Volume 64 • Issue 1 • May 2014

Journal of Achievements in Materials and Manufacturing Engineering

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

The superficial layer quality alloying by electro spark deposition method

S. Spadło*, P. Młynarczyk

Division of Materials Science and Munitions Technology, Kielce University of Technology, Al. Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland

* Corresponding e-mail address: sspadlo@tu.kielce.pl

Received 11.03.2014; published in revised form 01.05.2014

ABSTRACT

Purpose: The paper presents a brief study of electro-discharge mechanical machining with an elastic, discrete electrode.

Design/methodology/approach: The electrode is elastically pressed against the machined surface. This modified alloying method offers the following possibilities: machining of surfaces of complex shapes, high productivity, and ease of process automation. Attention has been given to the relation between the alloying effects and machining conditions.

Findings: The superficial layer obtained by electro spark deposition method using brush electrode consist of several layer. At the top, a molten and resolidified layer, called recast layer, is observed. this layer is usually present because material transfer in electro spark deposition method is mainly based on melting process of the workpiece material. In the recast layer in machining condition the mixing and diffusion of the material hot electrode and the workpart can occur.

Research limitations/implications: The factors causing the chemical composition, surface roughness and residual stress of superficial layer have also been taken into consideration. Attention has also been given to the relation between the material of electrode and the superficial layer chemical composition.

Originality/value: The electrical discharge mechanical machining process has been used for more than 60 years. A new type of this method, which employs the tool-electrode in the form of a rotating brush consisting of wires, employed for alloying process, has been presented.

Keywords: Spark deposition; Brush electrode; Superficial layer

Reference to this paper should be given in the following way:

S. Spadło, P. Młynarczyk, The superficial layer quality alloying by electro spark deposition method, Journal of Achievements in Materials and Manufacturing Engineering 64/1 (2014) 39-44.

MANUFACTURING AND PROCESSING

1. Introduction

Due to the present trend in constructing machines, alloys of special properties are often used. These materials are characterised by mechanical durability and high resistance to abrasion and corrosion. Cutting such materials may prove difficult because most of them are hard to cut. The process is made even more difficult by the fact that parts made of these alloys are of complex shapes. In these circumstances it is advisable to use BEDMA (Brush Electrodischarge Mechanical Alloying) as the surface alloying process.

BEDMA involves gradual removal of the extra material from the surface of the part being machined by electro-erosive, electro-chemical and mechanical processes [1]. Apart from the removal of the material, mass exchange processes between the hot electrode and the machined part take place, being the result of the mixing of the partially melted electrodes and diffusion processes. As a result of those processes the chemical composition and geometrical structure of the superficial layer of the part is formed. Consequently, the resulting layer exhibits new properties [2-6].

In the BEDMA process [2] a rotating metal brush is used as a tool and the process is performed in the presence of a machining fluid, which is water-glass in water solution with composition ratio lower than that used in erosion-mechanical cutting (< 10%). The position of the brush should be properly chosen, as shown in Fig. 1a to ensure deflection (Δ) of the tool components big enough to allow mechanical rupture of the anodic layer on the surface of the workpiece and an initiation of an electrical discharge. After the initiation is achieved and the plasma channel is built a rapid local increase in temperature occurs on the peak of roughness which causes melting, evaporation and metal removal. Fig. 1b shows the principle of this process. Electrochemical, electro discharge and mechanical phenomena and their interaction can be found in BEDMA.

In electrical discharge machining spark discharges are the main factor influencing the formation of the superficial layer [1,7]. As a result of single discharges local melting and material evaporation occur, resulting in roughening of the surface in the form of craters. They are determined, but as the craters overlap and are randomly distributed their structure must be random in nature.

2. Experimental investigations

The investigations aim to explain the phenomena occurring in the process of electrodischarge mechanical machining with the brush electrode as well as to determine the influence of the machining conditions on the surface layer conditions.

