

INFLUENCE OF CORRELATION BETWEEN EDM`S PARAMETERS WITH THE FORMATION OF SURFACE DEFECTS IN PRODUCTS MACHINED BY ELECTRICAL DISCHARGE MACHINING.

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Abstract *The Electrical Discharge Machining is classified as a non-conventional manufacturing process, and it is used for machining a range of materials with high hardness in pieces with complex geometries. In this process the material is removed by heating and vaporization produced by electrical discharges and due to its high temperatures on the surface, surface defects can emerge, such as: cracks, material´s properties change, surface integrity and texture change, high roughness and formation of recasted layer, which is called white layer. These surface defects due to their propagation, can produce a premature fracture of products machined by EDM. This paper shows a study of correlation between EDM´s parameters with the level of superficial defects development, which can lead to premature failure of die cast mold machined by EDM. The correlation of parameters was determined through experimental matrix that uses the DOE methodology (Design of Experiment). In order to evaluate the surfaces of some machined samples a stereo optical microscopy, SEM (the scanning electron microscope) and a microhardness profile machine were used. The results show that in the worst machining condition, which is caused by association of long electric discharge pulse time-on and graphite machine-electrode, it is possible to minimize the amount of surface defects, without applying a subsequent machining process such as polishing, just using the reduced time-on´s electric discharge pulse, copper electrode and dielectric fluid with base of hydrocarbon.*

Keywords*: EDM, EDM parameters, superficial defects and white layer.*

1.INTRODUCTION

The metal-mechanical industry uses many manufacturing processes to create products and/ or components. The correct manufacture in metal-mechanical industry depends on a precise process to be applyed and to ensure that this choice gives the necessary characteristics on the product's use and application. Besides it should also be noted the lower cost involved in manufacturing and higher stability for the process and tooling. In order to determine the manufacturing process the choice is limited by some product or tool's features, such as material composition, high hardness of this material, product's complex geometry and surface integrity, requiring in some cases the application of non-conventional processes for their manufacturing (Chiaverini, 1986).

Manufacturing processes, that use the concept of higher volume of material removal at the lowest cost on machinery and tools, have priority to be applied on metal-mechanical industry (Leone, 2000). According to Fonseca (2001), these special characteristics are observed in the process of casting by injection, which is considered ideal because of the high production capacity when applied to certain aluminum products. The process of injection is capable of producing high volume of parts, through a machine called injector, which injects the liquid metal inside the cavity of a metal die with pressure values ranging from 70MPa to 140MPa at high speeds. The die is made using materials of high hardness to withstand the repeatability of the injection cycles, and to maintain the structural homogeneousness in order to ensure durability during injection, avoiding premature breaks and defects. According to Vendramim (1995), the process of aluminum melting by injection, is among the methods of industrial processing of metals, one of the most severe, regarding the request of the die. High mechanical strength combined with high temperatures involved, the chemical reactions produced by the molten aluminum on the surface of the die and the geometric complexity of parts produced, stresses specially the dies and tooling involved. Therefore these requests require that the die and tools show high performance, both in life as in stability of the material structure. The casting process also involves high costs for their implementation and a die represents roughly 30% to 40% of all costs involved in the process of injection.

A non-conventional manufacturing process can be applied to produce an injection die and one of the best and most widely processes available is the electrical discharge machining (EDM), according to a search conducted by the Fraunhofer Institute (2004). The machining by electrical discharges EDM, or electro-erosion, is a process where the material's removing occurs through a high-frequency electrical discharges that cause melting and vaporization of electrically conductive material (Amorin, 2002). Therefore, the process is capable of producing holes, grooves and other complex shapes in materials with high hardness which by conventional processes, would be impossible to be done.

The EDM is a complex process, which requires knowledge of their variable controls (Lima and Corrêa, 2006). When any component is machined by EDM two important aspects should be noted. First is related to the geometrical irregularities of the surface which is called "surface texture", and second, with the changes of the material surfaces and sub-surface layer, called "surface integrity". In the machining of some products or tools, these two aspects, surface texture and integrity should be defined, measured and kept within specified limits to ensure durability and quality of these products and tools. The fig.1 shows the two main aspects and factors of influence.

