SURFACE TEXTURE AFTER WIRE ELECTRICAL DISCHARGE MACHINING

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Abstract

Wire electrical discharge machining (WEDM) belongs to the advanced technology widely used in the engineering industry. In WEDM process material is removed from workpiece by series of electrical sparks. The article studies the interactions between process parameters and the final quality of the generated surface (for steel 1.2201). The influence of WEDM parameters: initial current I_w (A), initial pulse time t_w (μs), discharge duration t_{on} (μs), on the surface roughness were experimentally evaluated. The obtained results show that surface roughness *Ra* after WEDM process for the first cut is the range between 1.9 - 2.5 μm. The primary factor in determining the treatment process is the energy of electrical discharge. The effect of the WEDM parameters on the functional parameters of surface roughness: *Sk* - roughness of the core, *Spk* roughness of the peak, *Svk* - roughness of the valleys are also presented and discussed.

Keywords: Wire Electrical Discharge Machining, surface texture

1. INTRODUCTION

Wire electrical discharge machining (WEDM) is a kind of thermal machining process, which allows the shaping of complex parts especially of hard difficult to machining materials. In the WEDM process, the working electrode is a thin wire with a diameter of 0.02 - 0.5 mm, usually made of brass. The physics of the erosion phenomenon is complex. In the wire electrical discharge process, the material is removed from the workpiece as a result of electrical discharges between the work electrode and the surface of the workpiece. Removal mechanism of the material in WEDM is mainly the result of the electrical discharge which causes melting and evaporation in local surface layers of both the workpiece and the working electrode. The heat also causes evaporation of the dielectric liquid and induces high pressure waves which removed the molten and/or vaporized metal. In place of discharge crater is formed, part of the melted metal "thrown" to electrode gap and removed together with the flowing dielectricn [11]. During machining, there are hundreds of electrical discharges that form the characteristic surface texture formed by overlapping craters from individual discharges. Surface texture proporties is one of the most important factors determining its ability to: abrasion resistance, hardness, corrosion resistance, resistance to thermal shocks, coating quality and more [1, 2, 4, 20, 21, 23].

The basic parameters and machining conditions determining the physical phenomena occurring in the WEDM process are: electrical parameters (pulse on time, pulse off time, current, voltage, pre-impulse time), parameters related to the working electrode (wire tension, wire speed, material of electrode, electrode diameter), parameters related to the dielectric (degree of ionization, volume flow, type of dielectric) and workpiece (type and height of the material) [6, 7, 14, 16, 19]. The published results of the WEDM are concentration to: optimization of cutting parameters [3, 10, 17, 18, 22], discribed of the surface layer [5, 8, 9, 13], control and monitoring process stability [12, 14]. However, analysis of surface texture parameters related to functional parameters of surface roughness are not enough described. Therefore in this paper present experimental investigation of the influence of electrical process parameters (initial current I_w (A), initial pulse time t_w (μs), discharge duration t_{on} (μs)) on the texture of the workpiece.

2. EXPERIMENTAL WORK

2.1. Experimental details

The workpiece material used in the present investigation is steel 1.2201 heat treated to a hardness of 62 HRC. The steel is characterized by high abrasion resistance and a small deformation during hardening. Steel 1.2201 is used in the production of tools for machining, plastic processing (punches, dies), for the production of molds for injection, sheet metal cutting knives, measuring tools. The study was conducted on ROBOFIL 190 of Charmilles. The working electrode was a brass wire with a diameter of 0.25 mm. Dielectric (deionized and demineralized water) was given into the gap between electrode from the upper and lower nozzle. The samples were prepared in one clamping block of material. 15 sections were cut with dimensions of 10 x 10 mm, with a height of 100 mm. Investigated process parameters was discharge duration in range t_{on} = 1.4 - 1.8 (μs), initial current in range I_w = 4 - 12 (A), initial pulse time t_w = 0.2 - 0.6 (μs). The rest of parameters of WEDM were hold constants: voltage discharge U = 25 (V), wire speed V_d = 10 m·min^{-1}, volume flow of the dielectric Q_v = 54 l·min^{-1}, wire tension force F_n = 1.4 daN.

