USE OF HYBRID PROCESS AJEDM IN STEEL AISI M2

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Abstract: *The thermal interaction of Electrical Discharge Machine (EDM) mechanically enhanced by the cleaning action and better distribution of electrical discharges produced by the abrasive particles in the Abrasive Water Jet Machining (AWJM) process, make possible the hybrid process of Abrasive Jet Electrical Discharge Machining (AJEDM), which was developed in the Tribology and Materials Laboratory (LTM) in the Universidade Federal de Uberlândia (UFU). In the AJEDM, an enhancement in the washing system is observed due to the pressure increase in the dielectric fluid. As a direct consequence, there is an increase in the values Material Removal Rates (MRR). The main goal of this research was to evaluate the performance of two different kinds of abrasive materials, the silicon carbide (SiC, 600 mesh) and aluminum oxide (Al_2O_3, 600 mesh) and the effects of the pressure variations of the deionized water with abrasives in the machining of the ABNT M2 steel during the moderate drafting shift, using an electrolytic copper tool. Four different work pressure values were analyzed (80, 130, 170 and 240 bar) on the hydrojet, which had a constant flow and the concentration of abrasive varying according to the pressure changes, adapted to the EDM. The analysis of the pressure variation showed that when raised, the pressure has a direct effect on the amount of abrasive dragged by the deionized water flow, and thus, produces a higher MRR. The SiC abrasive produced better MRR when compared to the Al_2O_3. There is also an increase on the Relative Volumetric Wear (RVW), which is compensated by the increased MRR. An adhesion of abrasive particles was also observed on the surfaces machined by AJEDM, using scanning electron microscopy and punctual EDX analysis. These surfaces are similar to the ones machined using EDM conventional process since both presented pores, micro-fissures and resolidified particles adhesion.*

Keywords: *EDM; Erosive wear; AJEDM; Dielectric Fluid; Machining speed.*

1. INTRODUCTION

Nowadays the transforming industries face big challenges when they need to machine special alloys with extremely high hardness, ceramics and composites. The application of the traditional machining is not usual economically viable or effective on the making of appliances with these materials. To solve these challenges, new machining processes must be developed as, for instance, the hybrid machining techniques. These techniques combine different physical properties, mechanical action, that is used by the usual processes for material removal, allied with thermal, chemical or electro-chemical interactions applied in non-conventional manufacturing processes.

The EDM process happens between two electrical conductive materials, one tool electrode and one appliance electrode. They produce the formation of the arc through electrical discharges when in the presence of a dielectric fluid. The tool works apart from the appliance, maintaining a gap between both. A plasma flow is formed between the two electrodes, in the work gap. This flow keeps in its interior a very high pressure and a constant flow of electrons and ions, which flow freely while the current is active. By the time the current is turned off, the pressure drops immensely, promoting a collision of the ions and electrons with the surface of the electrodes (McGeough, 1988).

The Dielectric fluid has an important role in the process, controlling the power of the opening discharge. The fluid might be kerosene, enhanced hydrocarbon (both derived from petroleum), deionized water or other aqueous solutions (Fuller, 1989).

The EDM is a thermal process. The material is removed by the heat produced by the electricity flow between the tool and the appliance. The parts of the material nearer the electrodes, where the arc initiates and finishes, heats to the point of vaporization. Thus, a large quantity of material is pulled off the surfaces and dragged out of the work gap by the dielectric fluid. The area heated by the arc is rapidly cooled by the dielectric fluid, as well as the small quantity of material pulled off. Some metallurgical changes occur on the electrode's surface due to the rapid cooling (McGeough, 1988).

As the material's surface is heated rapidly by the electric discharge, and cooled abruptly by the dielectric fluid, a recast layer is formed in this region, causing pore formation, thermal stress and the appearing of micro fissures on the grain boarders. Besides, there's the adhesion of eroded particles on the material's surface. It is estimated that about 85% of the removed material recasts on the surface. Because of that, the performance of EDM process is considered low.

According to Fuller (1989), AJM process removes material on the surface of a piece by means of abrasive particles action, mixed with a high speed flow of gas.

In the AJM process, the abrasive particles are usually aluminum oxide, or silicon carbide powder, that are transported by a jet that flows through a hole located in the edge of a tungsten carbide or artificial sapphire beak, separated by a certain distance from the work piece (McGeough, 1988).

The AWJM process, that merges the water's erosive action with the abrasive power of the particles carried by a jet of water, is a combination of the AJM and WJM processes. The AWJM uses a jet of water of high flow speed that works under high pressure, to produce a flow of water that flows very rapidly. A flow of small abrasive particles is introduced to the water flow and is dragged by the same in a way so they are mixed to it, producing the capacity to make the cut of different kinds of materials (Benedict, 1987).