The following factors influencing the machining results have been examined:

- kinematics parameters (v_0 - tangential speed of the brush electrode, v_f - linear feed-rate),
- electric parameters (U - voltage of supply, E - pulse energy, τ - pulse time duration),
- material of brush electrodes (tungsten, molybdenum, chromium-nickel steel) and diameter of wires,
- value of the deflection (Δ) of the hot electrode filaments.

The layer is shaped by the energetic effect of the discharge on the electrodes and the following phenomena are caused by such a discharge:

- superficial melting of the anode and cathode,
- expulsion of the material into the inter-electrode area and its consequent solidification,
- transfer of the melted material from the hot electrode onto the part surface,
- mixing and diffusion of the particles of the transferred material into the workpiece material,
- temperature increase of the surrounding layers,
- very fast cooling of the superficial layer due to the heat transfer through the part core.

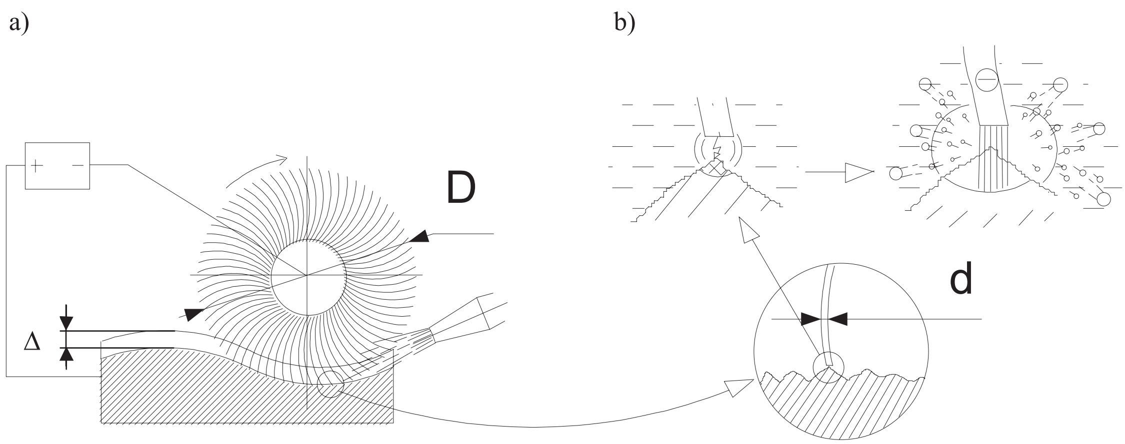

Fig. 1. Principle of the electrical deposition process (Δ - deflection of the wire, D – the diameter of the brush, d – the diameter of a single wire)

The above factors have influenced the following output parameters:

- productivity,
- parameters describing the geometry of the surface layer (R_a, R_t, S_m, D_q, W_a, W_t, W_{sm}),
- surface texture,
- metallographic structure of the superficial layer,
- superficial layer chemical composition,
- microhardness distribution in the superficial layer.

With typical parameters of machining the mechanical contact of the brush with the melted metal can cause the liquid metal to spread over the machined surface, as a result of which the peaks of roughness are flattened. An increase in pressure, with low voltage applied, can cause the depassivated layer to be torn off. Eventually, it leads to a direct contact of the electrodes and the fading of the discharges. That, in turn, changes the nature of the process to electromechanical. In these circumstances the main process that forms the geometrical structure of the surface layer is furrowing the surface with each part of the brush.

Detailed examinations of the superficial layer carried out by means of X-ray diffraction microanalysis have shown that apart from the removal of the material from the machined surface, particles of the hot electrode are transferred to the machined part. As a result of these processes a 5-10 micrometers thick modified layer is created. When molybdenum, tungsten or chromium nickel steel electrodes are used, the concentration level of these elements in the superficial layer increase up to 10%.

Some wires affect the surface by electrical discharges and by the above-described process of mass transfer from the cathode to the anode and thermochemical modification of the superficial layer. Other wires affect the surface in an electromechanical way [8]. The mechanical contact of the wires with the machined surface is accompanied by an electric current without any discharges. This electro-mechanical influence results in smoothing the roughness peaks created by the electric discharges and in the temperature increase of the machined surface. The effect of a single discharge shown Fig. 2.