In investigated WEDM machine increasing discharge duration t_{on} cause increase of the discharge current. The electrical discharge is generated in two stages, a pre-pulse is generated in the first phase (initial current I_w and initial pulse time t_w), its function is to properly prepare the conditions in the gap. Second phase is appropriate discharge impulse wich causing erosion of material. Between the pulses there is an interval of adjustable duration t_{off}, where the plasma channel closes, the partial removal of the treatment products and the cooling of the electrodes. The impulse energy affects the cutting speed as well as the state of the surface texture. The discharge energy can be controlled using the parameters described above. This energy must be selected in such a way that it does not cause the wire break.

2.2. Measuring surface texture

Roughness of cut samples were measured using the Taylor-Hobson FORM TALYSURF Series 2 scan profilometer. For each sample, area 2 x 4 mm was measured. The X-axis and Y-axis discretization step was 10 μm. To characterize the surface texture after WEDM processs following 3D parameters surface roughness was discribed:

- arithmetic mean of the deviations from the mean *Sa* - average value of the absolute heights over the entire surface. It may be obtained by adding individual height values without regard to sign and dividing the sum by the number of the data matrix, where M is a number of points per profile, N the number of profile and $z_{x,y}$ the height of the profile at a specific point.

$$Sa = \frac{1}{NM} \sum_{x=0}^{N=1} \sum_{y=0}^{M=1} \left| z_{x,y} \right| \tag{1}$$

- density of tops *Sds* - number of summits of a unit sampling area, which relies on the eight nearest neighbour summit definition, peak is defined if it is higher than its eight nearest neighbours:

$$Sds = \frac{1\, number\ of\ summits}{(M-1)(N-1)(\Delta x \Delta y)} \tag{2}$$

- high of the surface *St* - total height of the surface
- height of 10 points of the surface *Sz* - mean of the distance between the 5 highest peaks and the 5 deeps holes.
- symetry of the distribution curve of depths *Ssk* - a negative *Ssk* indcattes that the surface is composed with principally one plateau and deep and fine valleys. In this case the distribution is sloping to the top. A positive *Ssk* indicates a surface with lot of peakes on the plane. The distributions is sloping to the bootom.

$$Ssk = \frac{1}{NMS_q^4} \sum_{x=0}^{N=1} \sum_{y=0}^{M=1} z_{x,y}^3 \qquad (3)$$

3. RESULTS AND DISCUSSION

3.1. Properties of surface texture after WEDM

The surface texture after wire electrical discharge machining has an isotropic nature. Surface roughness is generated by overlapping traces (craters) of individual electrical discharges. The crater shapes defines the obtained topography of manufacturing parts. The surface texture after WEDM (**Figure 1**) is random with high surface density of tops *Sds = 1758 pks / mm*^{2}, roughness *Sa* = 2.52 µm.

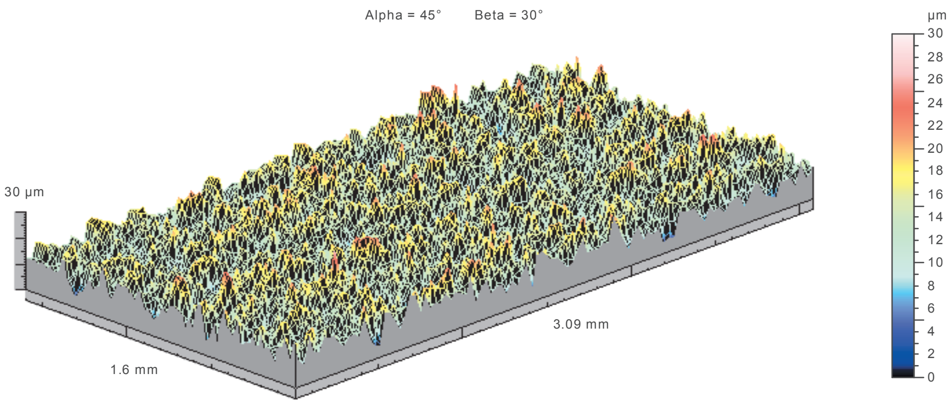


Figure 1 Surface texture after WEDM process for parameters: discharge duration t_{on} = 1.8 µs, initial current I_w = 8 A, initial pulse time t_w = 4 µs