According to Summers (1995), in the AWJM process, the material removal happens due to the impact of the abrasive particles bring carried by the water flow. The MRR promoted by the impact is directly related to the feeding rate of the abrasive particles to the machine, the flow rate of the abrasive particles and the impact speed they reach. The speed is modified due to the high feeding pressure of the water flow.

The use of abrasive particles in a water jet increases the power of the jet, making the cut of almost all kinds of commercial materials possible. When compared to the AJM process, the water provides higher kinetic energy level to the abrasive particles than the usual air flow, with less risk, once the water is less compressible, enabling higher pressures with less risk. Besides, the abrasive water jet can use the effect of the impact of the abrasive particles against the material surface, producing a synergic effect from both components, water jet and abrasive particles, which interact to increase the material removal power (Summers, 1995)

According to Kansal *et al*. (2006), amongst all non conventional machining methods, the EDM is one of the most used for the manufacturing of tools as molds or matrixes. This process allows the machining of any electrical conductive material, independently of its hardness or shape. Since its invention, many efforts have been made to improve its performance and stability. Process stability is a key factor on making it controllable. The demands for high precision machining, with a good superficial quality and high MRR are key factors for the tools sector of industries. On the attempt to fulfill these demands, an addition of powder on the dielectric fluid was introduced to the EDM. The powder added improves the dielectric rigidity of the dielectric fluid, which means that the isolating force of the dielectric fluid decreases, and thus, the distance between the tool and the part being worked increases. This increase in the gap distance produces a uniform washing of the material taken from the piece. As a result, the process becomes more stable, increasing the MRR and improving the superficial finish.

According to Arantes (2007), the thermal interaction of the EDM, which material removal happens through fusion and vaporizing with the interaction of the mechanical assistance of the abrasive powder action from the AWJM, make the use of the hybrid process of AJEDM possible. Besides, it produces a better distribution of the electric discharges with the increase of the gap size and consequently, a larger MRR, due to the impact of the abrasive particles in to the work piece's surface.

The combined process of AJEDM proposed, consists in the introduction of changes on the operational configuration of the EDM process, with the use of a high pressured water jet with powder abrasive, usually carbides, oxides or nitrites applied in different granulometry. This process allows an improvement of the material removal mechanism and the finish of the machined pieces, besides allowing the use of aqueous and byoecologic dielectric fluids (Fapemig and UFU, 2009).

The purpose of this paper was to evaluate the performance of the SiC and Al_2O_3 abrasives, both with 600 mesh granulometry, in the AJEDM hybrid process, as well as the variation effects of different values of work pressure. For such, the MRR, the Tool Wear Rate (TWR), the RVW and the morphology of the surface were analized.

2. METHODOLOGY

The research was made in a penetration EDM machine, model EDM 440NC, along with a hydrojet machine of nominal pressure of 250 bar. As the dielectric fluid, deionized water was used, and SiC and Al_2O_3 as the abrasives, both with 600 mesh granulometry. Table 1 shows the Vickers Hardness values of the abrasives used in the experiments. The work pressures used were, 80, 130, 170 and 240 bar, with a work flow fixed to 1000 liters an hour.

Table 1. Vickers Hardness of the abrasives used in the experiments.

Abrasive	Hardness (HV)
SiC	2.100–2.600
Al_2O_3	1.800–2.000

2.1 Adaptations made on the EDM machine

Figure (1) illustrate, schematically, the equipments and accessories needed for enabling the AJEDM hybrid process:

- EDM Machine;
- Hydrojet machine;
- Deionized water feeding system, including: deionizer device, water reservoir, manometer, feeding pistol, hose, and connections;
- Abrasive feeding system, including: storing barrel for the abrasive, feeder, *venturi* beak, hose and connections;
- Abrasive and water mixture feeding system, including: centrifugal pump, decantation Box for abrasive storage, hose and connections.

