# Optimization of Cutting Parameters in the Wire Electrical Discharge Machining of VC131 Tool Steel

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*Abstract*— **The wire electrical discharge machining process (WEDM) is largely employed in the metal mechanic industry - especially in its tooling sector, as tools generally have complex geometry and are made of hard materials with low usinability, which hinders the application of conventional machining processes. This work presents an investigation of the influence of the cutting parameters in the WEDM process of the VC131 tool steel. A FANUC ROBOCUT α-OiE equipment was used in the experiments. The machining of the VC131 steel in the 'as supplied' condition (untreated), with a hardness of 19 HRC, and after a quench and temper heat treatment, with a hardness of 53 HRC, was analysed. This work aims to compare the cutting parameters generated by the equipment, which are based on technical tables, with those optimized by the operator. In this study, the machining time, the material removal rate and the surface finishing obtained before and after the optimization of the cutting parameters were compared. There was an important gain in the material removal rate and a small loss in the surface finishing when the machine parameters were adjusted to improve the performance of the machining process of the VC131 tool steel before and after the heat treatment.**

*Index Terms* — **Wire electrical discharge machining. Steel. Material removal rate.**

## I. INTRODUCTION

THE wire electrical discharge machinig (WEDM) process offers great advantages, as it is a cutting method that may be applied to any electrical conductor, hardened (heat treated) materials included. Besides, a stress relieving treatment after machining is not required and the material microstructure is not affected by the process. During the machining process, the wire, which serves as electrode, follows a pre-programmed path that may be determined either by manual input into the machine's control panel or by using a specific CAM software. The use of this process enhances the competitiveness of industries, as it allows them to offer precision products with complex geometries.

## II. LITERATURE REVIEW

The companies of the metal mechanic sector, especially the tool makers, frequently use the VC131 tool steel for making parts and tools to be used in production. However, a great issue faced by those companies is related to the difficulties in machining heat treated materials without affecting their mechanical properties.

According to Dibitongo et al (1989), the electrical discharge machining process (EDM) has attracted attention of industries as it is a technical advance that allows for the machining of parts with varied and complex geometries, that would be difficult or even impossible to obtain through other traditional machining processes, such as milling and drilling.

As stated by Uddeholm (2002), the temperature at the cut region may reach up to 50,000 °C during the electrical discharge machining process. However, this process has some advantages when compared to traditional machining process, as in those processes physical contact between the cutting tool and the part is required, whereas such contact does not happen in the electrical discharge process. Consequently, no mechanical force is applied on the surface of the machined part, which allows for preserving the microstructure of its material.

According to ENGEMAQ (1986), the electrical discharge machining is based on the possibility of removing material from the machined part by thermal effects, which result from the electrical discharges between the electrode and the surface of the part. Nowadays, there are two types of machining discharge processes: the die sinking and the wire electrical discharge processes, that are both illustrated, respectively, in fig.1A and fig.1B.

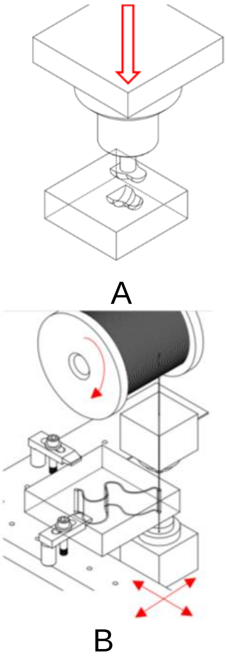

Fig 1 Schematic drawings representing (A) the die sinking electrical discharge machining process and (B) the wire discharge machining process

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As stated by Sommer et al (1994), in both types of processes, the upper head of the machine and the base tank embody the positive and negative terminals, which are key parts of the electrical circuit. During the cutting process, the part is immersed in dielectric fluid, which may be either deionized water or oil and serves insulator and cooling fluid. When the wire approaches the part and the insulating resistance of the dielectric is breached by the electric tension that exists between the wire and the surface of the part, an electric current between both appears and causes the opening of a slit on the part's surface. That slit is then filled by dielectric fluid.

As stated by Sommer (1994), the mechanical properties of the wire employed as electrode in the WEDM process are of key-importance, as well as its melting point. In turn, both characteristics are directly related to its chemical composition. In this process, it is desirable that the wire is slightly worn out in order to prevent short-circuits.

According to Sommer et al (1994), the process of removing material by using electrical discharges is in use since the 1950s. Nonetheless, it was only in 1969 that the Swiss company Agie produced the world's first electrical discharge machine. Initially, the equipment was capable of machining with cutting speeds (Vw) as high as 21.5 mm2/min. Years later, in the beginning of the 1980's, equipments that followed the same concept but incorporated new technologies allowed for machining with cutting speeds as high as 64.5 mm2/min. As stated by Hespanhos et al (2009), the wire electrical discharge machines have greatly evolved during the last years, and nowadays they're capable of working with cutting speeds as high as 500 mm2/min.

