing heterogeneity was detected for med mode

equaling to 0.11 mm. It would be reasonable to process bimetal alloy in med mode with minimum processing heterogeneity.

CONCLUSIONS

Theoretical model facilitating estimation of EDM rate of steel-copper bimetal has been developed. Experimental data confirm satisfactory agreement with theoretical calculations concerning occurrence of step on bimetal surface after processing.

It is demonstrated that the amount of material removed per one pulse depends on pulse energy as well as on thermophysical constants of processed material.

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REFERENCES

[1] Shabgard M. 2014. Experimental investigation into the EDM process of γ -TiAl/M. Turkish Journal of Engineering & Environmental Sciences. 38: 231-239.

[2] Ojha K., Garg R.K. and Singh K.K. 2010. MRR improvement in sinking electrical discharge machining: a review. J Miner Mater Charac Eng. 9: 709-739.

[3] Ablyaz T. R., Simonov M. Y., Schlykov E. S. and Muratov K. R. 2016. Surface Analysis of Bimetal After EDM Machining Using Electrodes with Different Physical and Mechanical Properties. Research Journal of Pharmaceutical, Biological and Chemical Sciences. 7(5): 974-981.

[4] Ablyaz T.R., Khanov A.M., and Khurmatullin O.G. 2012. Sovremennye podhody k tekhnologii elektroerozionnoi obrabotki materialov. [Current approaches to electrical discharge machining of materials]. Perm: R&D polytechnic university.

[5] Pogonin A. A., Boiko A. F. and Blinova T. A. 2010. Dispersnyi analiz produktov elektroerozionnoi pretsizionnoi obrabotki [Disperse analysis of results of electrical discharge machining]. Tekhnol. Mashinostr. 6: 26-28.

[6] Zhurin A.V. 2005. Metody rascheta tekhnologicheskikh parametrov i elektrodov-instrumentov pri elektroerozionnoi obrabotke [Calculation procedures of process variables and electrode tools upon electrical discharge machining]: Cand. Thesis. TGU, Tula.

[7] Kabaldin Yu. G., Sarilov M. Yu. and Bilenko S. V. 2007. Povyshenie ustoichivosti protsessa elektroerozionnoi obrabotki i kachestva obrabotannoi poverkhnosti na osnove podhodov iskusstvennogo intellekta [Achievement of steady electrical discharge machining and quality of processed surface on the basis of artificial intelligence]. Komsomolsk-on-Amur: KnAGTU.

[8] Serebrenitskii P. P. 2007. Sovremennye elektroerozionnye tekhnologii i oborudovanie: uchebnoe posobie [Current electrical discharge procedures and equipments: Guidebook]. Saint Petersburg: Balt. State technical University.

[9] S`yanov S. Yu. 2002. Tekhnologicheskoe obespechenie kachestva poverkhnostnogo sloia detalei pri elektroerozionnoi obrabotke [Engineering support of quality of surface layer upon electrical discharge machining]: Cand. Thesis. BGTU, Bryansk.

[10] Foteev N.K. 1994. Upravlenie kachestvom poverkhnosti tekhnologicheskoi osnastki pri elektroerozionnoi obrabotke. [Surface quality management of technological equipment upon electrical discharge machining]. Elektron. Obrab. Mater. 2: 5-7.

[11] Ablyaz T. R. 2016. Roughness of the machined surface in wire EDM. Russian Engineering Research. 36(8): 690-691.

[12] Ablyaz T. R. and Zhurin A. V. 2016. Influence of Wire-Cut Electrical Discharge Machining on Surface Quality. Russian Engineering Research. 36(2): 156-158.

[13] Dey S. 2013. Experimental Study Using Different Tools. International Journal of Modern Engineering Research (IJMER). 3(3): 1263-1267.

[14] Janmanee P. 2010. Performance of Difference Electrode Materials in Electrical Discharge Machining of Tungsten Carbide. Energy Research Journal. 1(2): 87-90.

[15] Tsai H. 2003. The properties and characteristics of the new electrodes based on Cr-Cu for EDM machines. International Journal of Machine Tools & Manufacture. 43(3): 245-252.