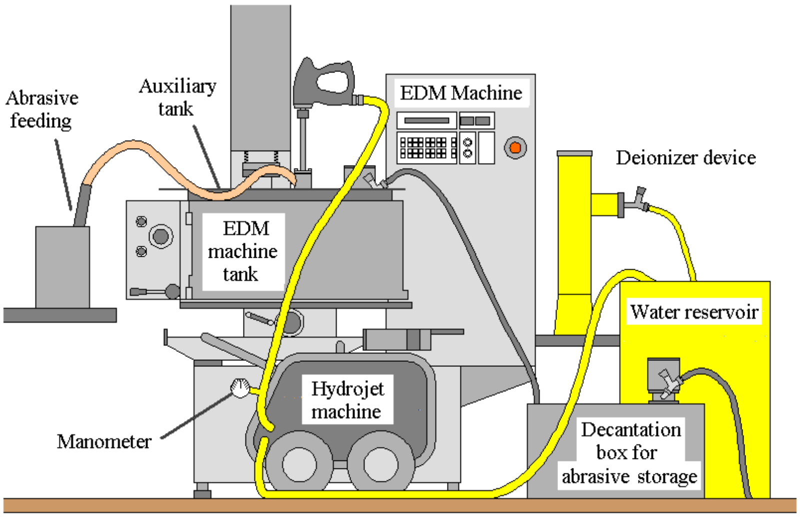

Figure 1. Schematic drawing of the AJEDM process

It was necessary to design, manufacture and assemble an auxiliary tank, so that no contamination would occur on the EDM dielectric fluid that flows through the machine's tank when it goes into working. The selected material was stainless steel, to resist the corrosive attack of deionized water. Protection wings and lids were installed to avoid dripping caused by the high pressure water jet. A device was adapted in the auxiliary tank for the samples, as was a support bead for the *venturi* beak and tool electrode stuck to the EDM leadstock that required redesigning and assembly. Figure (2) shows such adaptations and highlight the centrifugal pump for the flush of the mixture of water and abrasive particles fixed to the lid, the high pressure pistol in the hydrojet machine to feed the deionized water connected to the support and the pressure regulator beak.

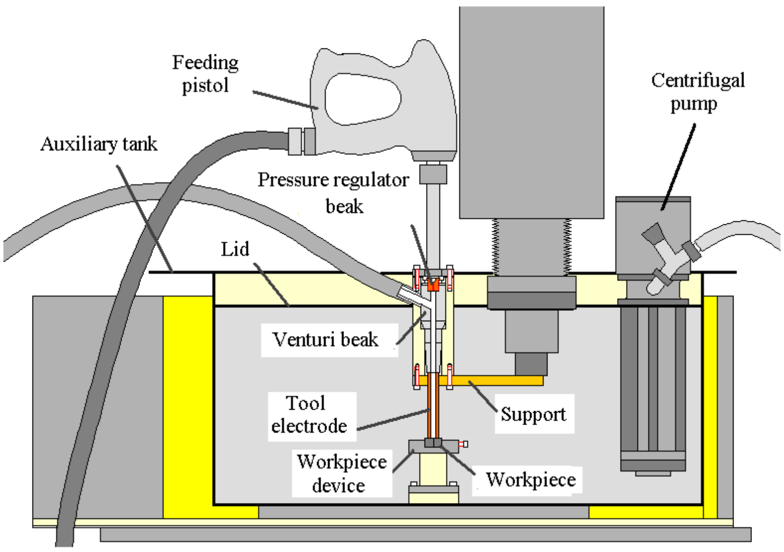

Figure 2. Schematic drawing of the auxiliary tank assembled to the machine

Figure (3) shows the adaptations that were assembled in EDM machine for the testing.

Figure 3. Picture illustrating the adaptations that were made to the EDM machine for the application of the AJEDM hybrid process

ABNT M2 steel bars of cross sectional 12,7x12,7 mm and 101,6 mm long; tool electrode of electrolytic copper of tubular sections of 19,05 mm for external diameter and 6,35 mm for internal diameter with 30 mm long. The angle of attack of 90º. Figure (4) shows the tool electrode and the machined part with the cavities highlighted.

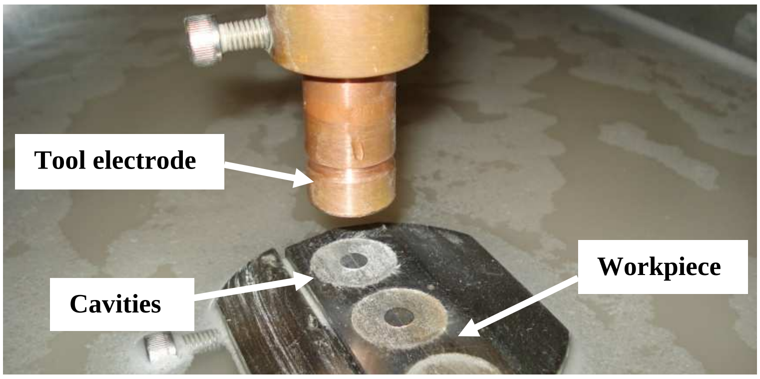

Figure 4. Picture illustrating the tool electrodes and the machined part with the cavities being highlighted

The pressure was monitored using a manometer installed in the output of the hydrojet machine, as shown in Fig. (5). The pressure adjustment was done switching the pressure variation beaks, which are mounted in the *venturi* system beak, as shown in Fig. (2).