Depending on the energy supplied; the individual parameters of the surface geometry are changed. The randomness of the structure is due to the rapidly disappearing autocorrelation function *Sal* = 0.0508 mm (**Figure 2a**). The structure is characterized by a positive *Ssk* = 0.344, which indicates a surface with lot of peaks on the plane. The distribution of ordinates is normal (**Figure 2b**) - the structure is characterized by unfavorable bearing capacity of surface. The difference between the *St* = 26.3 µm and *Sz* = 25.4 µm parameters is small; the share of random vertices and indentations is negligibly small, which indicates the stability of discharges.

a) b)

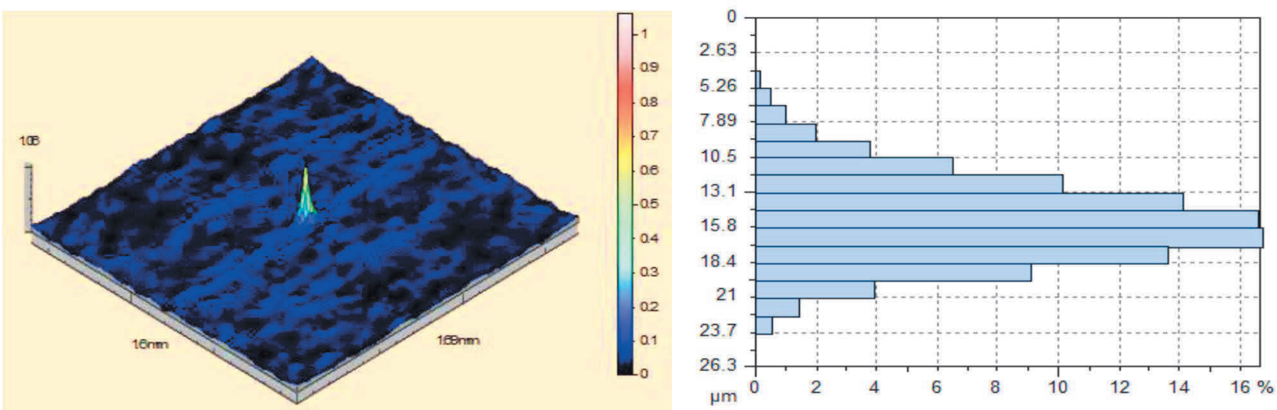


Figure 2 3D autocorrelation function (a) and distribution of ordinate (b)

One of the basic parameters to evaluate the tribological properties of a surface is the bearing capacity curve, which describes the cross-sectional area unevenness (**Figure 3**). For the test sample, the bearing surface on the average plane is 47.5 %. The value of the roughness of peaks is *Spk* = 3.69 µm. This parameter can provide the basis for assessing the surface resistance to abrasion. The roughness of core *Sk* is a measure of the effective depth of inequality and is 7.94 µm. The roughness of valleys *Svk* (reduced depth of the cavities) describes the ability to maintain fluid through the sliding surfaces and is 2.42 µm. Percentage contribution of vertices is described by the parameter *Sr1* (upper bearing of surface) and is 11.6 % and percentage contribution of the recesses is described by the parameter *Sr2* (lower bearing of surface) is 92.2 %.