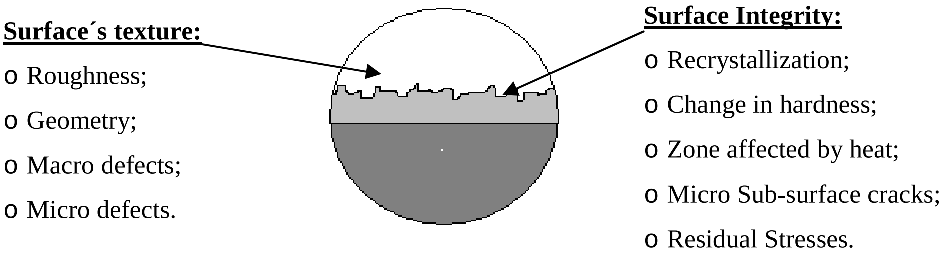

Figure 1. Basic representation of a surface machined by EDM showing the two main issues and factors of influence. (Lima and Corrêa, 2006)

According to König and Klocke (1997), the main means of controlling these two aspects during machining by EDM are directly related to the parameters of the process, among which are:

- Machine-electrode: Silva (2006) describes that this parameter is the mean by which energy is transported to the part-electrode and the material used in its construction directly affect the result of the energy transport. The shape of the machine-electrode determine a model/die in the part-electrodes through electrical sparks that occur during the process;
- Part-electrode: Lee and Tai (2003) evaluate all of the factors that affect the formation of micro-cracks, thermal conductivity has great influence, since a material with higher thermal conductivity has the ability to quickly conduct the heat, removing it from the region and thus reducing the tendency for crack formation;
- Removal rate: this parameter is directly related to the electric current and frequency required in the process (König and Klocke, 1997). The rate of material removal is equal to the volume of removed material from the piece at a time unit (McGeough, 1988). The time of electrical discharge (t), the arc voltage (V) and intensity of the current (I) are the controlled parameters related to cracks formation according to Lee and Tai (2003), therefore when an increase of the pulse-on average duration is generated , a greater thickness of white layer and residual stress are formed on the material surface. These two conditions tend to make a large micro-cracks formation;
- Dielectric-fluid: This parameter is related to control the opening discharge power, to promote cleaning in the gap between the tool and the product and to assist process cooling (Fuller, 1989). The fluid can be kerosene, additived hydrocarbon, both derived from oils, deionized water and even some water solutions.

These parameters control certain machining conditions and can cause the phenomena between the process and the product, such as: high temperatures, surface chemical reaction, density of energy, residual stress and surface mechanical or metallurgical properties modification. Uddeholm (2002), describes that the influence by erosion produced during electrical discharge on a machined material is completely different from that presented in materials machined by conventional methods. The surface of the material is exposed to high temperatures from 10.273K up to 50.273K, causing the vaporization of material. These high temperatures cause changes in properties on the material surface and can cause surface defects that promote breakage, wear or premature failure (Yoshida, 2002). The graph of fig. 2 shows the failures percentage of injection dies casting related to its manufacturing process by EDM. These failures in dies affect approximately 31% of the downtime cost in the casting process and can be minimized through optimization of the manufacturing process (Yoshida, 2002).

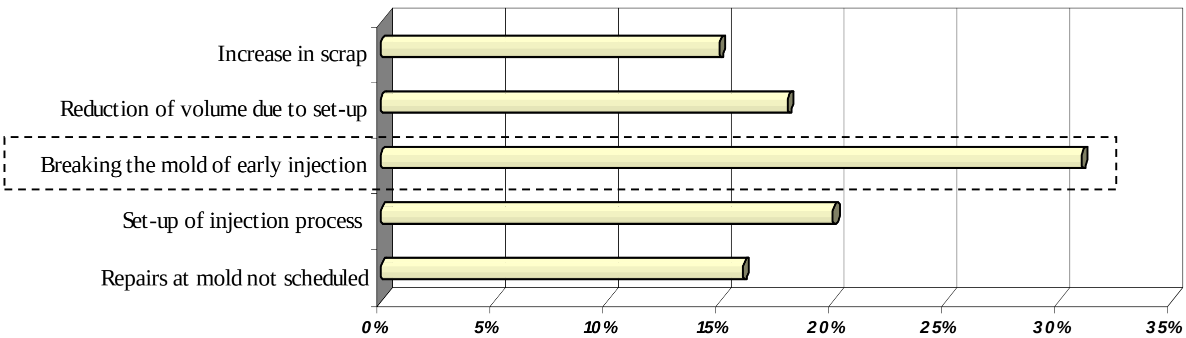

Figure 2. Graph costs caused by failures in the process of the die injection casting. (Yoshida, 2002).

This percentage of defects in dies from the manufacturing process is minimized or eliminated, currently, by application of other processes after EDM, which are: polishing and surface treatment (Fagundes, 2002). These processes minimize or eliminate superficial defects caused by EDM, thus increasing the durability of the dies. Nevertheless this practice makes the process of EDM dependent on the correction of its defects by subsequent processes when their EDM parameters are not optimized.

