LAYERS AFFECTED BY THERMAL PROCESSES IN THE CASE OF SOME NONCONVENTIONAL MACHINING METHODS

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ABSTRACT: In the larger group of nonconventional machining processes, there are some machining processes that use the thermal effect in order to generate a material removal from the workpiece. The theoretical analysis of such processes showed that particles are directed to the workpiece layer and there, a part of the particles kinetic energy is transformed in thermal energy, able to melt and even to vaporize the workpiece material. The presence of the thermal effect could generate structural changes in the surface layer and these structural changes could be highlighted by the variation of the microhardness in surface layer, along a direction perpendicular to the machined surface. Some experimental researches developed in the case of the hybrid machining, by electrical discharges and by electrochemical dissolution, on test samples made of medium and high carbon content, proved a high microhardness immediately under the machined surface and a decrease of the microhardness as the distance from the machined surface increases; this fact shows that in the considered case, a quenching process developed.

KEY WORDS: nonconventional machining processes, kinetic energy, thermal effects, surface layer microhardness.

1. INTRODUCTION

The current necessities of the human society development led to the use of various machining methods in order to obtain products able to ensure a high level of civilization. If the machining processes applied in manufacturing technologies are analyzed, one can take into consideration a classification which includes classical or traditional machining methods and, on the other hand, non-conventional or non-traditional machining methods. Generally, the nonconventional machining methods could be defined as a group of machining methods based on a supplementary energy directed to the machining zone, so that either a classical machining process develops in better conditions or the material removal occurs on new principles, fundamentally distinct in comparison with the principle of plastic deformation, which is valid in case of the cutting processes or of an extended set of machining processes involving plastic deformation as a way to change the dimensions or the shape of the workpiece.

A modality to transfer the supplementary energy to the machining zone could be based on the thermal effects; indeed, there are some nonconventional machining methods which uses the change of kinetic energy of various particles in thermal energy able to contribute to the increase of the temperature of the surface layer of the workpiece up to values when the workpiece material is melted or even vaporized. Such machining methods are the electrical discharge machining, the electrochemical discharge machining, the plasma beam machining, the laser beam machining, the electron beam machining etc.; these machining methods are based on thermal and chemical effects generated at the contact of particles (electrons, ions, photons) with the workpiece material.

The objective of this paper is to establish if common aspects could be identified in such machining processes, essentially based on the material removal from workpiece due to thermal effects.

Abdulkareem et al. considered [1] that in the plasma column specific to the electrical discharge machining, temperatures of about 8000-12000°C could be reached. Also, in the case of the electrical discharge machining, Kumar et al. appreciated [3] that some changes could be generated by the thermal phenomena and if one exams the structure of the surface layer, the following layers could be highlighted: spattered layer, recast (white) layer, heat affected layer.

2. THEORETICAL CONSIDERATIONS

Let’s take into consideration a particles beam directed from a specialized source to the workpiece surface (fig. 1).

If one supposes that the particles beam has energy $E_1$, at the contact with the workpiece surface this energy is divided in:
a) A part $E_2$ of energy which is absorbed by the workpiece material, determining the increase of the surface layer temperature. The quantity $E_2$ of energy is influenced by the workpiece material capacity of absorbing the radiation having a certain wave length;

b) A second part $E_3$ of energy that could be transported to the environment by the particles of the beam rejected by the workpiece surface layer. As in the case of energy absorption, there are properties which facilitate the radiation penetration in the surface layer of the workpiece, in this case one may highlight the capacity of the material to reflect the radiation of a certain wave length. Such a situation could be specific, for example, to the case of laser beam directed to the workpiece surface; by considering the radiation wavelength, one may notice that there is the possibility that a significant beam energy could be reflected by the workpiece surface, at least in case of certain materials, able to reflect the laser radiation.

c) A third part $E_4$ of energy which is send to the environment as thermal energy developed as a consequence of the particles beam penetration in the workpiece surface layer. In fact, this energy has a delay in comparison with the impact moment; only after a certain dissipation of the thermal energy generated in the surface layer as a consequence of the beam particles impact, one may notice that a part of the thermal energy is directed to the environment.

d) It is clear that from the thermal energy $E_2$ generated as a consequence of the particles beam impact with the workpiece surface layer, only a part $E_5$ is really absorbed by the workpiece material, determining here certain changes. In such conditions, the following relation could be written:

$$E_5 = E_2 - E_4$$

(1)

In the case of laser beam machining with material removal from workpiece, in order to obtain a more controlled material removal and a higher quality of the machined surface, along the laser beam a jet of compressed air is sent; in this way, a supplementary removal of the heat developed in the machining zone could be highlighted; it is expected that the compressed air jet contributes to a more intense cooling of the workpiece zone previously affected by a temperature increase.

