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Influence of machining parameters on the surface integrity in electrical discharge machining

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ABSTRACT

Purpose: The aim of this research is to make a study of the influence of machining parameters on the surface integrity in electrical discharge machining. The material used for this study is the X200Cr15 and 50CrV4 steel for dies and moulds, dies castings, forging dies etc.

Design/methodology/approach: The methodology consists of the analysis and determination of the white layer thickness WLT, the material removal rate MRR, the electrode wear ratio EWR and the micro hardness of each pulse discharge energy and parameters of electrical discharge machining.

Findings: The Results of the tests undertaken in this study show that increasing energy discharge increase instability and therefore, the quality of the workpiece surface becomes rougher and the white layer thickness increases. This is due to more melting and recasting of material.With the increase of the discharge energy, the amount of particles in the gap becomes too large and can form electrically conducting paths between the tool electrode and the workpiece, causing unwanted discharges, which become electric arcs (arcing). these electric arcs damage the electrodes surfaces (tool and workpiece surfaces) and can occur microcracks.

Research limitations/implications: A possible future work would be the development of a general the phenomenal of the residual stress of the wire electrical discharge machining in titanium alloys. The behavior is of the residual stress studies are planed in the future.

Practical implications: The relationship found between the total energy of discharge pulses, composition of the steels and the type of machining on the surface integrity (the surface texture, the metallurgical surface aspect, the microhardness in the heat affected zone, HAZ) of different workpiece materials has an important practical implication since it allows selecting the best cutting condition combination from the points of view both the security and the economy for the established requirements in each case. Results are of great importance for aerospace and automotive industry.

Originality/value: The paper is original since the bibliographical review has allowed testing that, although works about these themes exist, none approaches the problem like it has been made in this work. The paper could be an interesting source of information for engineers and researchers who work with machining dies and also significant complex parts in aeronautics.

Keywords: EDM; Energy discharge; White layer thickness WLT; Metallographic aspect; Cracks; HAZ

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Materials manufacturing and processing

1. Introduction

The appearance of the EDM constitutes a true industrial revolution because it is well the first time, in the history of the industry, that we can carried out machining with a tool that has an inferior hardness.

This process appears by a perfect reproduction of the shape of the tool on the workpiece. It uses thermal energy to generate heat that melts and vaporizes the workpiece by ionization within the dielectric medium. The electrical discharges generate impulsive pressure by dielectric explosion to remove the melted material. Thus, the amount of removed material can be effectively controlled to produce complex and precise machine components. However, the melted material is flushed away incompletely and the remaining material re-solidifies to form discharge craters. As a result, machined surface has microcracks and pores caused by high temperature gradient which reduces surface finish quality.

Since the EDM has been an indispensable operation in the manufacturing processes, the electrical discharge machining has been in the last few years the centre of interest of several researchers [1-15].

Katz et al. [10] preceded a research in which the goal is to establish a relationship between the input and the output parameters to create a possible model process. A number of authors have performed research related to increase the material removal rate (MRR) and to reduce the electrode wear ratio (EWR) such as Ferreira (2005) [11] who studied the micro machining with copper tungsten electrode and the effect of different parameters such as tension, current of discharge, impulse time and dielectric pressure on the variation of the surface aspect by examining its topography and its microstructure with an electrons scanner. The microanalysis of the debris during machining was the subject of search of Khanra et al [12], they treated the influence of the energy parameters on the debris composition when machining a mild steel by a micrographic analysis SEM which is important to understand the mechanism of removal of matter during an EDM operation.

Among the authors who studied the influence of EDM parameters on surface roughness, there is Kiyak et al [13] investigated their research on machining of 40CrMnNiMo8-6-4 tool steel. It was observed that surface roughness of workpiece was influenced by pulsed current and pulse time. “Higher values of these parameters increased surface roughness. Lower current, lower pulse time and relatively higher pulse pause time produced a better surface finish”.

The relationship between EDM parameters and surface cracks was investigated by Lee et al [14] analyzed 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”. They conclude that the white layer thickness is mainly influenced by the pulse-on duration, and that it increases as the pulse-on duration increases, and if cracks appear they would be micro-cracks and exist in the white layer (WL); initiating at its surface and travelling down perpendicularly towards the parental material. The temperature distribution on the machined surface by wire EDM was the subject of search of Keith Hargrove et al [15]. They developed a method of finite element to model the distribution of temperature in the part and to measure the thickness of the heat affected zone HAZ under conditions of different cutting parameters, they found that the optimal parameters reduce the HAZ thickness that they calculated from a criticized temperature: 400°C beyond which the layer known as thermal affected. The minimum thickness found of this zone is 9.4 µm for a tension of 4V and time of impulse 8 µs; what means smaller the tension and the time of impulses is, finer the heat affected zone HAZ.