The preliminary results from this study show that the tables with machining conditions given by EDM manufacturers and the uncertain combination of EDM parameters when undertaken by die manufactures can cause damage to the surface of the machined material. These defects, such as cracks on and in the surface layer, recasted white layer, change of material hardness and surface roughness were found during the machining tests using standard conditions. For these tests the EDM parameters combination were used following common parameters for the die industry:

1 - Part-electrode: Material electrolytic copper;
2 - Machine-electrode: steel H13 premium with heat treatment;
3 - Dielectric fluid: Fluid-based hydrocarbons aditivado;
4 - Rate of removal: the pulse-on time of electric discharge 23μs, the pulse-off time of electric discharge 10μs, 120V voltage and current 6A.

Other controls were used according to standard set-up of the EDM machine. As shown in fig. 3, the surface of the sample-body after machining shows morphological changes, such as craters, grooves and cracks. The fig. 4 (a) shows the recasted layer thickness and cracks that cross this layer and reach the substrate and fig. 4 (b) shows that even after polishing, these defects are still present on the surface.

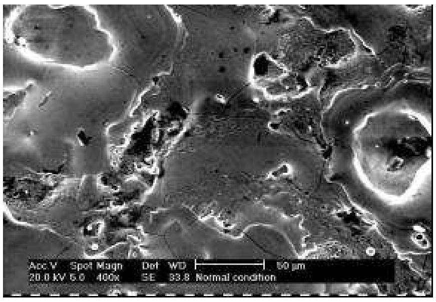

Figure 3. Defects evidence on the body surface regarding the preliminary study examined by SEM, 400x.

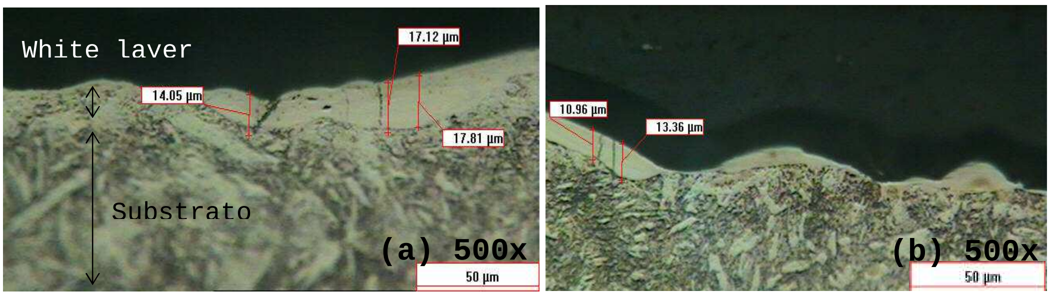

Figure 4. (a) Thickness of the white layer and cracks on the body surface regarding the preliminary study. (b) white layer and cracks still present after polishing.

These defects are partially removed after the process of polishing, but cracks that reach substrate are not removed and are still present points of recasted layer causing surface heterogeneity. Based on the preliminary study results the parameters were chosen for a more complete study. This article aims to examine the main effects of the variation of EDM parameters on integrity and surface texture of the raw material used in the die manufacturing for aluminum injection. It is expected to minimize the premature failure of the dies and to eliminate subsequent machining process. Therefore, understanding and control of phenomena governing the process of EDM can ensure the integrity and durability of products made by this process.

2. EXPERIMENTAL PROCEDURE

The machining of the samples was made by a penetration EDM model DXC45 manufactured by Japax. The total machining time was standardized in continuous 6h and the machined diameter was ∅16mm.

In order to evaluate the influence related to the superficial integrity and texture of AISI H13 steel. The machining parameters levels (2 levels for 3 machining parameters) were compiled in a DOE (Design of Experiments) matrix. The DOE methodology used in the matrix of experiments is based on Taguchi and aims to reach a better combination of the chosen controlled process variables in order to get a maximum number of information with a minimum number of experiments. The classic form of the DOE matrix provides a pre-determined number of experiments. Nevertheless this technique also allows the identification of significant factors of a process and their optimal levels. Thus, it is possible to obtain a reduction in the variability of the experiments which has fundamental importance in terms of quality and cost reduction leading to an optimization of the tests (Rodrigues, 2001). The calculation to determine the number of the applied experiments, depending on the parameters and their levels, is shown below:

n = number of levels applied to each parameter of the experiment;

v = number of parameters of the experiment;

$\boldsymbol{n^v}$= formula for calculating the number of experiments to be used and matrix determination according to DOE;

The analysis performed by this article shall be determined by the variation of three parameters at two levels based on the EDM state of the art review, so the number of experiments of the completed matrix is obtained by the following calculation:

$\boldsymbol{n} = 2$

$\boldsymbol{v} = 3$

$\mathbf{2^3} = 8$ experiments.

However, the matrix 2^3 allows the optimization of the tests using the reduction of optimum and repetitive levels according to DOE methodology. The final matrix of experiments that will be used in this article is shown in tab. 1:

Table 1. Matrix experiment reduced to three parameters at two levels.