Figure 5. Manometer installed in the output of the hydrojet pump for pressure monitoring

2.2 Input parameters on the Hybrid AJEDM process

Each set of three tests for different pressure values and abrasive types lasted for 5 minutes (summing up to 24 tests). The deionized water's conductivity was verified by a conductivimeter keeping it to less than 10 μS. The machining regime chosen was the moderate wear with EDM parameter compatible with the stated by Arantes (2007) in the development of AJEDM process, which are pointed in Table (2). The work regime selected was obtained according to the adjustment of the established in the EDM 440NC machine's manual, for the machining condition of a steel piece with an electrolytic copper tool electrode, always obeying the parameters for the combining of such materials. The regime to reach a satisfactory combination of machining processes, EDM and AWJM, was chosen in a way that a larger amount of material is removed from the machined piece with a lesser wear of the tool.

Table 2. EDM parameters for a moderate wear regime on the AJEDM hybrid process.

Tool Polarity (electrolytic copper/steel)	Positive
Tension (V)	110
Current (A)	18
T_{on} (μs)	200
TS (1/3 current)	6
DT (%)	70
Wearing time (s)	6
Periodic distancing of the tool (mm)	0.4
Time frame between wearing and tool's distancing (s)	0

The polarity indicates the electrode position, if anode or cathode, regarding the electric discharges, producing a higher MRR from one of the surfaces, usually the tool electrode's one, since it has to have as less wear as possible. The polarity must be swapped on the machine.

The ionizing and plasma duct formation tension will be kept constant, according to the parameters established by the machine's manual. The discharge current consumed throughout the process, has a direct influence on the surface quality and on the efficiency of the operation, thus, a better quality implies in a lower current and MRR with a bigger machining time, in the machine used during the experiment the current value depends on the TS parameter, adjusted on the machine, the current is worth 3 times the TS. DT is related to the pausing time frames, t_{off} and pulse duration, t_{on} in the case of the machine used in the experiment is given on values percent. The Equation (1) determines its value

$$DT = \frac{t_{on}}{(t_{on} + t_{off})} 100 \qquad [\%] \tag{1}$$

Where: t_{on} = pulse time [μs] and t_{off} = pausing time [μs]

The gap size and sensibility were adjusted in a way to get the best performance from the process when put together with the remaining parameters applied during the machining operations.

2.3 Parameters analyzed after the use of AJEDM process

During the experiment execution the sample and the tool electrode were weighted three times before and after each machining operation. An electronic scale with a maximum load of 310 grams and a 10^{-3} resolution was used.

The mass variation was determined by the difference between the initial and final mass, obtained used the Eq. (2)

$$\Delta_m = m_i - m_f \qquad [g] \tag{2}$$

Where: m_i = initial mass [g] and m_f = final mass [g]

In order to quantify the MRR, Eq. (3) was used.

$$MRR = \frac{\Delta_m}{(0.00768)t} \qquad [mm^3 / min] \tag{3}$$

Where: Δ_m = mass variation [g], t = machining time [min] and the constant 0.00768 g/mm^3 that corresponds to the specific weight of the ABNT M2 steel (Arantes, 2007).

In order to quantify the tool wear rate (TWR) of the tool electrode, Eq. (4) was used.

$$\boldsymbol{TWR} = \frac{\Delta_m}{(0.0089)\boldsymbol{t}} \qquad [\text{mm}^3/\text{min}] \tag{4}$$

Where: Δ_m = mass variation [g], t = machining time [min] and the constant 0.0089 g/mm^3 that corresponds the specific weight of the electrolytic copper.

Equation (5) was used to determine the RVW, which is the relation between TWR and MRR, expressed in percentile.

$$\boldsymbol{RVW} = \frac{\boldsymbol{TWR}}{\boldsymbol{MRR}}100 \qquad [\%] \tag{5}$$

The superficial integrity of the sample was observed using Scanning Electron Microscopy, in order to identify the morphology of the machined surface.

3. RESULTS DISCUSSION

The MRR, TWR and RVW are represented in the graphics on Figures (6), (7) and (8). Figure (6) shows the results of MRR obtained in the machining using AJEDM process with the SiC and Al_2O_3 abrasives of 600 mesh granulometry, with a work pressure of 80, 130, 170 and 240 bar, with deionized water for dielectric fluid.