Boileau et al [16] pointed out that the composition of metal has a significant effect on the rate of dissolution but the composition of the solution of EDM (NaCl, NaF, NaBr) didn’t appear to have any significant effect on the dissolution speed of metals. Moreover, they have proposed that precise that the use of I in the solution of EDM is not recommended if the target metal contains sufficient Ni. The parameters optimisation in some particular theoretical models related to the complex EDM phenomena was been investigated based on the Tagushi method by Ramakrishna et al [17] they found that the increase in the exposure time induced sparks more uniform and more stable what is necessary to reduce the Electrode Wear Ratio EWR and roughness and that the increasing of the wire tension reduced its vibration and improves the surface quality of the machined part.

Mahardika et al [18] presented a new method for monitoring microEDM processes by counting discharge pulses and it presented a fundamental study of a prognosis approach for calculating the total energy of discharge pulses.

Finally, Singh et al [19] published results of an experimental investigation carried out to study the effects of electrodes material changes on the performances of machining of a steel EN-31. They concluded that the best rate of machining is carried out with the aluminium or copper electrode. The copper and copper tungsten electrodes have a minimal wear rate and give the smallest roughness values.

From the literature survey, it has been observed that no extensive work has been done to analyse the surface roughness, hardness and aspect on the work material X200Cr15 and 50CrV4. There exists a great need for investigating the effect of various electrode and workpiece materials, pulsed discharge currents, energy discharge pulse on these surface characteristics.

Table 1.
Chemical composition of work piece material 50CrV4 and X200Cr15

Material	Chemical composition, %						
	C	Mn	P	S	Si	Cr	V
50CrV4	0.5-0.55	0.8-1	0.03	0.03	0.15-0.4	1.05-1.2	0.1-0.2
X200Cr15	2	0.3	-	-	0.3	15	0.15

Table 2.
Tests conditions

Parameters	Test n°1	Test n°2	Test n°3	Test n°4	Test n°5	Test n°6	Test n°7
Electrod Material	Copper (Cu)	Copper (Cu)	Copper (Cu)	Copper (Cu)	Copper (Cu)	Graphite (Gr)	Graphite (Gr)
Average intensity I (A)	3	10	13	25	30	3.5	25
Pulse discharge energy W (J)	5.76	38.4	99.84	384	460.8	5.67	465
Electrode wear ratio EWR %	0.75	0.3	0.25	0.2	0.15	7	0.5
Material removal rate MRR (mm^3/min)	2.1	30	44	152	200	2	200

2. Experimental procedures

This study was carried out on two electric discharge machining EDM machines “ONA Basic type B360” and a Robofil 310 EL0201 technology Charmilles. It consists of studying the machining parameters effects on the steels 50CrV4 and X200Cr15 (chemical composition of Table 1) with simultaneous hardness 230 and 460 HV and making comparison between them. To evaluate their influences, we have decided to examine some surface of the characteristics such as the toughness using the measure device Test Well and the surface aspect using an optical microscope. For a tension maintaining fixed at 30 V, the tests conditions are given in the table 2. After EDM, there is any treatment.

3. Results and discussion

3.1. Examination of the metallographic surface aspect

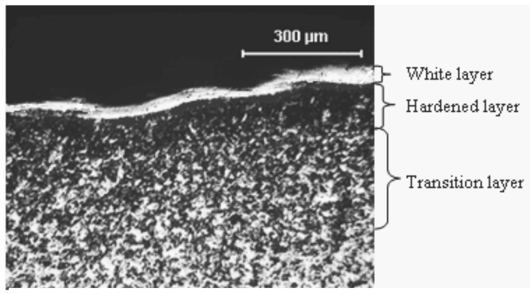
In not-molten metal, but sufficiently near to the line of fusion (Figure 1), the fast thermal cycle can cause structure transformations. Moreover, in the immediate vicinity of the molten metal, the heated areas at very high temperature undergo an enlargement of the grains and sometimes a local fusion of the grains joints which causes the formation of particular structures components.

We release a structure of superposed layers which are starting from surface: the white layer, the hardened layer and the transition layer. The white layer reveals a structure of solidification rich in carbon. The hardened layer is made up of a martensitic structure added to the residual austenite.