Experiment	Parameter A	Parameter B	Parameter C
1	A1	B1	C1
2	A1	B2	C2
3	A2	B1	C2
4	A2	B2	C1

The parameters and their levels used to prepare the experiments matrix were extracted from the studies of Lee & Tai (2003), Arantes (2003) and Drodza (1983). For each combination is expected that the quality of the parameters promote different yields in surface finishing, level of surface defects and recasted layer thickness. The parameters and other controls used during the tests are described below:

1 - The EDM parameters and controls were used in the machining of part-electrode steel AISI H13 with thermal conductivity equal to 28 W/m °C and with application of heat treatment. The part-electrode was not examined at two levels because not showing significant difference in the thermal conductivity of the materials currently used in die industry. At the study of Lee & Tai (2003) were investigated steels AISI D2 and AISI H13 which have large difference in thermal conductivity, but the steel AISI D2 is unusual in industry for dies.

2 - To the machine-electrode parameter, two levels of variation were defined to identify the influence of electrode material type with defects. The material defined for the electric machine were the electrolytic copper and/or graphite. According to Monhi (1993), the electrode with electrolytic copper is conventionally employed in the industries because it can provide high wear relation and high thermal conductivity.

3 - The machining was made using kerosene and/or additived hydrocarbon as dielectric fluid. The dielectric properties for the fluids used are described in tab. 2.

Table 1. Fluids dielectric properties used in the tests. (Intech, 1996)

Dielectric fluid	Fulgency Point (ºC)	Viscosity (SUS 40ºC)	Fluidity Limit (ºC)
Hydrocarbon	106	32-35	-20
Kerosene	40	32-35	-44

4 - The values for time-on of electric discharge pulse were defined as 9µs and/or 27µs, the voltage and current were kept at 120V and 8A respectively. The current of 8A was based on the scales used by die machining industry, it is known that the currente intensity value influence directly at rate of removal, but the main objective of this study is the analysis of usual conditions at industry and propose optimal parameters. The results presented by Tung and Lin (1998), also did not show significant variation of white layer thickness due to a drastic increase in the rate of removal of material when the currente pulse is high.

5 - The gap was set at 0.045 mm to allow better flow of dielectric fluid in the machined area. Other controls and machining parameters were set according to the EDM machine manual and was kept the time-off of electric discharge pulse in 12 μs for all tests. The tests of machining by EDM were realized according to the combination shown in the final matrix experiments with the description of parameters and their levels, tab. 3:

Table 3. Reduced matrix of experiment with the combination and a description of the three parameters and two levels.

Experiment	**EDM Parameters**		
	Electro-Machine	**Dielectric fluid**	**Time-on of discharge eletric pulse**
1	Graphite	Hydrocarbon	27 μs
2	Copper	Hydrocarbon	9 μs
3	Graphite	Kerosene	9 μs
4	Copper	Kerosene	27 μs

Samples were machined using the parameters selected in the tab. 3. After that, these samples were submitted to the following tests:
1 - Analysis of the topographic morphology by SEM (scanning electron microscopy) with magnification of 400X for the identification of micro-defects and variations in surface texture;
2 - The roughness of machined surfaces in the tests were evaluated by the parameter Ra, because the EDM finishing level is equivalent to polishing or retifer, and also the parameter Ra is usual at the assessment of die during its machining. According to Amorin (2002) the parameter Ra is the most used during the evaluation of the roughness in EDM search. The value of roughness in Ra was set at 0.4 μm to 0.8 mm for the cut-off of evaluation.
3 - The samples were processed by cutting, polishing and etching with a 5% Picral solution;
4 - Analysis of superficial integrity checking the thickness of the layers formed and superficial micro-cracks that can reach the substrate;
5 - Profile of microhardness was conducted primarily in the white layer and than in other points toward the substrate. The distances of the measurements after the first one realized at white layer are: 15μm, 30μm, 45μm, 80μm and 1mm. The microhardness test was performed in HV_{100}.

3. RESULTS AND DISCUSSION

3.1. Surface morphology

The fig. 5 shows the sample surface with evidence of its different surface morphology due to the melting and cooling condition of the not vaporized material by electric discharge during machining.