The cutting speed, determined in mm2/min, is related to the equipment's capability of machining materials. According to GF Agie-Charmilles (2007), the technological evolution made it possible to obtain a good surface finish in the machining of surfaces, with average roughness as small as 0.05 μm (N3 class).

The most important parameters in the wire electrical discharge machining process are:

VM: Machining electric voltage [ V ];
T: Wire tension [ g ];
WF: Wire feeding speed [ m/min ];
FR: Water flux [ l/min ].

The VM parameter is related to the adjustment of the amplitude of the electric pulses responsible for the cutting. The bigger the VM value, the greater is the peak amplitude of the electric pulses and, therefore, the cutting speed. Still, as VM grows, the wire tends to break more easily.

The T parameter is important in reducing vibration during the machining process, which affects the precision of the cut. Generally, the bigger the T value, the smaller is the vibration. However, an increment in T in rough machining makes the wire more prone to rupture.

The wire feeding speed (WF), on its turn, is proportional to the cutting speed. For an example, in rough machine operations, where higher cutting speeds are used, the wire thins out quicker than in finishing operations – that happens because of the greater wear caused by the more intense electrical discharges in the first type of operation.

The water flux (FR) consists in the amount of dielectric fluid that is injected in the system per unit of time and, therefore, to the speed of the fluid that leaves the injection nozzle. The greater the jet speed, the greater is the wire vibration and, hence, the cut precision decreases.

## III. EXPERIMENTAL PROCEDURE

The experiments took place in the wire electrical discharge machining laboratory of the SENAI "Roberto Mange" Faculty of Technology. A FANUC WEDM CNC machine was used. The machine was of the ROBOCUT α-OiE model and had a command of the FANUC Séries 31i-WA type.

Initially, the WEDM machining tests were performed with typical cutting parameters, that were generated by the equipment and based on its technical tables. After, those parameters were optimized to improve the cutting efficiency and the material removing rate. The cutting parameters generated by the machine and the optimized ones are shown in Table I.

TABLE I
CUTTING PARAMETERS GENERATED BY THE MACHINE AND THEIR OPTIMIZED VALUES.

| *Parameter* | *Machine* | *Optimized* |
|---|---|---|
| *VM [V]* | *31* | *34* |
| *T [g]* | *1300* | *1000* |
| *WF [m/min]* | *10* | *15* |
| *FR [l/min]* | *15* | *18* |

Test specimens were machined from VC131 tool steel in two conditions: as supplied, with a hardness of 19 HRC, and after a quench and temper heat treatment, with a hardness of 53 HRC. The chemical compositions of the test specimens was evaluated through a spectrometry chemical analysis made by the SGS Labmat Análises e Ensaios de Materiais Ltda. The results of the analysis are shown in Table II.

TABLE II
CHEMICAL COMPOSITION OF THE VC131 TOOL STEEL USED.

| C | Si | Mn | P | Cr | W |
|---|---|---|---|---|---|
| 1.910% | 0.270% | 0.617% | 0.001% | 10.931% | 0.609% |

| Ni | Mo | Cu | V | Co | Fe |
|---|---|---|---|---|---|
| 0.134% | 0.009% | 0.045% | 0.125% | 0.025% | BASE |

After the WEDM experiments were performed, the hardness of the cut surfaces of the specimens was measured using a FUTURE-TECH (model LC-200RB) table durometer. Five indentations were made on the cut surface of each sample; of those, the two first measurements were discarded and the three last ones were used to calculate the average hardness on the surfaces.

Measurements for the evaluation of the surface finish of the machined parts were made using a portable surface roughness tester of the model Mahr – MarSurf M300C. For each part, the measurements were performed on three different regions on the cut surface. Then, the values obtained from the three measures were used to calculate the average surface roughness.

For each machining condition, three straight cuts, perpendicular to the length of the VC131 test specimens, were made. The cut sections were of square geometry, they had 37.50 mm sides and a cut area of 1406 $mm^2$. The cuts were made with a 5 mm spacing between them, as depicted in fig.2.

