ANALYSIS OF THE MECHANICAL INTERACTIONS OF THE FILAMENT BRUSH ELECTRODE ON THE FORMATION OF THE SURFACE ROUGHNESS

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Abstract

The article presents the results of research on the influence of the conditions of erosion mechanical machining using a brush electrode on the formation of the surface layer properties. The physical interactions which occur in the process and affect the formation of the surface layer properties have also been described. It has been noted that it is possible to achieve compressive stress in the process by choosing proper parameters. A mathematical model and results of a simulation of the mechanical influence of a single filament on the machined surface have also been presented.

Keywords: Brush electrode, mechanical interaction, surface layer, roughness

1. INTRODUCTION

Electrical discharge machining (EDM) is nonconventional machining process. To improve EDM machining many researchers are trying to develop hybrid processes [1 - 8]. Hybrid machining process is combination of two or more processes for more effective way of material machining process. A large number of studies is devoted to understanding physical process during machining [9 - 15].

So far the machining process using filamentary metal brushes in the shape of disks has been used in surface machining to remove corroded layers, to prepare metal surfaces to be galvanized, and to produce surfaces of high adhesion to be coated with paint, glue, etc. Recently the process has been developed to include operations such as removing sharp edges and burrs, flashes and bosses from machine parts made of alloys of non-ferrous metals, as well as cleaning welds. Using brushes with densely packed filaments made of hard steel broadens the range of uses to include the micro-milling of ordinary constructional steels of low hardness, which are machined with the tips of the filaments. To summarize, the typical uses of metal brush tools are limited to machining materials of a hardness lower than that of the material the filaments of the brush are made of.

Using filaments made of abrasive-grain-filled polymers allows the brushes to be used to machine the surfaces of materials of high hardness.

On analysis of the advantages of using brush tools the author suggests a new machining operation that combines mechanical, electrochemical, and electro-erosive processes acting on the machined item. Thanks to the synergetic effect, this type of hybrid machining - BEDMM (Brush Electrical Discharge Mechanical Machining) makes the metal removal process more cost-effective [1, 2].

The use of brushing tools in an automation environment will necessitate a clear understanding of important brush performance characteristics such as forces. An understanding of such characteristics is important, as surface preparation processes require a detailed knowledge of interrelationships between productivity of machining and brush operating conditions. For example, it is recognized that electrical discharges generated during electricalerosion-mechanical processes are closely related to the mechanical characteristics of the filament [14].

2. STATICS OF A SINGLE FILAMENT BRUSH

Since the elements of a disk brush tend to deform easily, the use of the brush in erosion mechanical machining changes the character of mechanical interactions with the machined surface in contrast to deformation-resistant electrodes. An increase in the value of the pressure force at the filament tip as a function of displacement along the surface inevitably leads to a break in the anodic film and initiates discharges whose frequency can be determined, among others, by the vibrations of individual filaments of the electrode.

The mechanics of the movement and filament wire interactions with the machined surface is complex. The wire becomes deformed in a way that is difficult to analyse. It is caused by confounded boundary conditions which allow only an approximate solution to the equation of its motion.

Let us consider a tentative analysis of a filament load.

The basic assumptions are:

- inertial forces are neglected,
- the filament tip moves along a rigid surface.

Additionally, due to low packing density, interactions between individual wires are ignored. It is assumed that the filaments are placed radially from the hub centre and are restrained at the hub outside radius and obey Hooke's law. The filaments are straight before they come into contact with the machined surface. They are deflected perpendicularly to the axis of rotation, with the radial run-out of the disks being ignored. Filament deflection is examined in a mobile reference system $K\ \xi\ \eta$ (**Figure 1**) where $\eta = \eta(\xi)$ is its elastic deflection assuming that there is no influence of non-dilatational strain.