According to the maximum temperature reached, we can find in this zone all the intermediate structural states between the non-affected base metal annealed and that of the molten metal. The thermal dilation of the thermally affected layer is not uniform, which induces to the non synchronization of the changes of volume and thus of the deformations exceeding the elastic strain that metal can accept.

The white layer thickness (WLT) evolution according to the discharge energy W (Figure 1a), seems to be very influenced by the energy of machined materials in EDM.

a)



b)

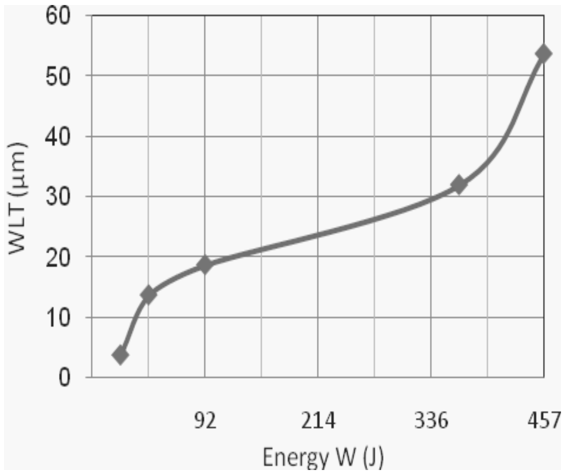


Fig. 1. (a) The composition of the heat affected zone HAZ, (b) Influence of the white layer thickness WLT on the discharge energy W in EDM

The discharge energy W for EDM is defined as:

$$W = \int_0^{on} U(Ti)I(Ti)dTi \tag{1}$$

where W denotes the discharge energy (J), U represents the discharge voltage (V), I is the peak current (A) and Ti the pulse-on duration (microseconds).

The WLT is formed by the molten metal which was not ejected far away by the dielectric, but is re-solidified (Figure 2) on the surface of the machined part. It is composed mainly of martensitic and austenite not transformed.

a)

b)

c)

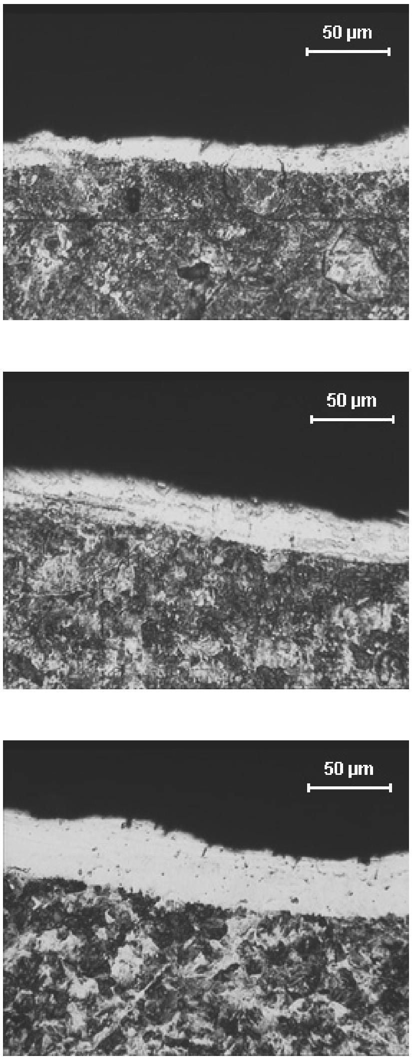


Fig. 2. Analyse of the White Layer Thickness WLT as a function of the machined energy W observed under an optical microscope; (a) W = 38.4 J, WLT = 13.7µm; (b) W = 99.84 J, WLT = 18.7µm; (c) W = 384 J, WLT = 31.95µm

The variation thickness of this layer is explained by a superficial hardening of the part worked by the spark and which depends on the individual power of the spark.

A surface heating of worked surface produces by the spark cause a double hardening of surface at a temperature which exceeds 900°C, correct temperature of hardening for this type of steel. The dielectric fluid thus acts like a liquid of hardening. In addition, the influences of the material removal rate and the electrode wear ratio on the thickness of the white layer thickness WLT [20] are opposed (Figure 3), indeed for an increase in *MRR* from 46 to 171 mm^3/min induce the rise of the thickness of this layer from 10 to 52 µm, and for this same rise we witness a reduction in *EWR* from 0.67 to 0.15 % (Figure 3), and thus a rise in the thickness of the heat affected zone, HAZ in the workpiece contributes to an increase in the tool life.