The electrical erosion phenomena, which occur during machining with the brush electrode, are accompanied by a mechanical contact of the elastic brush wires, which are pressed against the machined surface and move at high speed. It results in removing the machined part particles, which do not adhere closely to the surface and cause surface smoothing.

The surface texture is random and consists of micro-craters covered by micro-irregularities resulting from the dynamic effects of the melted metals particles transfer, thermocapillary waves, etc. with the distinct summit levelling due to the mechanical effect of the brush elements.

The final effect of the process is shown in Fig. 3a. It is a surface machined with voltage applied $U = 12$ V. The results of the research have been supplemented by the profilogram of a surface machined in the BEDMA process. Its analysis shows that removal of material occurs mainly at the peaks of the roughness.

On closer inspection [9] the profile (Fig. 3b) of the surface appears to be asymmetrical. Two structures can be distinguished, the primary one, being the result of spark discharges and seen as craters in the shape of spherical caps, and the secondary one, being the result of mechanical and electrochemical processes, mainly seen at the peaks of roughness. The peaks being flat, the roughness of the layer has an advantageous profile.

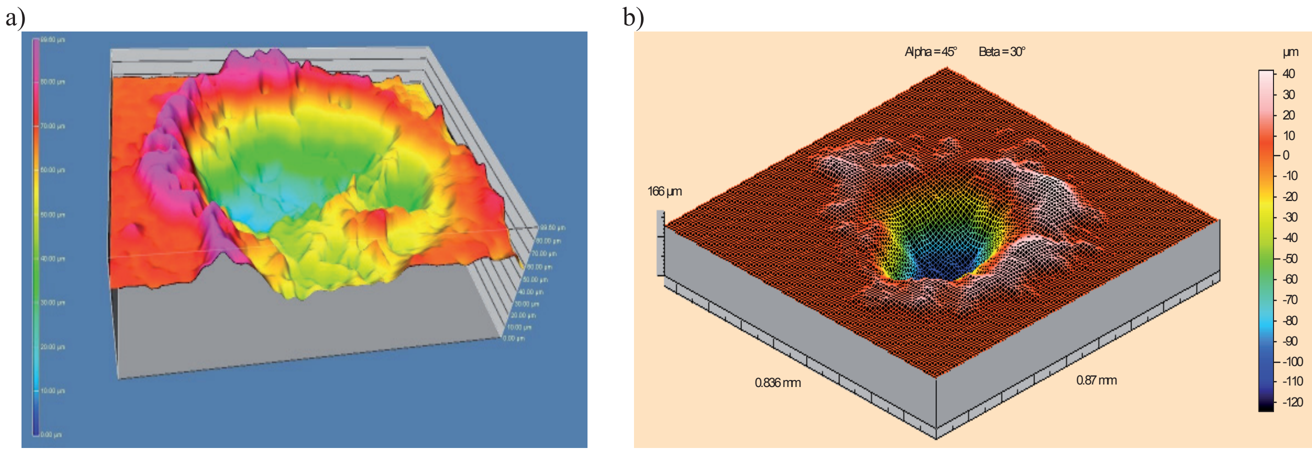

Fig. 2. Topography of the alloying surface: a) the effect of a single discharge in the form of a crater, magnification 200x, b) 3D profilogram of a single crater; $\Delta = 0.3$ mm, $U = 8$ V, $d = 0.3$ mm