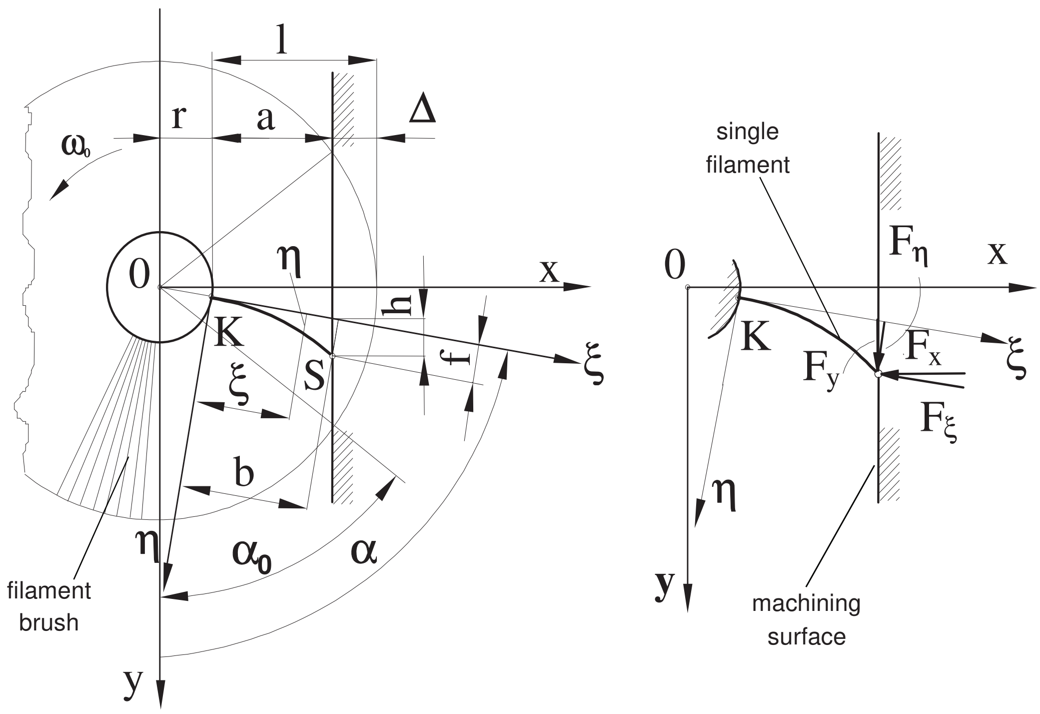


Figure 1 Geometry of a particular filament brush deformation and constant $0xy$ and mobile coordinates system $K\xi\eta$, $\xi\eta$ - current coordinates points of the wire, S - point of contact with the wire and surface of the workpiece, ω_0 - angular velocity of the brush, α_0 - initial contact angle of the tip of the wire, α - angle of rotation, a - distance between hub and machining surface, r - diameter of hub, b, f - coordinates of the tip of the wire (f - deflection of the wire), l - length of the wire, Δ - penetration depth, $F_{(index)}$ - force components.

The differential equation of the bending line is:

$$EI\frac{\eta''}{(1+\eta'^2)^{3/2}} = F_\eta(b-\xi) + F_\xi[\eta(b)-\eta(\xi)] \tag{1}$$

where:

EI - filament flexural rigidity.

$$\eta'(\xi) = d\eta/d\xi,\ \eta''(\xi) = d^2\eta/d\xi^2, \tag{2}$$

and

$$0 \le \xi \le b. \tag{3}$$

The geometry of the examined problem produces the following relationships:

$$h = f/\sin\alpha, \tag{4}$$

$$b = \frac{a+r}{\sin\alpha} - r + h\cos\alpha = d + h\cos\alpha, \tag{5}$$

$$d = \frac{a+r}{\sin\alpha} - r. \tag{6}$$

We assume that:

$$F_y = \mu F_x \tag{7}$$

$$F_\xi = c_1 F_x,\quad F_\eta = c_2 F_x \tag{8}$$

$$c_1 = \sin\alpha - \mu\cos\alpha, \tag{9}$$

$$c_2 = \cos\alpha + \mu\sin\alpha \tag{10}$$

where:

$$\alpha = \omega_0 t \tag{11}$$

α - angle of rotation,
μ - coefficient of friction between the filament tip and the machined surface,
ω_0 - angular velocity of the brush.

The function $\eta(\xi)$ should also satisfy the following condition:

$$l - \int_0^b \sqrt{1+[\eta'(\xi)]^2}\,d\xi = 0 \tag{12}$$

It is difficult to obtain numerical solutions for equation (1) with constraint (12). Analytical solutions can be obtained if the values of $\eta(\xi)$ are small enough to enable the linearization of the left-hand side of the equation (1). The details of the solution of equation (1) with initial conditions:

$$|\eta(0)| = 0 \quad \text{and} \quad |\eta'(0)| = 0 \tag{13}$$

and with the assumption that the wire tip (for $\xi = b$) has point contact with the surface (then $\eta''(b) = 0$)) have been presented in [1, 14].