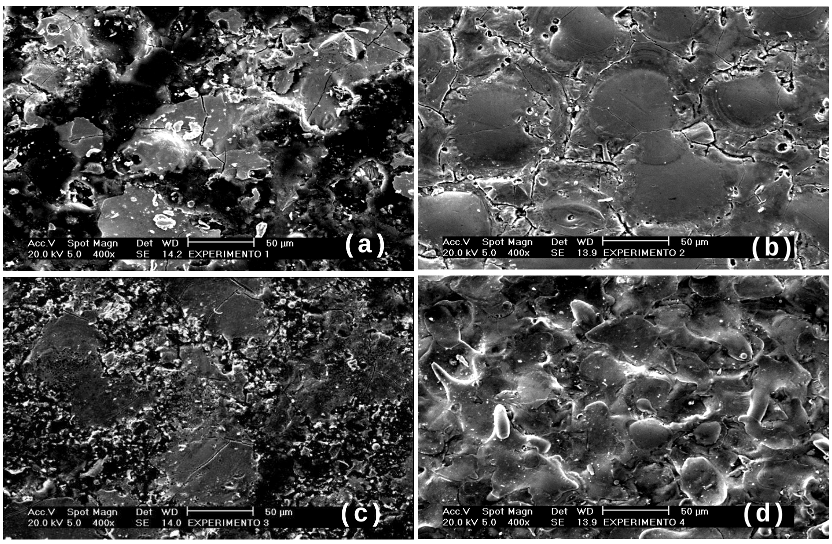

Figure 5. Images obtained by SEM with magnification of 400x concerning the surface morphologies resulting from the experiments. (a) experiment 01, (b) experiment 02, (c) experiment 03 and (d) experiment 04.

According to the images obtained by SEM and shown in Fig.5, in the machined surfaces morphological changes resulting from the formation of craters or bumps caused by molten material overlay are observed, it is also possible to be observed the formation of cracks and re-melting of surface layer. This morphological change generated by the melting of material, in a certain portion of the surface, due to high temperature generated during the electric discharge. These melted regions were cooled by dielectric fluid and most of the material was carried out by the flow of fluid in certain experiments. But a lot of material that should be filled out and returned by the flow of the dielectric surface of the machined material causing greater morphological changes, this condition can be observed in experiment 01.

The condition of machining prepared for the experiment 01 with time-on 27 μs, increases the duration of the electric discharge generating a longer period of resistance to passage of fluid in the dielectric-gap, thus cleaning the machined area is undermined. Arantes (2003) describes that for better cleaning and cooling the flow of dielectric fluid, must be continuous and have the least resistance, because we need to contact the machined immediately after the occurrence of electrical discharges to remove material expelled and reduce the heat generated. This condition is achieved with greater efficiency for a shorter time-on the electric discharge as the result of machining condition shown in the experiment 02 using time-on 9μs.

Another factor that affected the surface quality and which may have been caused by the long duration of the electrical discharge was the increase of sparks per unit of time, because more often the time-off in the machining dielectric fluid has time to become deionized. A stopped time too soon and a very long time-on can result in double sparks, leading to a constant burning electric arc between the machine-electrode and part-electrode, resulting in a surface defect. The risk of increasing the rate of arc is large when is difficult the cleaning condition provided by the fluid. The electric arc produces large craters or recasted areas in machined surfaces (Uddeholm, 2002).

The main cause of the sparks can be related to inadequate cleaning, resulting in lost chips or other particles that form a bridge between the machine-electrode and part-electrode. This effect can be obtained with a graphite electrode that carries traces of other materials or due to fragmentation of the machine-electrode.

The machining condition which connected graphite electro-machine with the higher time-on was a combination of experiment 01, the result showed large machining cracks, high level of craters generation and large irregularities on the surface. Therefore, the surface morphology had a great change when there was reduction in the cleaning and cooling due to long time-on associated with the discharge of sparks caused by waste in large quantities from the graphite electrode. The type of dielectric fluid did not directly influence the results of the surface morphology change, because using the same hydrocarbon dielectric fluid in experiment 01 it was obtained the worst condition in the surface morphology and the best condition was obtained in experiment 02.

3.2. Superficial finishing

The roughness is the state of surface roughness and its morphology, after the experiments the largest value of roughness in Ra and the greatest morphological changes were obtained when applied to long time-on of electric discharge, associated with the graphite machine-electrode. The associative factor between these parameters creates more inefficient cleaning due to roughness of machined region, caused by the amount of impurities of the graphite material and recasted material expelled during electrical discharges of long duration. As demonstrated by research Arantes (2003) the quality of machined surface decreases when the electro-piece is subjected to long periods of electrical discharge, raising the rate of evaporation of the dielectric and creating more bubbles, thereby causing a deficiency in the cleaning and fast removal of heat from particle imploded after the electric discharge. For the experiments can be verified that the type of dielectric fluid does not directly influence the results of roughness Ra, as the experiments with the worst and the best level of roughness hydrocarbon used as the dielectric fluid.

The tab.4 shows that the greatest value in Ra was in experiment 01 and the second was obtained in experiment 03 which combines the lowest time-on of the graphite electrode. Therefore, the surface roughness has more influence when the electro-piece is machined with the electro-machine graphite, due to the recasted layer of material associated with the particles detached from the graphite electrode. This phenomenon can be evidenced by the wear of 9% in thickness and 22% in the rays of the machine of graphite electrode compared to the electro-electrolytic copper. Another factor that corroborates with the results of this analysis is the study of Lima and Correa (2006) which showed the formation of major irregularities in the material surface when machined by the graphite electrode.