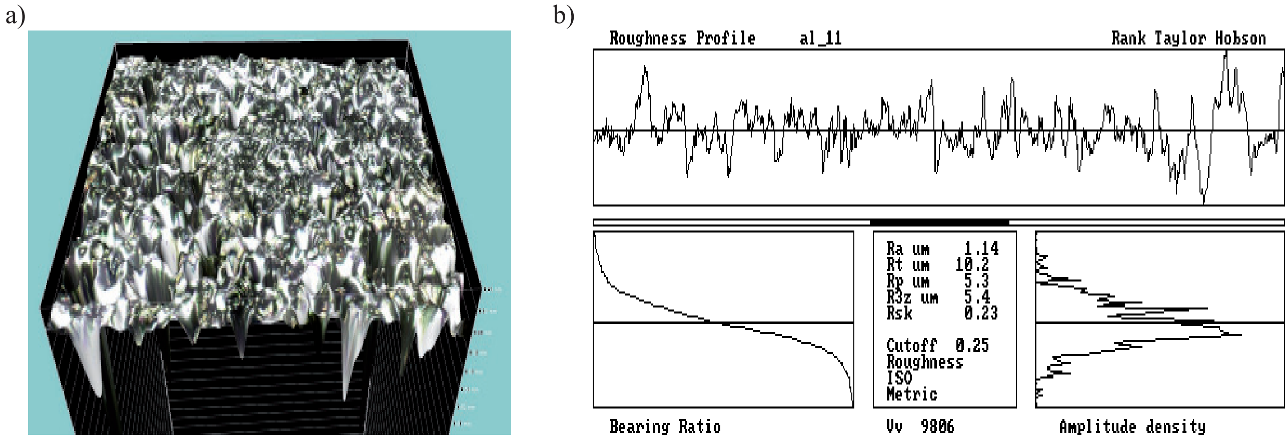

Fig. 3. Microphotograph of a surface (a) and profilogram of a layer (b) after being BEDMA process, the voltage applied $U = 12$V, $d = 0.3$ mm, $v_0 = 3.6$ m/s (tangential velocity), $v_f = 12$ mm/min (feed rate)

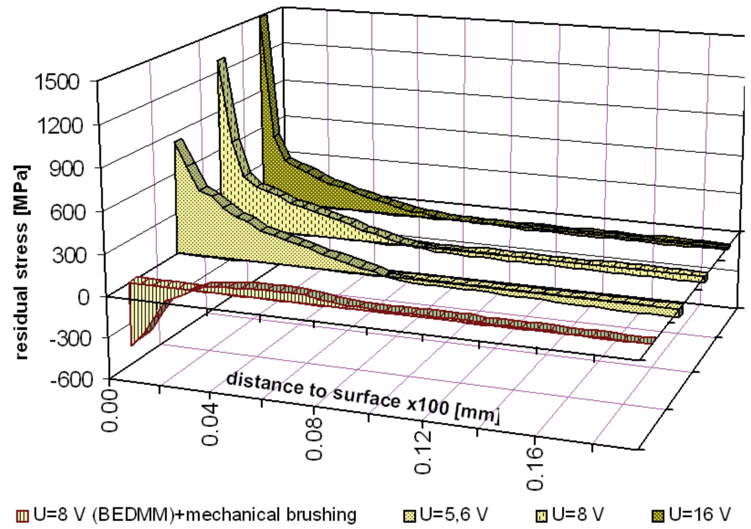

Fig. 4. Residual stresses BEDMM machined workpieces U = 5.6, 8, 16 V, parameters of machining $\Delta = 1$ mm, $v_0 = 3.6$ m/s, $v_f = 12$ mm/min, material of workpiece carbon steel (0.45%C)

Residual stresses in the superficial layer usually occur as a result of the melting and solidifying of the superficial layer. Examinations carried out using the Philips-Weisman method have demonstrated that the stresses are positive. They occur at a depth of no more than 100 micrometres. After BEDMM roughening machining (U = 16 V) maximum tensile stress achieved is 1500 MPa. Applying mechanical machining with a rotating brush to a part that has been BEDMM-machined creates compressive (negative) stresses in the superficial layer about 500 MPa. Some result of the investigation shows Fig. 4.

The metallographic structure Fig. 5a shows features typical of a surface machined by BEDMA. Superficial layer has a gradient structure with an increase of chromium and nickel content. At the top, a molten and resolidifier layer, called recast layer, is observed. This layer is usually present because material removal in BEDMA is mainly based on melting process of the workpiece material. In the recast layer in BEDMA condition mixing and diffusion of material working electrode and workpart can occur due to temporary, directly contact electrodes. Below the recast layer a heat affected zone is present. This zone comprises the workpart material which has undergone an influence by heat and has not been molten. In the case of steel, usually hardened [10].

