Effect of electrical discharge machining process
parameters on surface integrity during machining
cold work tool steel AISI D2

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ABSTRACT

This work-study presents the effects of process parameters of
electrical discharge machining of AISI D2 cold work tool steel
such as peak current and pulse-on time duration which tend to
cause metallurgical changes in surface of workpiece these
parameters have been investigated to explore their effects on
surface roughness and the microstructure changes like the depth of
white layer, heat affected zone and crack depth. The results shows
that the increase in current and pulse duration does affect the
amount of surface roughness ,white layer and heat affected layer
thickness , also crack length showed influenced by variation in
process parameters.

KEY WORDS :EDM, surface roughness, white layer ,heat affected
zone, and Micro-cracks.

1. INTRODUCTION

The Principles of Electrical Discharge Machining (EDM) is the
process of machining electrically conductive materials. This
method is commonly used in producing molds and dies have
complicated shapes and regardless the work - piece hardness
which is difficult to machining by the conventional process. This operation is using precisely controlled sparks that occur between an electrode and a workpiece in the presence of a dielectric fluid. The Electric sparks used in machining the specific workpiece contour in which takes the opposite exact shape of the electrode. The cutting tool (electrode) manufactured from electrically conductive materials, generally copper or graphite. The sparks create high temperatures causing melting and vaporization of work-piece and result in the crater on the surface as an opposite of electrode shape. During melting, the metal erode due to the high intensity of sparks and ejected out of crater by flushing and remaining metal re-solidified which is called a white layer or recast layer (WLT). The micro-cracks developed in this layer because of residual stresses.

The heat-affected zone layer (HAZ) produced due to the high temperature of the previous layer in which subjected to heat treatment; as a result, it develops different microstructure.

The surface integrity of EDMed surface is important feature it depends on their application of the component, and expressed by surface layers and surface roughness (Ra) properties. The previous studies indicated that the EDM process changes not only the surface of the work-piece material but also changes in the subsurface. The present work investigates the effect of process parameters of spark EDM; discharge current (A) and pulse on time (t-on) have been investigated for surface integrity.

2. LITERATURE SURVEY

A.G.Mamalis, G.C.Vosniakos, N.M.Vaxevanidis, and J.Prohàszka [1987], have explained the physic-chemical changes occurring during electro-discharge machining of steel (structural, medium - carbon and alloyed steels) surfaces. The authors were examined
and discussed quantitatively and qualitatively of metallurgical transformation and new structures, surface damage in the form of cracking and white layer formation, microhardness variations. The results confirm the inherent complexity of process. E.C. Jameson [2001] presented in his book Electrical Discharge Machining page 328 how the spark is controlled, and the importance of the dielectric fluid. H. T. Lee and T.Y.TAI, [2003] carried out study present the relationship between EDM parameters and surface cracks by using a full factorial design, based upon discharge current and pulse-on time parameters. They analyzes the EDM machining of D2 and H13 tool steels as materials ,the formation of surface cracks is explored by considering surface roughness ,white layer thickness, and the stress induced by the EDM process. A.Hascalýk and Caydas [2004] have explained the machining characteristics of AISI D5 tool steel in WEDM process, the parameters such as open circuit, pulse duration, wire speed and dielectric fluid pressure were changed to explore their effect on the surface roughness and metallurgical structure .

G.K.M.Rao, S.Satyanarayana, and M.Praveen [2008], had investigated the effects of current, pulse-on-time, and the duty factor on the material removal rate (MRR), surface roughness, and hardness. Also found that the crack length and the recast layer thickness increases with increase in current and decrease in case of pulse-on-time .

M.Shabgard, M.Seyedzavvar, and N.B.Oliaei [2011]presented the influence of EDM input parameters on the characteristics of the EDM process included machining features, MRR, tool wear ratio (TWR), and surface roughness. The results showed the desired EDM efficiency, surface roughness, and surface integrity when machining AISI H13 tool steel. M. Geostimiroovic, P.Kavac, M.Sekulic, and B.Skoric [2012]according to authors the heat
source parameters can be changed by the discharge current and pulse duration. R.Zeilmann, T.Vacaro, and F.M.Zanotto [2013] presented the main metallurgical alterations in surfaces machined by EDM process. The change of technological parameters caused the greater effects on the surfaces such as surface roughness and affected layer analysis.

3. EXPERIMENTAL DETAILS

This work has been carried out in the Advance Center of Technology workshops and Laboratories (Tripoli–Libya) for studying the Effects of Machining Parameters and Microstructural evolution on D2 tool steel. The chemical composition in weight percent are given in Table 1.