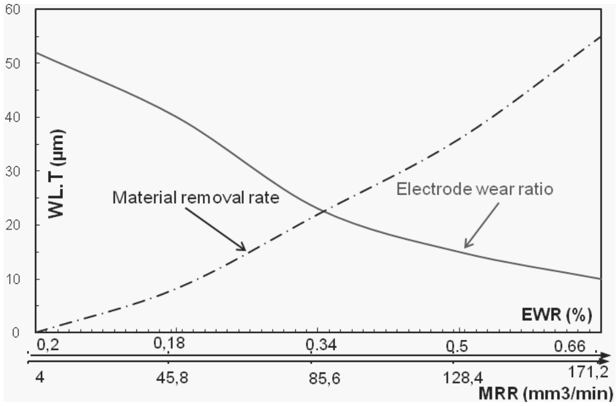


Fig. 3. The influence of the material removal rate MRR and the electrode wear ratio EWR on the thickness of the white layer

a)

b)

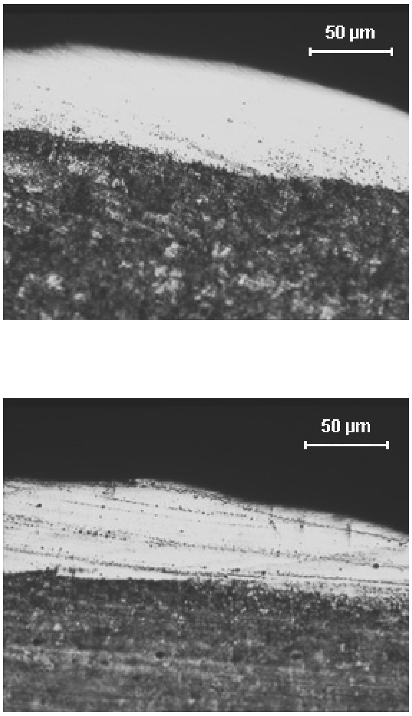


Fig. 4. Influence of the tool material on the white layer thickness WLT in roughing EDM; (a) Copper electrode WLT = 53.65 µm, (b) graphite electrode WLT = 51.88 µm

The Electrode Wear Ratio *EWR* is defined as the following equation:

$$EWR = \frac{TRR}{MRR} \quad (2)$$

where *EWR* is Electrode wear ratio (%), *TRR* is Tool Removal Rate (mm^3/min) and *MRR* is Material removal rate (mm^3/min).

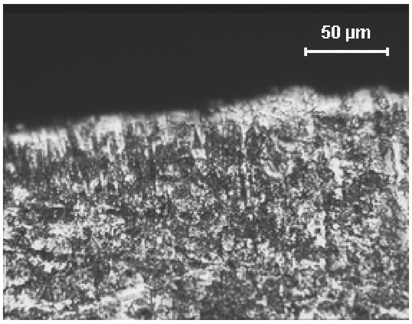
Comparison between the machined surfaces by various electrodes materials

By comparing the analysis results of the samples machined by a copper tool with those machined with graphite tool (Figure 4), for the same energy of discharge, we note that the white layer thickness almost does not vary according to the nature of material of the electrode. The big factors which influence the heat affected zone are the current, the discharge and pause duration and the inter-electrodes gap.

Comparison between different materials machined parts

The white layer thickness evolution according to the discharge energy (Figure 5), seems to be very little influenced by the nature of machined materials although their thermal and mechanical characteristics are different. Thus the increase in the hardness of material does not affect the metallographic aspect of the heat affected zone.

a)



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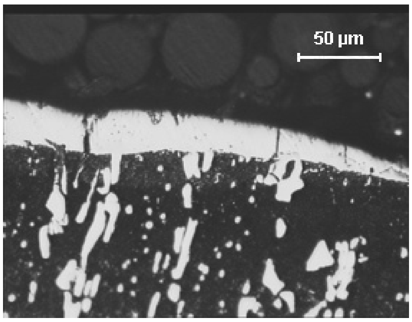
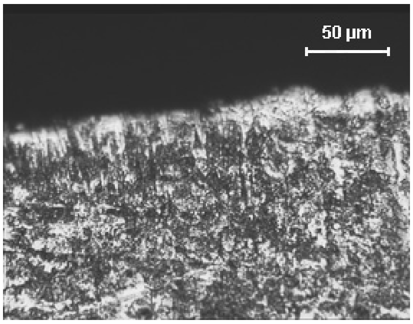