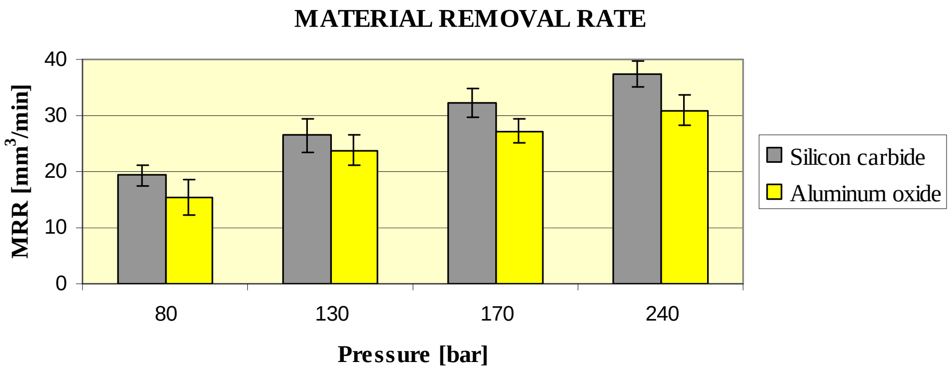

Figure 6. MRR results of AJEDM process on different pressure values with abrasive particles of SiC and Al_2O_3 600 mesh, deionized water dielectric fluid

The MRR results are compatible to Summers (1995) observations, the speed of the water that is modified according to the work pressure, has a direct influence over the MRR, since it increases the abrasive feeding rate and the flow rate. As verified by Arantes (2007), the high pressure jet (240 bar) enabled a higher removal of the eroded particles, what increased the machining speed. This increase made more effective the washing action of the micro particles that got recast on the surface. The SiC abrasive had a better result for the MRR when compared to the Al_2O_3 on the four different work pressures values, with an average gain of 10 to 25%.

Figure (7) shows the results of TWR obtained in the AJEDM process with the silicon carbide and aluminum abrasive of 600 mesh, in the work pressures of 80, 130, 170, 240 bar, with deionized water as the dielectric fluid.

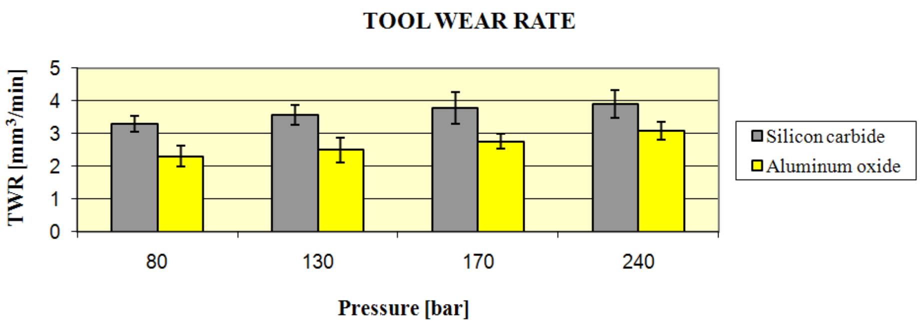

Figure 7. TWR results for the AJEDM process for different pressure values with the SiC and Al_2O_3 600 mesh, deionized water dielectric fluid

The TWR results show that the increase of the pressure has an influence on the wear of the tool electrode that occurs due to the fact that the tool's surface is susceptible to the same effects of the electric discharge and the erosive wear promoted by the abrasive particles that act on the surface of the machined piece. One can also observe a 30% bigger wear of the tool electrode when silicon carbide is used in comparison to when the aluminum oxide is used.

Figure (8) shows the RVW results obtained in the machining process using AJEDM in the work pressures of 80, 130, 170 and 240 bar with the SiC and Al_2O_3 of 600 granulometry with deionized water as a dielectric fluid.

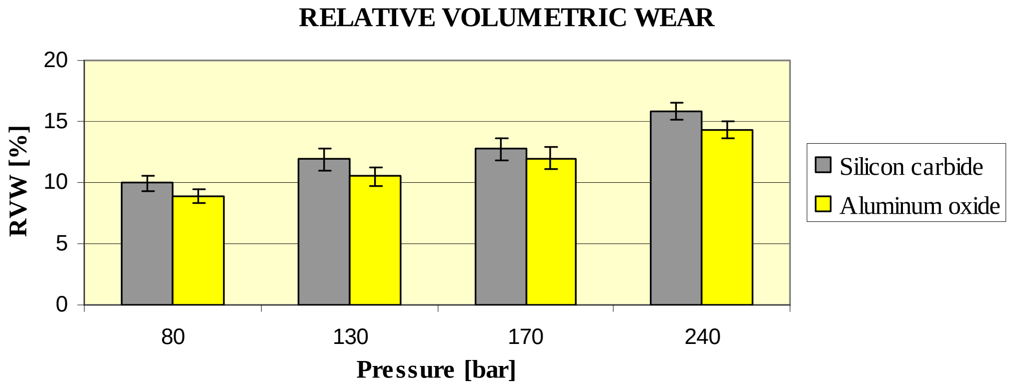

Figure 8. RVW results of AJEDM process for different pressure values with the SiC and Al_2O_3 600 mesh, deionized water dielectric fluid