Table 4. Roughness values obtained after machining.

Roughness Results Ra – Cut-off 0,8mm – Standard JIS1994					
	Experiment 01	Experiment 02	Experiment 03	Experiment 04	Preliminary Study
Results	3,15	0,96	1,66	2,12	2,55
					Unit: μm

3.3. Micro-hardness profile

The fig. 6 shows a region of identations performed on the samples. The first identation performed directly on the white layer and the other at distances shown in this figure 6. The values of the micro-hardness profile are shown in the graph of fig. 7, these values are average of 6 identations in each distance.

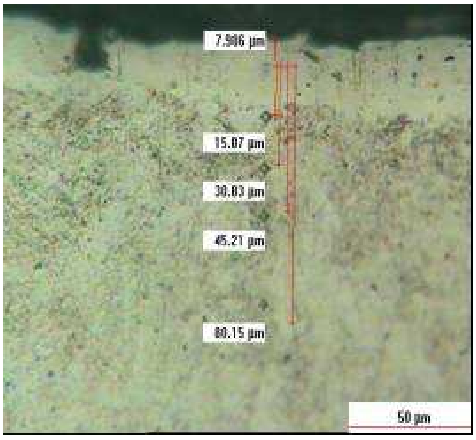

Figure 6. Regions of identation for measuring hardness in steel samples.

The results of the metallography analysis performed by the profile of micro hardness values showed by the graph of fig. 7 that the bodies of evidence have different machined layers. These layers can be differentiated according to the classification made by Cruz(1999) as below:

1 - Re-casted and re-solidified (white layer) zone: corresponding to the most superficial layer which was the first point of identação, this is the region that suffered the highest temperatures. The steel was melted and re-solidify by the action of the extraction of heat given by the dielectric. Microstructural, this layer is crude casting and re-melting of the material from the surface machined by EDM causes the concentration of retained austenite and martensite with some dissolved in carbide (Tung and Lin, 1998). The white layer is so densely infiltrated with carbon that have different structures, the substrate completely distinguishable. The white layer of enriched carbon also leads to high hardness and the microstructure caused an increase of two to three times the value of the hardness of the material after heat treatment. The values obtained show that the hardness value decreases towards the substrate, it is because the area is re-cast the greatest concentration of heat and the thermal conductivity of the part-electrode heat is dissipated without interfering the core substrate. However, when an increase in thickness of the re-cast as in experiment 01, the value of the hardness and greatly increases the subsequent layers have their values changed in greater proportion. This increase in hardness on the surface to spread the lower layers may decrease the impact resistance of the material (Yoshida, 2002). For an injection molding of aluminum, to reduce the impact of resistance on its surface can lead to premature failure of breakage when associated with pre-existing surface defects.

2 - Re-tempered zone: the region corresponding to temperatures higher than austenitization, tempered by the subsequent cooling as dielectric. Microstructural, this region consists of coarse martensite (Lim, 1998), due mainly to higher temperatures than those used in normal heat treatment;

3 - Tempering zone: corresponding to more internal regions of the surface, where the temperature exceeded the standard used in tempering. Microstructural, this region consists of coarse temper martensite (Lim, 1998).

The distinctions of these layers could be evidenced by changes in values of hardness in the regions analyzed. The hardness increase has occurred when generation of high temperatures and this phenomenon in machining by EDM was caused by the deficiency in the refrigeration and longer-on the electrical discharges, characteristics strongly presented in the experiment 01.

The experiment 01 showed higher values of hardness in the same regions analyzed in other experiments, the value of hardness in the white layer on the values of the subsequent layers showed significant change when compared with the hardness of material without machining which is approximately 410HV, the change is more pronounced in experiment 04.

Therefore, it was found that the increasing of the surface hardness is directly related to the thickness of the recasted layer (white layer), and for the subsequent layers the change of hardness is caused by the dissipation of heat generated on the surface toward the core of material.