Fig. 5. Comparison between the white layer thicknesses of two different work piece material in half completion EDM; (a) 50CrV4: WLT = 18.7µm, (b) X200Cr15: WLT = 17.76 µm

Comparison between the two machining types: EDM and WEDM

For the same discharge energy, the white layer thickness for the operation of machining by EDM is equal to 3,75 µm, whereas by wire electrical discharge machining WEDM is equal to 3,15 µm (Figure 6). Thus that it is an operation of machining per driving or wire, the micrographic aspect of the zone affected by heat is function only of operational parameters such as the current, times of pause and discharge and the distance inter-electrodes.

a)



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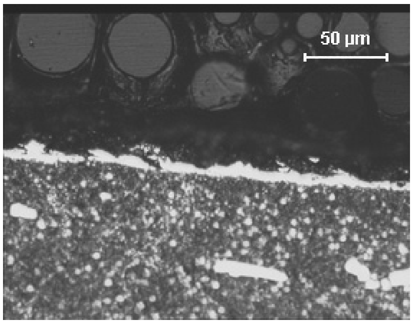


Fig. 6. Comparison between two surfaces machined by; (a) EDM, WLT = 3.75µm and (b) WEDM, WLT = 3.15µm

3.2. Evolution of the hardness

The influence of the discharge energy on the hardness profile

Hardness is usually defined as the resistance of the material to indentation. The hardness analysed is the Vickers one which is characterized by a rhombus print on the workpiece surface due to the applied charge by the pyramid diamond shape.

The micro-hardness profiles according to the discharge energy are exploited on the Figure 7; we notice that for the base material hardness between 205 and 235 HV, there is a variable hardening subjacent between 300 and 500 HV with the level from 50 to 100 µm of depth, therefore on the level of the heat affected zone. The hardening is more important and deeper as the flashing energy is higher.

Indeed, the increase in the energy induces implicitly an increase in the distance inter-electrodes and thus the increase in the flow of the dielectric which means the increase of the cooling speed and thus the formation of more martensitic which is characterized by its high hardness.

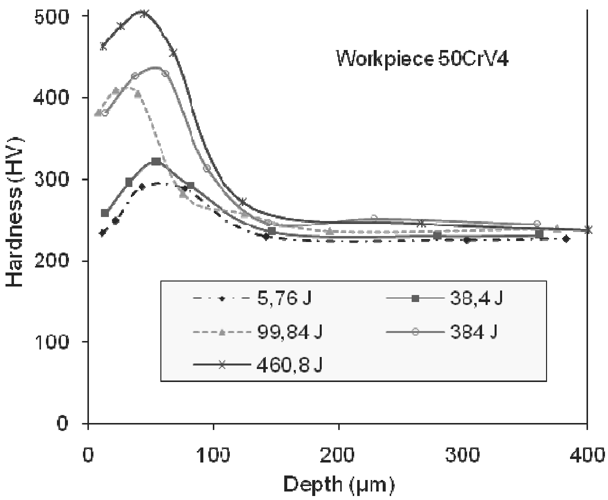


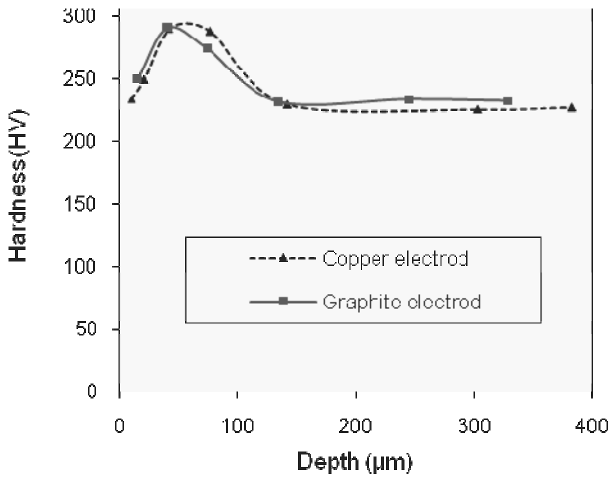
Fig. 7. The influence of the discharge energy on the depth hardness profile

In addition, we attend another phenomenon which modifies the hardness on the surface, it is the carbon enrichment; it is one of the physical phenomena which occur at the time of the flashing operation like the thermal distortions or the modification of volume accompanying the phases transformations. The dielectric interacts with material of the part and that of the electrode under the conditions of heat flux reigning at the time of the machining operation. It is particularly about enrichment out of carbon of the surface layers coming from the dielectric cracking.