The RVW results show that the increase of the work pressure changes the relative wear, however this wear is compensated by the increase of the MRR, which increases the machining speed. The SiC abrasive had a higher RVW when compared to Al_2O_3 for all the pressure values used.

Figure (9) shows the amount of abrasives SiC and Al_2O_3 spent for each work pressure analyzed.

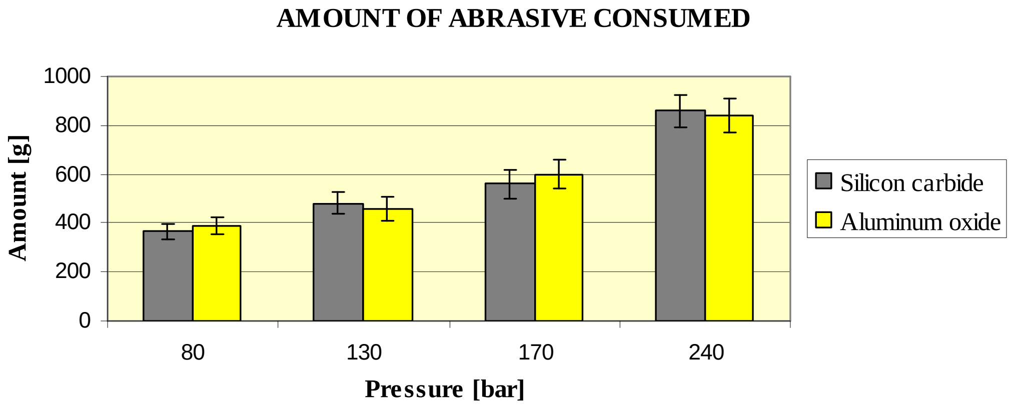

Figure 9. Amount of abrasive consumed in the AJEDM process for the different pressure values, deionized water dielectric fluid

Figure (9) shows an increase on the amount of abrasive consumed according to the pressure changes. The speed of the water, which is modified according to the pressure, increases the feed rate of the abrasives and the flow intensity.

Figure (10) shows an image of a Scanning Electron Microscopy taken from a surface machined with deionized water as dielectric fluid with SiC 600 mesh as abrasive in the hybrid process AJEDM with a work pressure of 240 bar. A SiC particle can be observed inserted on the surface in the region limited by the square in the figure. Figure (11) illustrates the EDX specter on that abrasive particle. The arrow in Fig. (10) indicates the place where the punctual EDX analysis was executed.