Graphs of the changes in the values of force components of the single filament F_ξ, F_η as a function of the rotation angle and filament diameter - *d* have been presented in **Figure 2**.

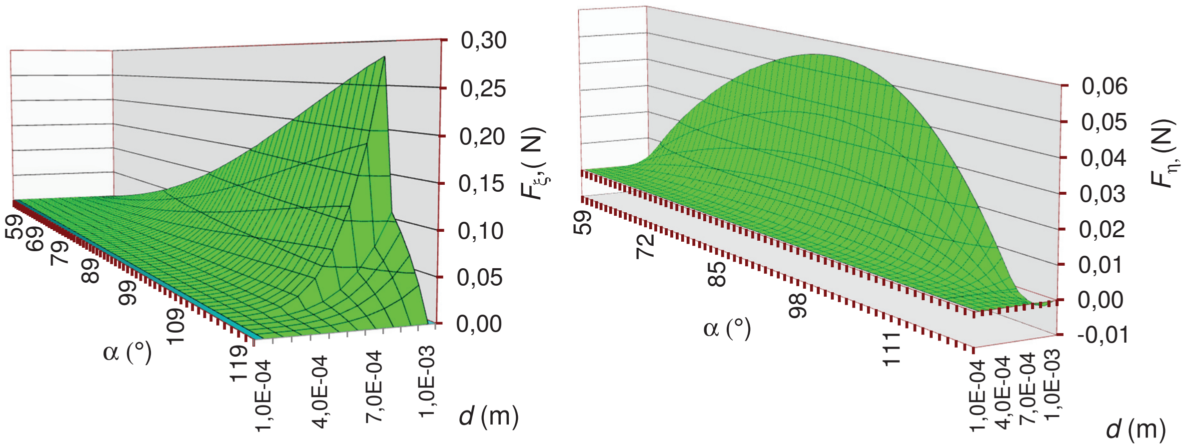


Figure 2 The relationship in the values of force components of the single wire $F\xi$, $F\eta$ as a function of the rotation angle $\alpha = \omega_0 t$ and diameter of the filament *d*. Parameters: l = 0.05 m, a = 0.04 m, r = 0.02 m, μ = 0.5.

3. RESIDUAL STRESS, SURFACE ROUGHNESS AND TOPOGRAPHY

In typical machining conditions on BEDMM process the mechanical contact between the tool and the workpiece occurs through the hard anodic-silicone layer.

The movement of the elements of the brush along the surface and their pressure on the surface caused the removal of the anodic layer from peaks of roughness and initiation of electrical discharges. Results of the investigation show that the melted metal can be smeared on the workpiece surface by the brush elements.

Under 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 the direct contact of the electrodes and 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 (**Figure 3**).

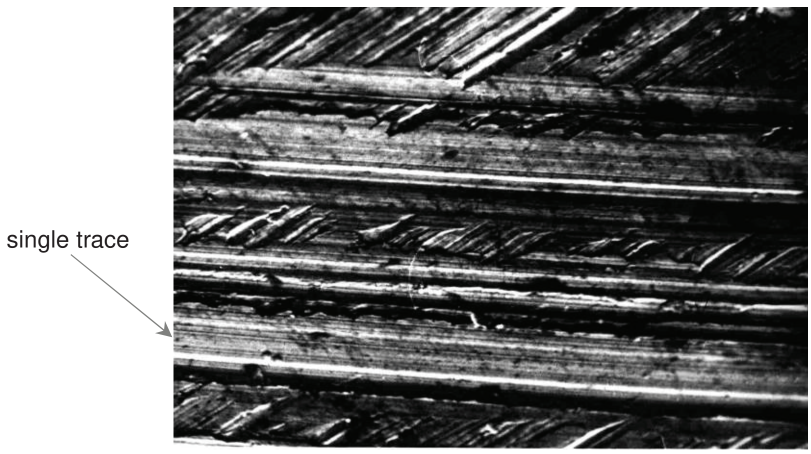
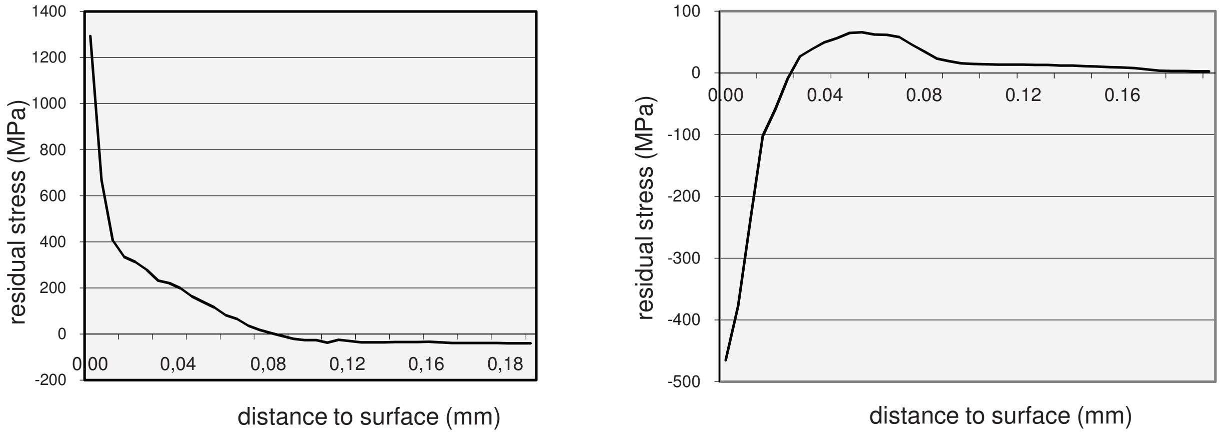