It is known that in the case of the above mentioned nonconventional machining processes (electrical discharge machining, laser beam machining, electron beam machining, ion beam machining etc.), the particles found in the beam could be photons,
electrons, positive or negative ions. The kinetic energy of these particles corresponds to the known relation:

$$W = \frac{m_pv_p^2}{2}$$  \hspace{1cm} (2)

where $m_p$ is the particle mass and $v_p$ is the particle motion speed. The particles mass could have values in an extended range, from the negligible mass of photons to the mass of some gas ions. It is known the electron mass $m_e=9.1066\times10^{-28}$ g.

Various values could be met in case of the motion speeds; if in case of photons, one may consider the light speed ($v=300000$ km/s), this speed could be lower in the case of ions.

In case of a metallic workpiece, it is expected that it has a crystalline structure, with the atoms / ions placed in the nodes. One may accept that these atomic structures could have an oscillation motion round the equilibrium position (fig. 2). When particles from the incident beam succeed to penetrate the workpiece surface layer, the energy of the incident particles could be absorbed and the oscillation amplitude of the atomic structures found in nodes increases. If the oscillation amplitude exceeds a certain value, the atomic structure could exit from the equilibrium position and the external observer could notice, for example, a melting phenomenon.

If the absorbed energy is even more intense, the oscillation amplitude of the atomic structures could increase up to such values that the atomic structures could leave the surface layer, being directed to the environment; this is the case of the material vaporisation.

If one continues the analyse of the thermal phenomena which occur in the workpiece surface layer, the hypothesis of a normal distribution of the energy in the beam could be taken into consideration (fig. 3). In a spatial coordinate system $xOyz$, one can consider such a distribution, when in an axial section through the beam, the Gauss’s law is valid:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$  \hspace{1cm} (3)

where $x$ is the distance, along the abscissa axis, from the beam axis, $\sigma$ – standard deviation and $\mu$ - mean of the distribution.

As above mentioned, as a consequence of the beam particles penetration in the surface layer, the kinetic energy of the particles found in motion is changed in heat energy; due to the probable normal distribution of the kinetic energy in the particles beam, the distribution of the heat energy in the workpiece surface layer could be also in accordance with the normal distribution law. The changes in the aggregation state of the workpiece material as a result of the heat developed could occur also in accordance with the normal distribution law. From the point of view of the machining process, one may notice a central zone where the temperature has high values and the workpiece material is vaporized (fig. 3); round of this zone, another characterized by the melting of the workpiece material could be met. A third zone could be that where only structural changes could be noticed; of course, finally, inclusively the zone where the material was affected by melting and vaporizing phenomena and where the material was re-solidified could be included in the heat affected zone [4].

If the energy in the vicinity of the particles beam axis is not high enough, the melting and vaporizing phenomena may be missing; this is the case of the thermal treatments applied to metallic materials by means of particles beams.

In case of machining processes characterized by material removal from the workpiece, various solutions could be used in order to remove the vaporized material and a part of the melted material, before its solidification. Thus, in the case of the electrical discharge machining, the vaporized and melted material solidifies in the dielectric liquid and it is removed from the machining zone just as result of the dielectric liquid circulation. In case of the laser beam machining, the jet of compressed air sent along the laser beam axis contributes to the removal of the material detached as vapours or liquid material from the workpiece. In case of the plasma beam machining, the plasma motion is the factor able to determine the removal of the melted and vaporized material from workpiece. Within the electron beam machining, a part of the material vaporized could be absorbed as a consequence of the vacuum pumps functioning.