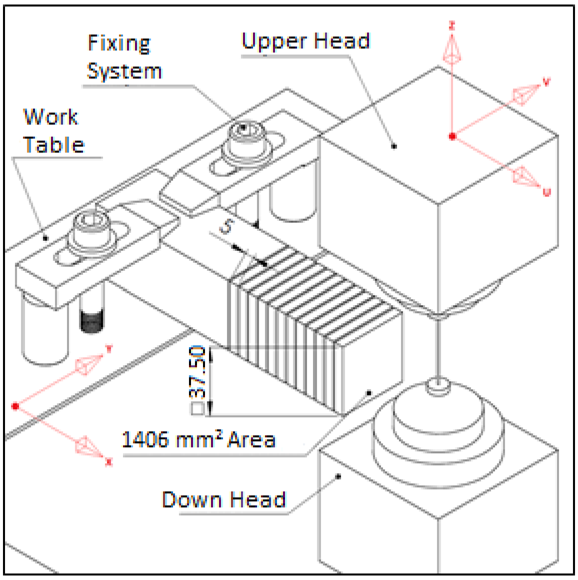

Fig 2 Experimental set up and geometry of the machined cuts.

In the experiments, the material was fixed to the machine's work table according to the information contained in the equipment operations manual and the manufacturer's recommendations. An uncoated Ø 0.25 mm Extra Hard 900 $N/mm^2$ brass wire tool-electrode, supplied by KAMETAL, was used. The electrode presents an elongation of 2 - 2.5 % and its composition follows the ASTM B-36 standard (63% Cu + 37% Zn).

In each experiment, the PM 21 cutting mode was used, as it is recommended for rough machining operations by the equipment's manufacturer.

The debris from the cutting operation were removed by 0.8 bar water jets, which were discharged by the upper and down nozzles of the machine heads, as recommended by the equipment's manufacturer for the employed wire diameter.

## IV. RESULTS

The first part of the experiment was performed using the cutting parameters that were generated by the machine software after it was inputted with the following variables: part's material, wire diameter and cut thickness. It was observed that the machine software generated the same parameters for the 'as supplied' material, herein called untreated material, and the heat treated material.

The average machining time, linear cutting speeds and material removal rates were registered. For each test condition, three samples were used. The results are described in Table III, and they indicate that the cut operations were well succeeded.

TABLE III
AVERAGE MACHINING TIMES, LINEAR CUTTING SPEEDS AND MATERIAL REMOVAL RATES OBTAINED IN THE TESTED EXPERIMENTAL CONDITIONS.

| | *MACHINE* | | *OPTIMIZED* | |
|---|---|---|---|---|
| *PARAMETERS* | *'AS SUPPLIED' UNTREATED VC131 TOOL STEEL 19 HRC* | *QUENCHED AND TEMPERED VC131 TOOL STEEL 53 HRC* | *'AS SUPPLIED' UNTREATED VC131 TOOL STEEL 19 HRC* | *QUENCHED AND TEMPERED VC131 TOOL STEEL 53 HRC* |
| *Machining time [min]* | *12.172* | *10.600* | *10.039* | *9.078* |
| *Linear cutting speed [mm/min]* | *3.082* | *3.538* | *3.739* | *4.131* |
| *Material removal rate [mm²/min]* | *115.5* | *132.7* | *140.1* | *154.9* |

In the first experiment, the material of the test specimen was the VC131 tool steel in the untreated condition, with no heat treatment and presenting a hardness of 19 HRC. The cutting parameters generated by the equipment's software were used. In these conditions, the recorded values for the average machining time, average cutting speed and average surface roughness (Ra) were 12 min and 10 s, 3.082 mm/min and Ra 2.541 µm, respectively.

In the second experiment, the test specimens' material and the set up were the same as in the first one, with the difference that the optimized cutting parameters were used. It was observed that the average cutting speed increased to 3.739 mm/min, which corresponded to a reduction in the machining time from 12 min 10 s to 10 min 02 s, and a slight increase in the cut surface average roughness to Ra 2.813 µm.

In the third experiment, the material of the test specimen was the heat treated VC131 tool steel, which had a hardness of 53 HRC. The cutting parameters generated by the equipment's software were used. In this case, the recorded values for the average machining time, average cutting speed and average surface roughness (Ra) were 10 min and 36 s, 3.5382 mm/min and Ra 2.652 µm, respectively.

In the fourth experiment, the test specimens' material and the set up were the same as in the third one, with the difference that the optimized cutting parameters were used. It was observed that the average cutting speed increased from 3.5382 mm/min to 4.131 mm/min, the machining time was reduced to 9 min and 05 s, and the obtained cut surface average roughness was Ra 2.899 µm.

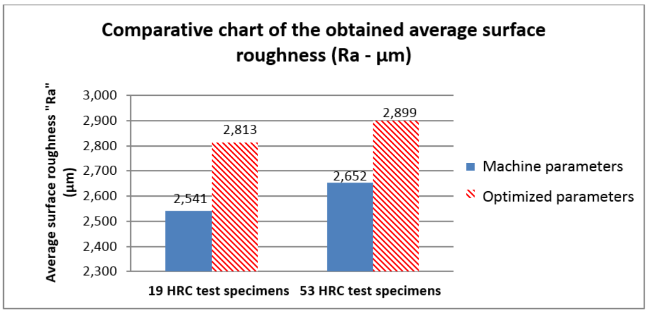

Fig 3 Comparative chart showing the average surface roughness (Ra) obtained in the machining of ‘as supplied’ VC131 tool steel test specimens (19 HRC test specimens) and heat treated VC131 tool steel test specimens (53 HRC samples).