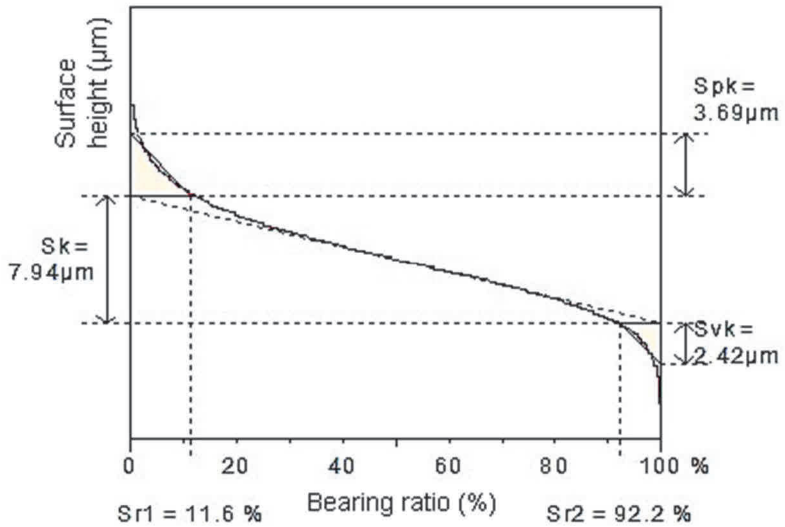


Figure 3 Abbott - Firestone curve for WEDM parameters discharge duration t_{on} = 1.8 µs, initial current I_w = 8 A, initial pulse time t_w = 4 µs

3.2. Influence of WEDM process parameter on surface roughness

Experimental investigation of influence WEDM process parameters: discharge duration t_{on}, initial current I_w, initial pulse time t_w on roughness *Ra* was conducted. Parameters of roughness *Ra* (**Figure 4**) are mainly dependent on the time pulse t_{on}, and therefore depend on the value of the electrical discharge energy (the increase of the t_{on} is combined with the increase of the discharge current I_c). The values of the basic roughness parameter of the profile are contained within the limits *Ra* = 1.92 ÷ 2.52 µm, thus corresponding to the roughness theoretical values for finishing and rough finishing obtained in one pass of the working electrode after the programmed path.

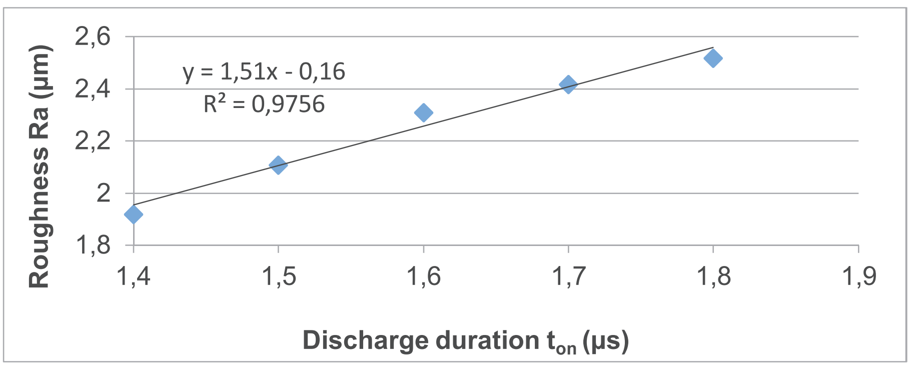
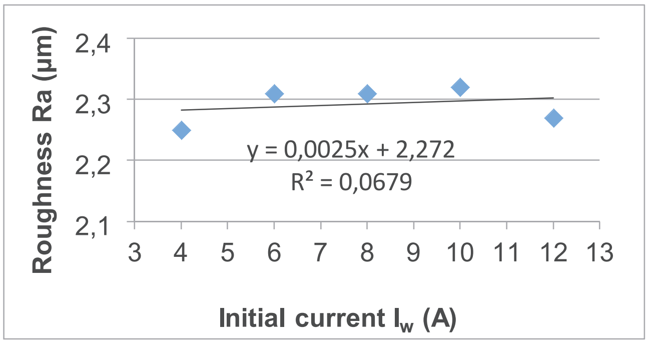


Figure 4 The dependence of surface roughness *Ra* from discharge duration t_{on} at constant initial current I_w = 8 A, initial pulse time t_w = 4 µs

The basic parameters characterizing the process of electrical erosion is the energy supplied to the electrodes. The pre-pulse discharge energy (initial curent I_w and its time t_w) does not significantly affect changes in height parameters of the roughness (**Figure 5a, b**). Results of experimental investigation shows that initial curent I_w and its time t_w have influence only for discharge stability. These two parameters responsible for the proper preparation conditions in the gap for the main discharge.

a)



b)