X-ray diffraction pattern obtained from the surface layer after the BEDMM process using a chromium nickel steel electrode shows Fig. 6.

The chemical composition of the superficial layer after the BEDMM process (U = 8 V, DC current generator) using a chromium nickel steel obtained by an X-ray diffraction analysis:

- workpiece – native material (steel 0.45% C): Cr 0.09%, Ni 0.08%;
- superficial layer machined by 1.4016 (1H18N9) – steel electrode: Cr 9.91%, Ni 5.25%;
- chemical composition hot electrode – steel electrode: Cr 18.0%, Ni 9.0%.

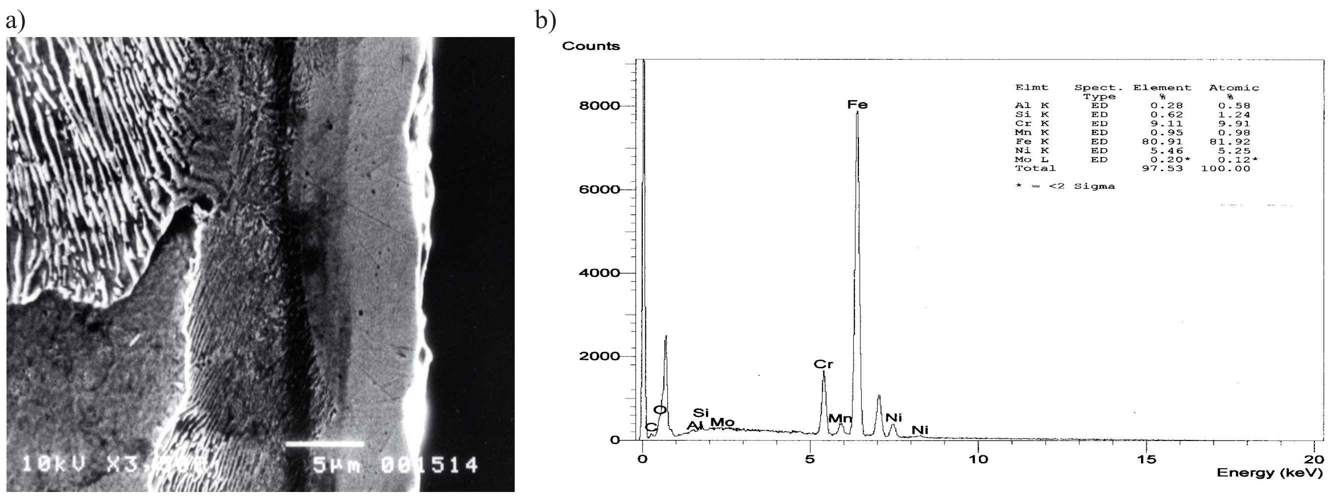

Fig. 5. a) SEM photographs of the metallographic microstructures of the surface layers after the machining process (U = 8 V) using the made of chromium nickel steel 1.4016 (1H18N9) electrode; material of workpiece carbon steel (0.45%C), magnification 3500x, b) X-ray diffraction pattern obtained from the surface layer after BEDMA process