Table 1: The chemical composition (wt. %) of D2 tool steel

<table>
<thead>
<tr>
<th>Cr</th>
<th>Mo</th>
<th>C</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.4</td>
<td>0.69</td>
<td>1.54</td>
<td>0.132</td>
<td>84.2</td>
<td>0.375</td>
<td>0.0218</td>
<td>0.003</td>
<td>0.24</td>
</tr>
</tbody>
</table>

The specimens were cut with dimensions (20 × 10 × 10 mm) as shown in Figure 1. Then the heat treatment cycle was applied as shown in Table 2. After hardening, the average hardness measured was 58 HRC.

Figure 1: The specimen
Table 2: The heat treatment cycle.

<table>
<thead>
<tr>
<th>Material</th>
<th>D2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardening temperature</td>
<td>1050 °C</td>
</tr>
<tr>
<td>Quenching media</td>
<td>Oil</td>
</tr>
<tr>
<td>Tempering temperature</td>
<td>400°C</td>
</tr>
</tbody>
</table>

A full factorial design of experiment applied using two parameters and three levels, the work-specimens were machined on Charmless park EDM Robo Form 2-LC with spark current 5, 10 and 20A and pulse on time duration was 100, 400 and 1600 µs, other machine parameters are fixed as indicated in Table 3. Each experiment was performed for 25 minutes.

Table 3: The experimental test conditions.

<table>
<thead>
<tr>
<th>Machine type</th>
<th>Ropo form 2-LC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse current (A)</td>
<td>5, 10, 20</td>
</tr>
<tr>
<td>Pulse on time (µs)</td>
<td>100, 400, 1600</td>
</tr>
<tr>
<td>Pulse off time (µs)</td>
<td>50</td>
</tr>
<tr>
<td>Voltage (v)</td>
<td>120</td>
</tr>
<tr>
<td>Tool material</td>
<td>Copper</td>
</tr>
<tr>
<td>Dielectric</td>
<td>Kerosene</td>
</tr>
<tr>
<td>Polarity</td>
<td>Positive</td>
</tr>
</tbody>
</table>

In this work the specimens were sectioned transversely by wire electrical discharge machine into two pieces then these sectioned specimens were grinded and polished to achieve a smooth and clean surface; then the specimens etched with 2% Nital reagent for about 10 seconds. These specimens were examined at various magnifications by using Optical Microscope (Nikon OPTIPHOT).
to characterize the evolution of microstructure and identify the effect of different parameters on the microstructure behavior. Then the micro-hardness were measured using Leica VMHT micro-hardness tester to identify the heat effected layer thickness.

4. RESULTS AND DISCUSSION

4.1 Effect of pulse on time and current on surface roughness:

The surface finish is an indicator of process performance in EDM work-piece and its main output characteristics. In this present study, the influence of main process parameter current and pulse on time on surface roughness during spark electrical discharge machining D2 tool steel with copper electrode is evaluated as shown in Table 4.

Table 4: The variation of surface roughness with pulse-on-time at constant current.

<table>
<thead>
<tr>
<th>Exp.No.</th>
<th>Current (A)</th>
<th>Pulse(µsec)</th>
<th>Ra (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>100</td>
<td>3.4</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>400</td>
<td>4.22</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>1600</td>
<td>4.62</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>100</td>
<td>4.24</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>400</td>
<td>5.1</td>
</tr>
<tr>
<td>6</td>
<td>10</td>
<td>1600</td>
<td>5.88</td>
</tr>
<tr>
<td>7</td>
<td>20</td>
<td>100</td>
<td>5.48</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>400</td>
<td>5.62</td>
</tr>
<tr>
<td>9</td>
<td>20</td>
<td>1600</td>
<td>6.6</td>
</tr>
</tbody>
</table>

An increase in the current and pulse on time tends to an increase in the surface roughness as shown in Figure 2. When the spark is high which caused an increase in the intensity of spark that produced a large crater depth on surface of the machined specimen due to the increase of the discharge energy in the gap between the electrode.
and work-piece. The period of transferring this energy, that causes more molten material to be ejected out of the crater that tends to the surface roughness of the machined surface increase.