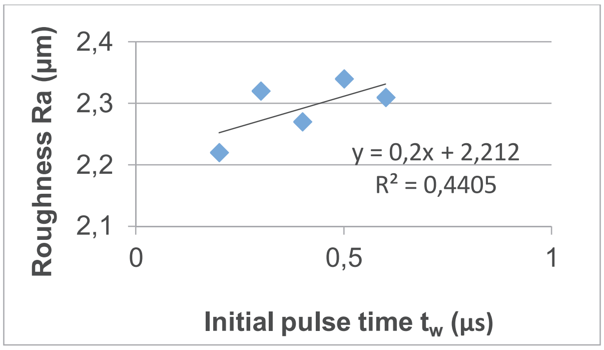


Figure 5 The dependence of surface roughness *Ra* from (a) initial current I_w at constant discharge duration t_{on} = 1.6 µs, initial pulse time t_w = 4 µs, (b) initial pulse time t_w at constant discharge duration t_{on} = 1.6 µs, initial current I_w = 8 A

4. CONCLUSION

One of the basic factors determining the use of wire electrical discharge machining in manufacturing parts is a properties of the surface texture. Surface roughness is generated by overlapping traces of individual electrical discharges. The surface texture after WEDM is isotropic with a high density of tops, with lot of peaks on the plane. The distribution of ordinates is normal the structure is characterized by unfavourable bearing capacity of surface. Experimental investigation of influence WEDM process parameters shows that discharge duration t_{on} has significant influence on the value of roughness *Ra*. Discharge duration, is a parameter that simultaneously determines the current of the discharge. As the pulse on time increases, the current also increases. This cause rise of discharge energy and consistently leads to generate high roughness surface. Initial current I_w and initial pulse time t_w, do not have significant influence for surface texture parameters.

ACKNOWLEDGEMENTS

This study was conducted with financial support from the Fundamental Research Funds of Institute of Manufacturing Technology Warsaw University of Technology, hereby gratefully acknowledged.

REFERENCES

[1] BAŃKOWSKI D., SPADŁO S. "Influence of the Smoothing Conditions in Vibro-Abrasive for Technically Dry Friction the Parts Made of Steel X160CRMOV121". *Proceedings of 25th International Conference on Metallurgy and Materials*, *METAL 2016*, pp. 1019-1024.

[2] CHMIELEWSKI T., GOLAŃSKi D., WŁOSIŃSKI W. Metallization of ceramic materials based on the kinetic energy of detonation waves, *Bulletin of the Polish Academy of Sciences Technical Sciences*, Vol. 63, 2015, pp.: 449-456.

[3] GHODSIYEH D., LAHIJI M. A., GHANBARI M.: Optimizing material removal rate (MRR) in wedming titanium alloy (TI6AL4V) using the Taguchi method, Research Journal of Applied Sciences, *Engineering and Technology*, Vol. 4, 2012, pp.: 3154 - 3161.

[4] HLAVAC, L. M., SPADŁO, S., KRAJCARZ, D., HLAVACOVA I. M. Influence traverse speed on surface quality after water-jet cutting for hardox steel. *Proceedings of 24th International Conference on Metallurgy and Materials METAL 2015,* pp. 723-728.

[5] HAN F., JIANG J., YU D.: Influence of machining parameters on surface roughness in finish cut of WEDM, *International Journal of Advanced Manufacturing Technology*, Vol. 34, Issue 5 - 6, 2007, pp.: 538 - 546,

[6] HO K. H., NEWMAN S. T., RAHIMIFARD S., ALLEN R. D.: State of the art. in wire electrical discharge machining (WEDM), *International Journal of Machine Tools and Manufacture*, Vol. 44, Issues 12 - 13, 2004, pp.: 1247 - 1259.

[7] HOU P. J., GUO Y. F., SUN L. X., DENG G. Q.: Simulation of temperature and thermal stress filed during reciprocating traveling WEDM of insulating ceramics, *Procedia CIRP, ISEM*, Vol. 6, 2013, pp.: 411 - 416.

[8] HUANG Ch. A., SHIH Ch. L., LI K. Ch., CHANG Y. Z.: The surface alloying behavior of martensitic stainless steel cut with wire electrical discharge machine, *Applied Surface Science*, Vol. 252, Issue 8, 2006, pp.: 2915 - 2926.