In all this situations, a part of the workpiece material found in liquid state, solidifies on the surface generated as a consequence of the machining process characterized by material removal from the workpiece. This means that the surface layer could include at least three zones (fig. 4):

- a zone including the re-solidified material;
- a proper heat affected zone;
- the zone which was not affected by the thermal effects.
3. EXPERIMENTAL CONSIDERATIONS

Consequences of the thermal effects could be met in the surface layers obtained by applying the above mentioned non-traditional processes.

Thus, in case of electrochemical discharge machining process, the surface layer is generated as a consequence of developing of electrochemical material removal, and of the thermal effects generated by the electrical discharges. The electrochemical process could not exert a thermal effect on the surface layer, since the temperature of the electrochemical process is too lower to generate a heat affected zone. This means that only the electrical discharges developed between the tool electrode and the workpiece surface could be the factors able to thermally affect the surface layer. Due to the connection of the workpiece to the positive pole of the direct current source, the particles which penetrate the workpiece surface layer are the electrons. The kinetic energy of the electrons is changed in a thermal energy and finally, melting and vaporizing phenomena develop. Small quantities of the workpiece material are thus detached and arrive in the work liquid, being removed from the work zone as a consequence of the liquid circulation.

In order to highlight the presence of the heat affected zone, the microhardness measuring could be applied. The changes of the microhardness could be easier noticed if the distance between the indenter effects is low enough; in our case, one adopted a distance of 0.02-0.03 mm. Since in such a case there was the risk that the marks are too close, the microhardness was measured along two lines perpendicular on the machined surface and, evidently, after a careful
preparing or the surface obtained by cutting the test sample along an axial plane to the hole obtained by electrochemical discharge machining. The results of the measuring the microhardness of the surface layer [2] were included in table 1.

The experimental results were processed by means of software based on the least squares method and the following empirical relation was established:

\[ HV = 798.699 - 4698.27d + 11408.84d^2 \]  

(4)

d being the distance from the machined surface where the microhardness was measured.

Table 1. Results of microhardness measuring in case of a surface layer obtained by electrochemical discharge drilling [2]

<table>
<thead>
<tr>
<th>Number of measuring</th>
<th>Distance from the machined surface, mm</th>
<th>Microhardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.02</td>
<td>699</td>
</tr>
<tr>
<td>2</td>
<td>0.04</td>
<td>724</td>
</tr>
<tr>
<td>3</td>
<td>0.08</td>
<td>397</td>
</tr>
<tr>
<td>4</td>
<td>0.11</td>
<td>379</td>
</tr>
<tr>
<td>5</td>
<td>0.14</td>
<td>355</td>
</tr>
<tr>
<td>6</td>
<td>0.17</td>
<td>340</td>
</tr>
<tr>
<td>7</td>
<td>0.18</td>
<td>321</td>
</tr>
<tr>
<td>8</td>
<td>0.20</td>
<td>357</td>
</tr>
<tr>
<td>9</td>
<td>0.22</td>
<td>353</td>
</tr>
<tr>
<td>10</td>
<td>0.24</td>
<td>364</td>
</tr>
<tr>
<td>11</td>
<td>0.26</td>
<td>332</td>
</tr>
<tr>
<td>12</td>
<td>0.29</td>
<td>355</td>
</tr>
</tbody>
</table>

The value of the Gauss’s criterion was \( S_G = 2978.525 \); this value is considered as an indicator able to offer an image concerning the adequacy of the mathematical empirical model to the experimental results. A graphical representation corresponding to the empirical mathematical model could be observed in figure 4. On can notice that in the case of a steel containing carbon enough, phenomena of quenching (developed as a consequence of the fast cooling of the material after the developing the electrical discharge) contributes to an increase of the surface layer microhardness.

4. CONCLUSIONS

There is a group of non-conventional technologies based on thermal effects generated in the surface layer of the workpiece. Usually, a beam of atomic or subatomic particles (atoms, ions, electrons, photons) are sent to the workpiece surface to be machined. In the surface layer, the kinetic energy of the particles is changed in thermal energy, which contributes to the material removal from the workpiece, as a result of developing melting and vaporizing phenomena. The material detached from the workpiece is removed by the circulation of a fluid. As an effect of the thermal phenomena, the structure of the surface layer could change and such changes could be highlighted be means of the microhardness variation; in this paper, some experimental results were presented, in order to prove the presence of the so-called heat affected zone.

5. REFERENCES