![Figure 2](image)

**Figure 2**: The variation of surface roughness with current and pulse-on time.

### 4.2 Effect of Pulse on Time and Current on Surface Integrity:

#### 4.2.1 Effect of Pulse on Time on White and heat effected layers:

The white layer is a thin layer, which appears on the surface of EDMed work-piece, it is mainly composed of martensite and retained austenite with some dissolved carbides. This layer has more effects on the work-piece quality due to formation of micro cracks, caused by rapid cooling results a poor surface accuracy. The increase in the thickness of the white layer and the heat-
affected zone by increase in pulse on time can be clearly observed from the experimental results as shown in Figure 3.

Figure 3: The effect of pulse-on-time on the white layer (WLT) and the heat affected zone (HAZ) thickness with a current 10 A.

Figure 3 indicates an increase of pulse on time from 100 µs to 400 µs which lead to an increase sharply to twice the white layer thickness, it was observed the increase is comparatively slow in white layer thickness at 1600 µs. Furthermore, increasing the pulse duration from 100 µs to 400 µs leads to slow increase in the heat affected zone, then increased sharply to 80 µm at the pulse duration 1600 µs. It was obvious from experimental test results as given in Figure 3, an increase of pulse duration has more effects on heat affected zone thickness compared with increase on thickness of recast layer as shown in Figure 4.
Figure 4: The white layer of EDMed work-piece photograph at constant current I=10A by varying Pulse-on-time: (a) 100 µs, (b) 400 µs and (c) 1600 µs with magnification of 100X.

4.2.2 Effects of current on white and heat effected layers:

The variations in the white layer thickness taken at different current values as been observed in the micrographs in Figure 5, it showed that an increase in the current had a slight increase in the heat effected layer in comparison with an increase in the white layer thickness.
Figure 5: The white layer of EDMed work-piece photograph at constant Pulse-on-time 100 µs by varying current: (a) 5 A, (b) 10 A, and (c) 20 A with magnification of 100x.

Figure 6 indicates that increasing the current had an effect on the white layer thickness and the depth of the heat-affected zone, and the increase in pulse current tends to increase significantly the white layer thickness because of a high pulse current generated stronger sparks causing a higher temperature that developed a formation of more molten material redeposit on the surface of the workpiece.
Figure (6): The variation of thickness of the white layer (WLT) and the heat affected zone (HAZ) with current.

**4.2.3 SURFACE CRACKING**

In the EDM operation, high spark intensity generated in the gap between electrode and work-piece material will be able to melt surface of work-piece. Some molten metal are flushing and remaining molten puddle more-solidifying on the surface (white layer). Due to this increase in the spark intensity, the temperature arising causing thermal stresses, which generate micro cracks, penetrate the white layer and may extend to next layers, which has effect on process performance. So that when the current increases the spark, intensity also increases, that can lead to an increase in crack length and crack width.

The effect of pulse-on-time on crack length shown in Figure 7 with current 10 A, it was noted that an increase in the pulse duration
from 400 µs to 1600 µs tends to decrease in crack length that is when the intensity of plasma channel expands. Then, the spark power is less subsequently causing a less amount of heat generated on the surface of the work piece, which results in thermal stresses developed in the material to decrease, and finally resulting in the reduction of crack length as shown in the Figure 8.

Figure 7: The variation of surface crack propagation at constant current of 10 A at pulse-on time (a) 1600 µs, (b) 400 µs, and (c) 100 µs with magnification of 400x.
Figure 8: The variation of surface crack length with pulse-on time 400, 100 and 1600 µs at constant current 10 A.

The Effect of current on surface crack length at constant pulse duration (400 µs) as shown in Figure 9. The average crack length is increased with an increase in current from 5 to 20 A. When the discharge current is high the spark intensity and discharge power are subsequently large amount of heat is generated on the surface of the work piece, which results in the thermal stresses developed and exceeds the strength of the material and so average crack length increases.

Figure 9: The variation in the surface crack length with current at constant pulse-on time 400 µsec.
5. CONCLUSIONS

In this study, the effect of input parameters of Electro Discharge Machining process including the peak current, pulse-on-time on the output parameters; surface roughness and surface integrity were experimentally investigated. The most effective factor parameters are the current and pulse-on-time, which increased the spark energy and surface roughness. The present experimental results reveals that the thickness of white layer and heat affected layer are altered by varying the current and pulse duration during spark electrical discharge machining. An increase in current and pulse on time leads to an increase in the surface roughness and the recast layer, also the results showed an increase in pulse on time more dominant in increasing the thickness of heat affected layer. The crack length also influenced by the variation in the current and pulse on time, by increasing the current it causes an increase in crack length and vice versa the increase in pulse on time tends to decrease in crack length.

6. ACKNOWLEDGMENT

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7. REFERENCES