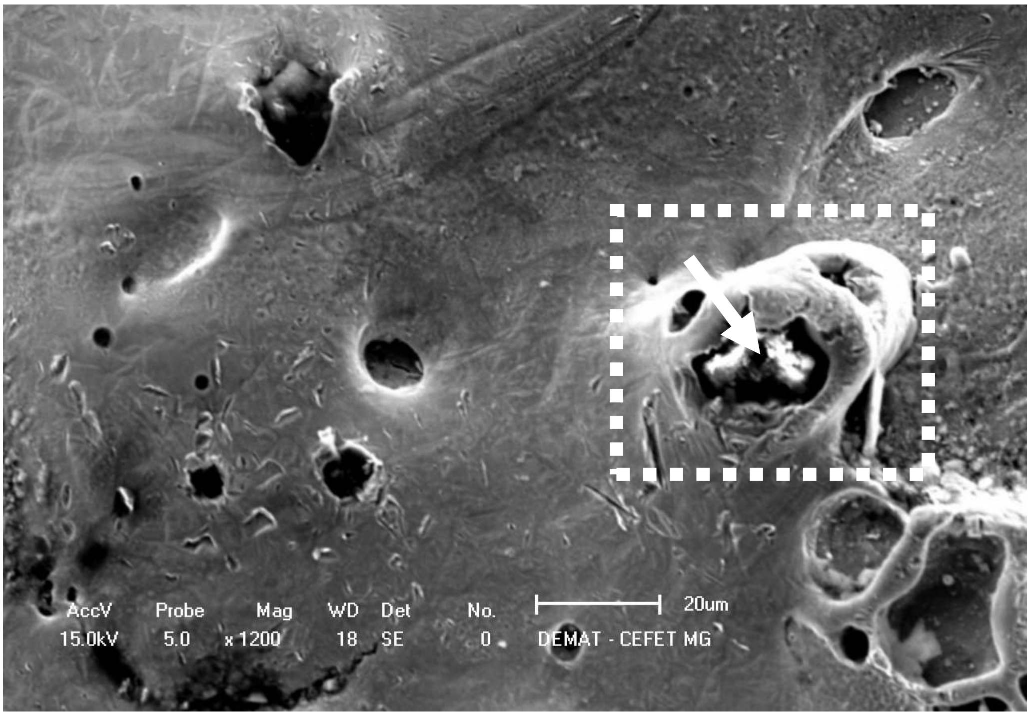

Figure 10. Scanning Electron Microscopy on the surface machined using AJEDM process with SiC 600 mesh and a work pressure of 240 bar

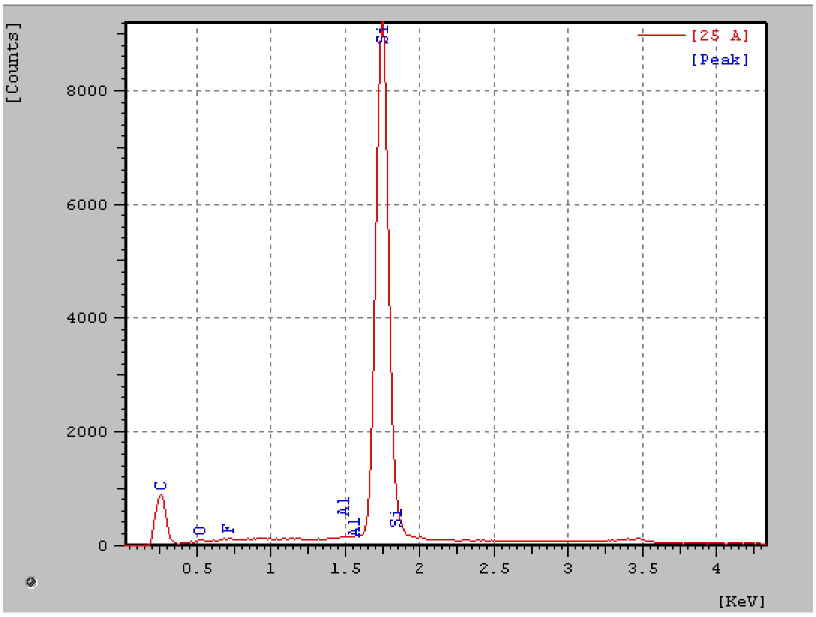

Figure 11. Image of the punctual EDX specter of the particle inserted to the surface machined by AJEDM process using SiC 600 mesh and work pressure of 240 bar

Figure (12) shows an image of Scanning Electron Microscopy taken of a surface machined with deionized water as dielectric fluid and Al_2O_3 600 mesh as the abrasive in the AJEDM process with a work pressure of 240 bar. A particle of aluminum oxide can be observed inserted on the surface of the machined piece in the region limited by the square. Figure (13) shows the EDX specter analysis made on this abrasive particle fragment. The arrow in Fig. (12) shows the exact location where the EDX analysis was made.