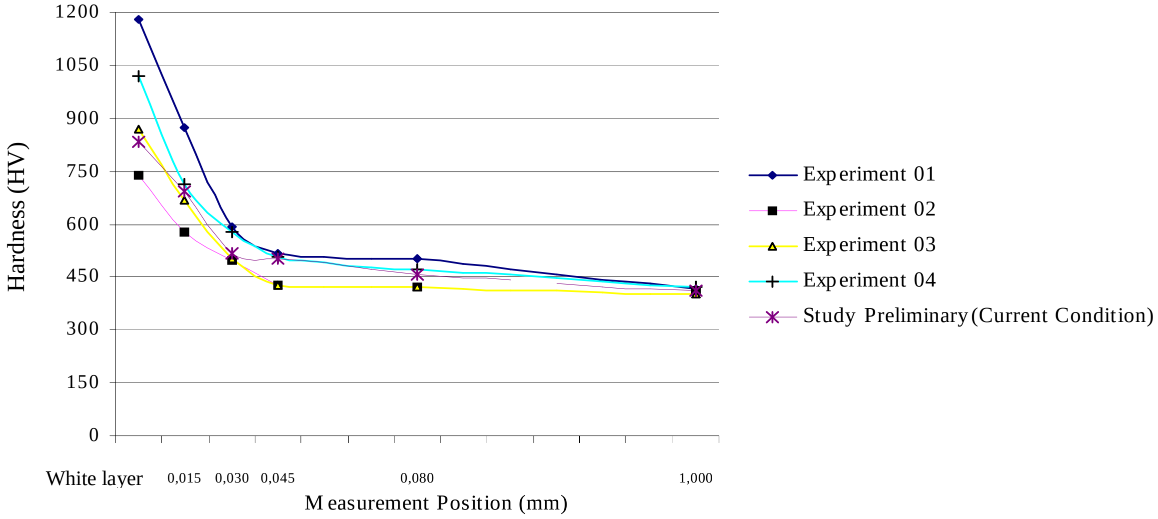

Figure 7 – The hardness profile obtained in the sample after experiment.

3.4. White layer and superficial defects

On the samples can be observed the presence of a layer due to interruption of the discharge, where the material is not expelled by washing solidified in the crater and surrounding region, which formed the top layer called the white layer. This layer shows changes due to chemical interaction with sub-products of the dielectric and the electrode-tool, and changes in its structure due to fast solidification of the material. The white layer and its properties are completely different from the material base as the amount of irregularities made and it is liable to endanger the life of the material if not removed. The thickness of white layer is influenced primarily by the current pulse and increases as the duration of the pulse energy is high. This is explained by the fact that the quantity of liquid metal, which can be washed away or is the dielectric constant (Dibitonto, 1989). Therefore, the more heat is transferred to the sample and increasing the duration of the pulse-on, the dielectric is increasingly unable to remove the melted material, and so it is deposited on the surface of the piece. During the cooling, the re-solidified material form the white layer and depth of this layer depends on the volume of material melted.

The analysis of Lee & Tai (2003) is supported by the results shown in fig. 8, where it is shown the thickness of white layer obtained after the machining tests. The highest value for the white layer thickness is obtained when is associated the longest time-on of electrical discharges to the graphite electrode, because again in this condition is obtained the lowest condition of cooling in function of the longest time of contact between the electrodes and the level of impurities detached of the graphite electrode.

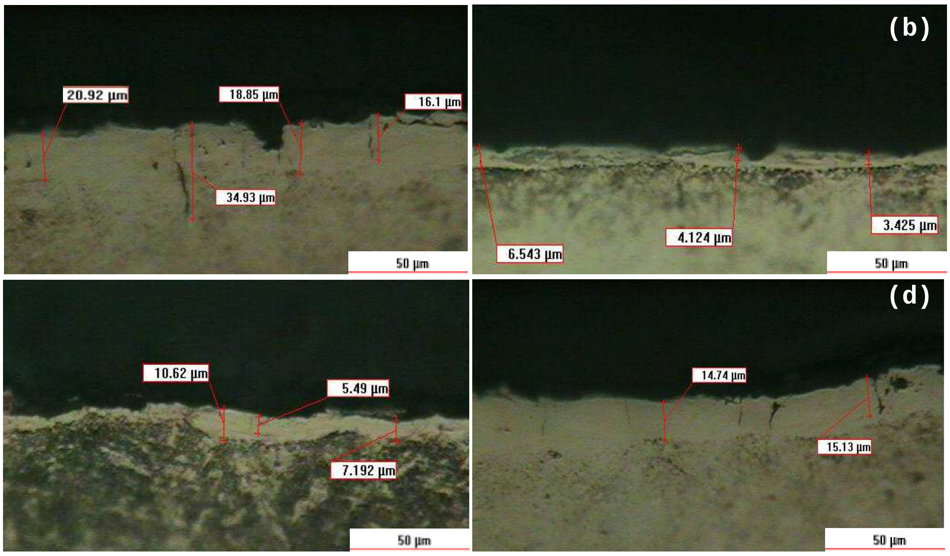

Figure 8. Images obtained by microscopy with magnification of 500x for thick white layers on the sample surfaces. (a) experiment 01, (b) experiment 02, (c) experiment 03 and (d) experiment 04.