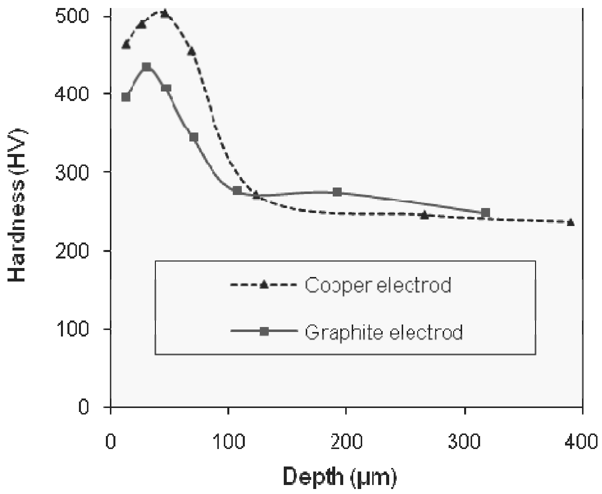
Comparison between the machined surfaces by various electrodes materials

In roughing, we notice a HAZ hardening of the part machined by a copper tool more important than that machined by a graphite tool (between 470 and 500 HV until a depth of 75 µm for a copper tool against 390 to 430 HV on a depth of 55 µm for that of graphite tool) while in finishing this difference does not appear, that returns to the effect that roughing, the average intensity is more important and due to the copper which is a better conducting material than graphite, the surface of the part more quickly warms up at more raised temperatures and thus with the flow of dielectric at the time of the current cut, the speed of cooling increases (Figure 8).
Lastly, in finishing, the metallurgical transformations and the chemical composition modification (enrichment out of carbon) are likely to introduce a hardening which depends primarily on the operational machining parameters.

a)



b)



(b)

Fig. 8. The influence of the tool material on the evolution of the hardness profile; (a) Completion of machining, (b) Roughing machining

3.3. Cracking in EDM

Figure 9 reveals the existence of cracks which start on the white layer and progress in the HAZ. The fundamental cause of cracking lies in the existence of the intern stresses which are created at the time of the machining operation. The surface density and the depth of these cracks are directly related to the machining conditions; more we increase the discharge energy, more the appearance frequency of these cracks increases. The distinctive characters of this type of cracking make some seek the causes in the physicochemical phenomena occurring at very high temperature. In fact, cracking at high temperature is due to the phenomena of segregation to solidification which because the enrichment in certain elements, as solidification progresses and that the intern stresses grow.

The explanations we can have for this type of cracking are founded on the enrichment of the crystalline joints of the subjacent structure in alloy elements which locally rise down the point of solidification and weaken the structure. The elements which have a harmful effect on steels and which increase its tendency to cracking are: silicon, nickel, sulphur, phosphorus and carbon [16].

The segregation comes owing to the fact that the grain boundaries generally constitute preferential sites for the impurities. The heating at very high temperature, during flashing, involves the enlargement of the grain of metal which implies the migration of the grain joints; during this migration, the joints of the grains rake the impurities which are in metal, and it is possible that this causes local concentrations in impurities. The presence of these cracks is also due to the presence of the elements strongly conducting in material as copper which let penetrate the current of discharge. It results preferential energy propagation from it through these elements which can lead to total or partial separation of certain grains.

4. Conclusions

The experimental study of the EDM of 50CrV4 and X200Cr15 workpiece steel provided important quantitative results for obtaining possible high surface finish quality and machining outputs as follows:

- Results of the tests undertaken in this study show that increasing energy discharge increase instability and therefore, the quality of the workpiece surface becomes rougher and the white layer thickness increase. This is due to more melting and recasting of material.
- With the increase of the discharge energy, the amount of particles in the gap becomes too large and can form electrically conducting paths between the tool electrode and the workpiece, causing unwanted discharges, which become electric arcs (arcing) that damage the electrodes surfaces (tool and workpiece surfaces) and can occur microcracks.
- Lower discharge current and lower pulse-on duration should be used for a lower hardened surface and thinner heat affected zone HAZ but reduces the material removal rate; consequently, the machining time will increase.
- It has been found that crack formation is caused by the stress induced by the EDM process. When the degree of induced stress exceeds the maximum tensile strength of the material, cracking will occur.

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