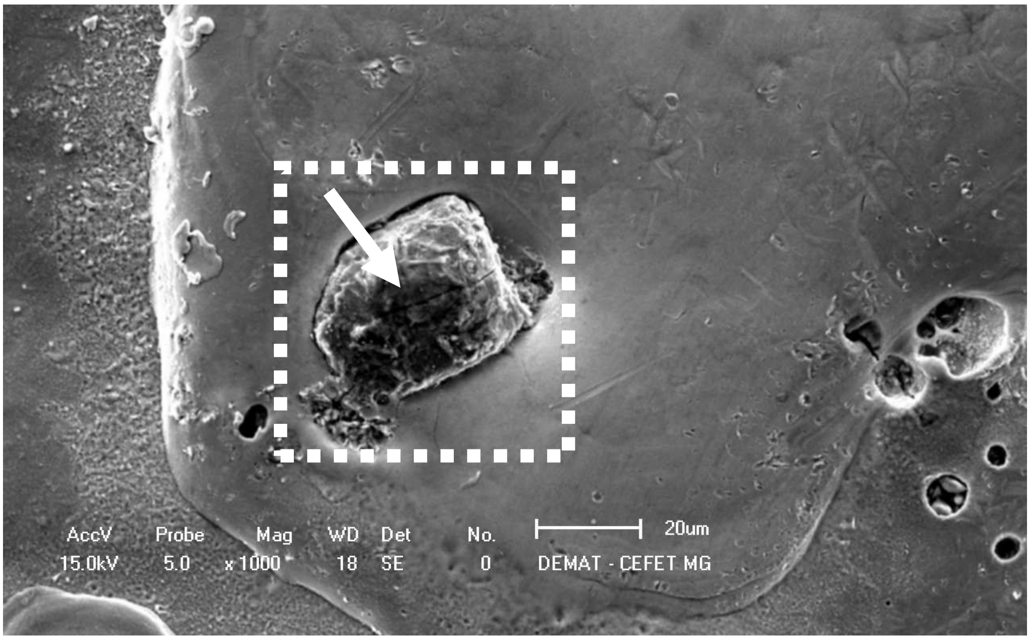

Figure 12. Scanning Electron Microscopy on the surface machined using AJEDM process with Al_2O_3 600 mesh and a work pressure of 240 bar

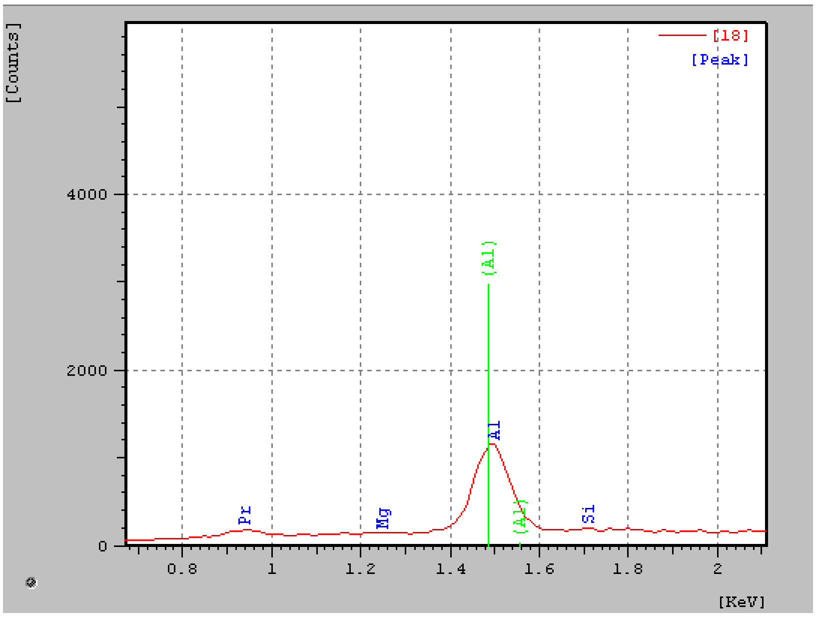

Figure 13. Image of the punctual EDX specter of the particle inserted to the surface machined by AJEDM process using Al_2O_3 600 mesh and work pressure of 240 bar

The results showed the surface machined by AJEDM process don't differ much from the surface machined with the conventional EDM process, there is pore formation, micro fissures and adhesion of recast particles. However, the fact that differs one another is the insertion of particles or fragments of the abrasives on the machined surface when the AJEDM process is used, as we can see in the EDX specter analysis made on the particles of SiC and Al_2O_3 inserted on the surface of the machined area.

The apparition of abrasive particles inserted to the machined surface shows that there was a significant participation of the abrasive particles in the process of material removal of the machine piece, causing the increase of the MRR.

4. CONCLUSIONS

The pressure variation has a direct influence on the MRR, since it has its value increased by increase of pressure for both SiC and Al_2O_3 abrasives.

The silicon carbide abrasive produced a better result for the MRR than the aluminum oxide, for the four different work pressure values.

The TWR of the tool electrode is also influenced by the increase of the pressure, since the surface of the tool also gets attacked by the abrasive particles.

The SiC abrasive had a higher value of RVW in comparison to the Al_2O_3 for the four different work pressure analyzed.

The increase on the deionized water pressure, used as dielectric fluid, promoted a larger consumption of both abrasive analyzed.

The surface machined with AJEDM process don't present a big difference from the one machined by EDM using conventional penetration, there are pores, micro fissures and the adhesion of recast particles, however some particles from both kinds of abrasives were inserted into the surface when the AJEDM process was used.

5. AKNOWLEDGEMENTS

To FAPEMIG, for the resources provided for the TEC APQ 01481/01 project, valid from 11/11/2009 to 10/11/2011.

To CAPES for the financial aid to the researchers.

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7. RESPONSABILITY NOTICE