[9] KOZAK J., RAJURKAR K. P., CHANDARANA N.: Machining of low electrical conductive materials by wire electrical discharge machining (WEDM), *Journalal of Materials Processing Technology*, Vol. 149, Issues 1 - 3, 2004, pp.: 266 - 271.

[10] KUMAR K., AGARWAL S.: Multi-objective parametric optimization on machining with wire electric discharge machining, *International Journal of Advanced Manufacturing Technology*, Vol. 62, Issues 5-8, 2012, pp.:617-633.

[11] KUNIEDA M., LAUWERS B., RAJURKAR K. P., Schumacher B. M.: Advancing EDM through fundamental insight into the process, *CIRP Annals - Manufacturing Technology*, Vol. 54, Issue 2, 2005, pp.: 64 - 87.

[12] KOZOCHKIN M. P., GRIGOR'EV S. N., et al. Monitoring of electric discharge machining by means of acoustic emission, *Russian Engineering Research*, Vol. 36, Issue 3, 2016, pp. 244-248.

[13] LAUWERS B.: Surface Integrity in Hybrid Machining Processes, *CIRP Conference on Surface Integrity (CSI), Procedia Engineering* Vol. 19, 2011, pp.: 241 - 251.

[14] LIAO Y. S., YU Y. P.: Study of specific discharge energy in WEDM and its application, International Journal of *Machine Tools and Manufacture*, Vol. 44, Issue 12 - 13, 2004, pp.: 1373 - 1380.

[15] NOWICKI B., PIERZYNOWSKI R., SPADŁO S. "Investigation of electro-discharge mechanical dressing (EDMD) of diamond abrasive wheels with conductive bonds using brush electrodes", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 220/3 (2006) 421-428. doi: 10.1243/095440505X32922

[16] ONISZCZUK D., ŚWIERCZ R.: Investigation into the impact of electrical pulse character on surface texture in the EDM and WEDM process, *Advances in Manufacturing Science and Technology*, 2012, pp.: 43 - 53.

[17] RAO P.S., RAMJI K., SATYANARAYANA B.: Effect of WEDM conditions on surface roughness: a parametric optimatization using taguchi method, *International Journal of Advanced Engineering Sciences and Technologies* Vol. 6, Issue 1, 2011, pp.: 41 - 48.

[18] SADEGHI M., Razavi H., ESMAEILZADEH A., KOLAHAN F.: Optimization of cutting conditions in WEDM process using regression modelling and tabu - search algorithm, *Proceedings of the Institution of Mechanical Engineers*, *Part B: Journal of Engineering Manufacture*, Vol. 225, 2011, pp.: 1825 - 1834.

[19] SCHUMACHER B. M., KRAMPITZ R., KRUTH J. P.: Historical phases of EDM development driven by the dual influence of "Market Pull" and "Science Push", *Process";17th CIRP Conference on Electro Physical and Chemical Machining (ISEM),* Procedia CIRP 6, Vol. 6, 2013, pp.: 5 - 12,

[20] SPADŁO S., KOZAK J., MŁYNARCZYK P. "Mathematical Modelling of the Electrical Discharge Mechanical Alloying Process";*17th CIRP Conference on Electro Physical and Chemical Machining (ISEM), Procedia CIRP*, Vol. 6, 2013, pp 422-426. doi 10.1016/j.procir.2013.03.031 WOS:000323434000071

[21] SPADŁO S., MŁYNARCZYK P., ŁAKOMIEC K. Influence of the of electrical discharge alloying methods on the surface quality of carbon steel, *The International Journal of Advanced Manufacturing Technology,* Vol. 89, 2017, pp. 529-1534.

[22] YANG R. T., TZENG Ch. J., YANG Y. K., HSIEH M. H.: Optimization of wire electrical discharge machining process parameters for cutting tungsten, *International Journal Advanced Manufacturing Technolog*y, Vol. 60, Issues 1 - 4, 2012, pp.: 135 - 147.

[23] ZIMMERMAN, J., LINDEMANN, Z., GOLAŃSKI, D., et al. Modeling residual stresses generated in Ti coatings thermally sprayed on Al2O3 substrates. *Bulletin of the Polish Academy of Sciences: Technical Sciences*, 61(2), 2013, pp. 515-525.