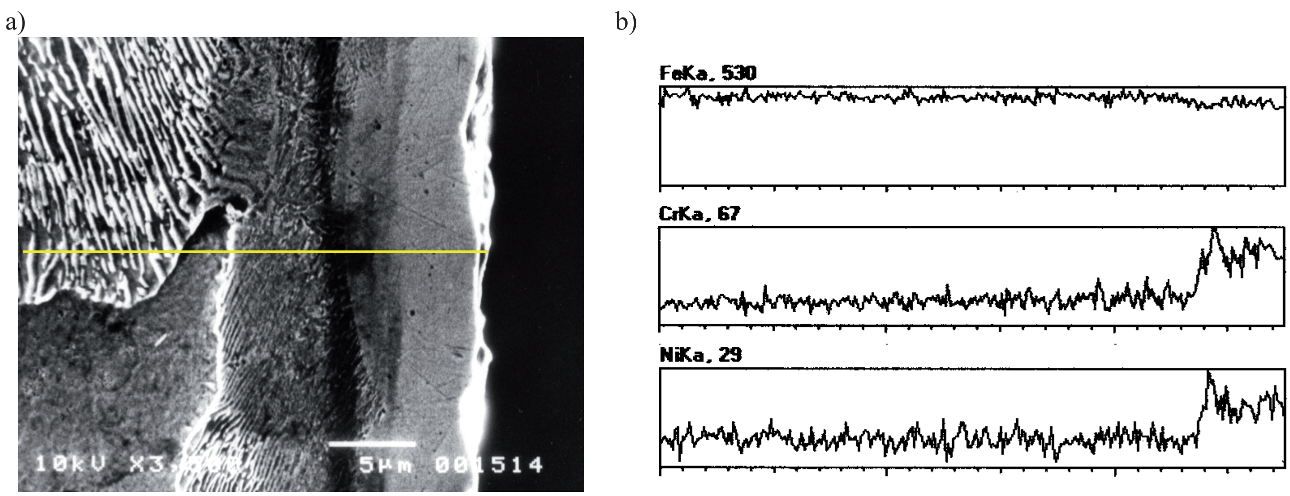

Fig. 6. X-ray line scan of the superficial layer after the BEDMA process (U = 8 V) using a chromium nickel steel electrode – a) (magnification 3500x); chemical elements distribution in the sub-surface layer – b)

3. Conclusions

The investigations into electro-discharge deposition with rotating brush electrodes have shown that:

- the surface layer subjected to the deposition process contains chemical components of the hot electrode (cathode),
- X-ray analysis of the molten and resolidified layer shows an increase of chromium (up to 10%) and nickel (up to 5%) content,
- thickness recast layer achieved about 5-10 micrometres,
- the metallographic structure of the superficial layer reveals properties that are typical of electroerosion discharge machining,
- the physical properties of the hot electrode and level of voltage significantly influence the machining process and its results,
- if the process is well controlled higher hardness, higher wear resistance of the superficial layer can be achieved.

Acknowledgements

The research is co-founded by the European Union from European Social Fund (ESF), project „Perspektywy RSI Świętokrzyskie – IV Etap”.

Literature

[1] B. Nowicki, R. Pierzynowski, S. Spadło, The superficial layer of parts machined by brush electro discharge mechanical machining (BEDMM), Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 218 (2004) 9-15.

[2] R. Pierzynowski, Some investigation of brush electrode alloying, Scientific Papers. Mechanics/ Academy of Technology and Agriculture in Bydgoszcz 46(225) (2000) 191-198 (in Polish).

[3] A. Miernikiewicz, Experimental and theoretical basis for EDM, Monograph 274, Cracow, 2000 (in Polish).

[4] B. Nowicki, A. Podolak-Lejtas, Investigations of the effect of combined EDM machining with burnishing process on the condition of the surface layer, Advances in Manufacturing Science and Technology 32/4 (2008) 5-17.

[5] B. Nowicki, A. Dmowska, A. Podolak-Lejtas, Morphology of traces made by individual electric discharge in the EDM, Advances in Manufacturing Science and Technology 33/4 (2009) 5-24.

[6] N. Radek, J. Konstanty, Cermet ESD coatings modified by laser treatment, Archives of Metallurgy and Materials 57/3 (2012) 665-670.

[7] L. Dąbrowski, R. Świercz, The study of the microstructure of the surface layer after treatment (EDM), World of Machine Tools 7/1-2 (2012) 26-30 (in Polish).

[8] B. Nowicki, R. Pierzynowski, S. Spadło, 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.

[9] S. Adamczak, E. Miko, F. Cus, V. Strojniski, A model of surface roughness constitution in the metal cutting process applying tools with defined stereometry, Journal of Mechanical Engineering 55 (2009) 45-54.

[10] A.D. Davydov, J. Kozak, Physico-Chemical Principles of Electrochemical Discharge Machining, Surface Engineering and Applied Electrochemistry 3 (1991) 3-13.