The analysis of the chart in fig.3 shows that, both in the machining of test specimens of untreated and heat treated steel, the average surface roughness obtained when the optimized cutting parameters were used is about 9 % greater than the surface roughness obtained when the cutting parameters generated by equipment’s software were used. However, it should be noticed that the process investigated here is a rough machining operation; therefore, the average surface roughness resulting from it does not correspond, necessarily, to the surface finish of the final product.

The result found in the analysis of the material removal rate may be better understood by examining the chart in fig. 4. The material removal rate depends on the cut area and the machining time, which, on its turn, depends on the different cutting parameters used in each experiment.

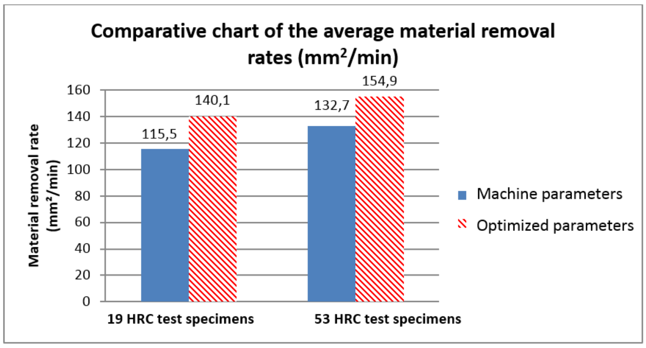

Fig 4 Comparative chart showing the average material removal rate obtained in the machining of ‘as supplied’ VC131 tool steel test specimens (19 HRC test specimens) and heat treated VC131 tool steel test specimens (53 HRC samples).

Another important point that should be mentioned is the wire rupture during the machining process. During the machining process of the test specimens of untreated steel, the wire broke once while the cutting parameters generated by the equipment software were used and twice when the optimized parameters were used. During the cutting of the specimens made of heat treated material, the wire did not break while the equipment parameters were used, however, it broke once when the optimized parameters were used. Therefore, it may be said that using the optimized parameters in the cutting process increases the frequency of wire ruptures during machinig, when compared to the cutting process that uses the parameters generated by the equipment.

The machining time is measured by the machine control system. It starts to be counted from the moment where the tool-electrode is energized and ready to effectuate the cut. fig. 5 presents a comparison between the machining times measured in the experiments where untreated VC131 was cut and the experiments where heat treated VC131 was cut. It may be noticed that the machining times were shorter for the cutting of heat treated material than for the cutting of untreated material.

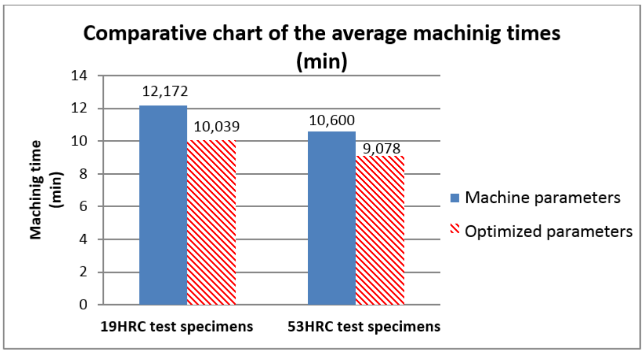

Fig 5 Comparative chart showing the average machining times measured during the machining of ‘as supplied’ VC131 tool steel test specimens (19 HRC test specimens) and heat treated VC131 tool steel test specimens (53 HRC samples).

## V. CONCLUSION

Through the experiments that were carried out, it was possible to verify that using the optimized cutting parameters improved the process performance. By comparing the machining operations where the equipment generated parameters were used and where the optimized parameters were used, both in the cutting of untreated and heat treated VC131 steel, it is observed that the machining time presented a 34.1 % reduction and the material removal rate improved in 25.4 % at the best condition, where heat treated material was machined with the optimized parameters. In this condition, the machining time was 9 min and 5 s and the material removal rate was 154.9 mm²/min. The worst performance was observed in the experiments with untreated steel where the machining was performed with the parameters generated by the equipment, where the average machining time was 12 min and 10s and the material removal rate was 115.5 mm²/min. However, it was observed that the average surface roughness (Ra) of the cut surfaces increased in about 9 % when the specimens were machined with the optimized cutting parameters.

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