The recasted area has superficial cracks that can concentrate stress and cause the drop of a die by thermal fatigue or low resistance to the impact of injection. The entire surface of the material may be compromised mainly when a crack extends beyond the white layer and reaches the substrate, this type of defect is worrying when the focus is the durability of the material machined by EDM. The elimination of superficial cracks is often performed by processes subsequent to EDM, but these processes remove the white layer and the defects contained therein, but the defects that reached the substrate are not eliminated and can cause failures in the future material machined by EDM. fig. 9 shows the level of superficial cracks caused during the tests and the values of the depths.

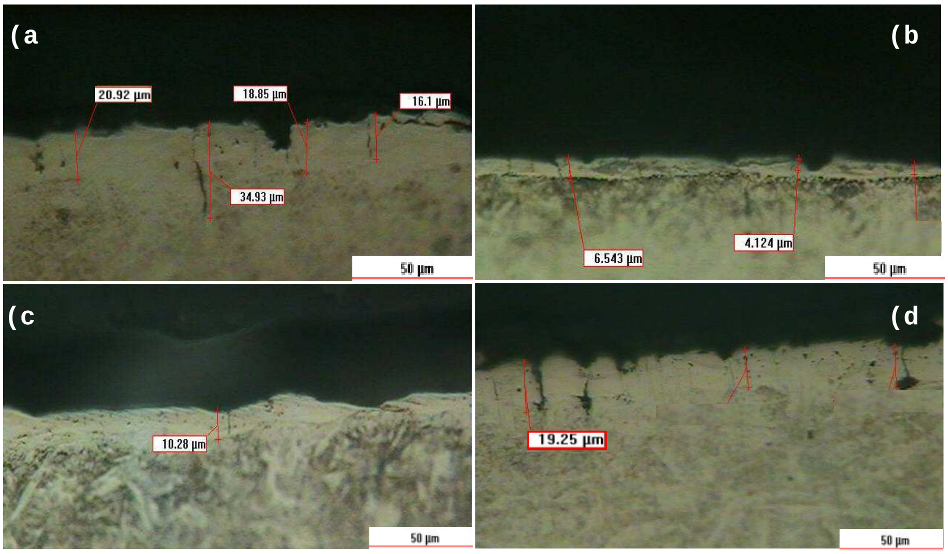

Figure 9. Images obtained by microscopy with magnification of 500x, showing the crack depths of on the surfaces of the samples. (a) experiment 01, (b) experiment 02, (c) experiment 03 and (d) experiment 04.

The experiments 02, 03 and 04 show that cracks initiate at the surface of the material and cover the entire thickness of white layer, ending its length between the white layer and the substrate layer affected by heat. But the experiment 01 shows a crack with a depth of 0,034mm and that reaches the substrate. The formation of crack reaching the substrate is not removed by polishing and it is originated from the concentration of heat during the electrical discharge(Lee & Tai, 2003). Again the most influent defect was caused by the combination of graphite-electrode with long electric discharge time-on.

4. CONCLUSION

The combination of the parameters during the experiment has allowed to detect the most influent factors on the origin of defects and determine range of parameters to achieve a better condition of machining. These factors are listed below:
A - A combination of graphite machine-electrode with time-on 27µs produced the worst results of: micro-hardness profile, recasted layer thickness, roughness Ra and depth of surface crack. The most influent aspect of these results is the long period of electrical discharge, but the graphite machine-electrode should also be considered an important factor for reducing the defects in the texture and surface integrity. The defects found with the association of graphite machine-electrode and time-on 27µs may cause a premature crack at the die;
B - The heating phenomenon due to lack of refrigeration was the main cause for generation of higher white layers, it is demonstrated in experiments using graphite machine-electrode and / or longer electric discharge time-on. The use of these parameters promotes a reduction of dielectric-fluid flow in the gap between the electrodes due to the generation of residues of graphite electrode and the high time of contact between the electrodes during the electric discharge. The direct contact between the electrodes does not occur, however, the gap between them is minimal to generate discharge;
C - The dielectric fluid used didn't show significant interference in the experiments, because the best and worst conditions of machining were obtained with both fluids. It is important to note that the use of kerosene type dielectric fluid is harmful to health then, it should be given priority to the dielectric base hydrocarbon;
D - The best condition for the machining of AISI H13 steel was used as the electrode, electrolytic copper and less time-on the electric discharge. When comparing the combination of parameters with the parameters used in the preliminary study, the only parameter changed was the amount of time-on, which increase was from 9µs to 23µs, but the preliminary study showed large defects in the texture and surface integrity. The reduction of electric discharge time-on increases the total time of machining, but minimizes surface defects and reduces the application of the subsequent process of EDM machining.

Through analysis we can conclude that it is possible to determine optimal parameters for a limited pre-set condition, because the process of machining by EDM is dependent on many factors.

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