Figure 3 A SEM photograph showing the traces of the mechanical influence of the brush on the steel surface, U = 8 V, d = 0.5 mm (diameter of single wire), v_0 = 0.7 m·s^{-1}, magn. 75x

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 µm. After BEDMM smoothing machining ($U = 8$ V) maximum tensile stress achieved 1300 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 **Figure 4**.



a) b)

Figure 4 Residual stresses distribution, a) - BEDMM machined workpieces $U = 8$ V, b) - BEDMM machined workpieces $U = 8$ V and mechanical brushing $U = 0$ V. Parameters of machining $\Delta = 1$ mm, $v_0 = 3.6$ m·s^{-1}, $v_f = 12$ mm·min^{-1} - feed rate, material of workpiece carbon steel C45

Figure 5 SEM photograph of a surface after being BEDMM machined the voltage applied $U = 12$ V and mechanical brushing $U = 0$ V, $d = 0.3$ mm, $v_0 = 3.6$ m·s^{-1}, $v_f = 12$ mm·min^{-1}, magn. 75x

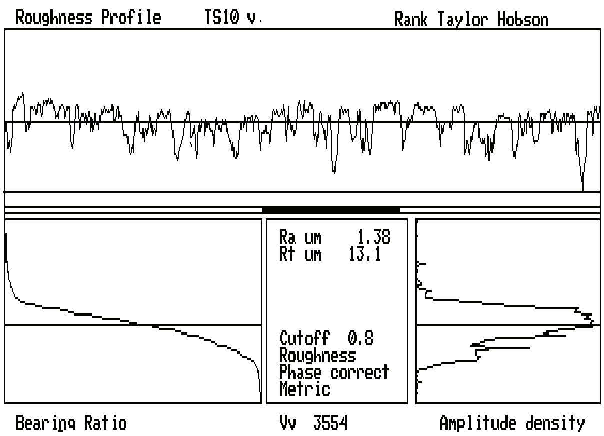


Figure 6 A sample profilogram of a layer after being BEDMM machined, the voltage applied $U = 8$ V, $d = 0.3$ mm - diameter of single wire, $v_0 = 3.6$ m·s^{-1} - tangential velocity, $v_f = 12$ mm·min^{-1} - feed rate

The direct contact between the elements of the brush and the machined surface as well as the heat produced by the electric current can cause mechanical removal of the metal, so-called 'electromechanical machining. SEM photograph (**Figure 5**) shows the surface topography of the carbon steel after the BEDMM process. The micro geometry peaks are flat (**Figure 6**). This points to the occurrence of mechanical levelling of roughness peaks by the brush elements.

4. CONCLUSIONS

With typical parameters of BEDMM the influence of mechanical processes caused by the working electrode on the formation of the geometrical structure of the layer is relatively small, as the processes occur mainly at the peaks of roughness,

The surface layer after BEDMM demonstrates the tensile stress distribution but it can be modified by applying the additional mechanical treatment in the end of machining (the spark circuit power supply should be turned off).

A decrease in the values of *Rm*, *Dq*, parameters coupled with greater deflection of parts of the electrode can prove that the peaks of roughness have been modified as a result of an increase of the forces at work between the electrodes.

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