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EDM PROCESS AIDED BY EROSIVE WEAR[1]

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Abstract

The low MRR (Material Removal Rate) observed on the Electrical Discharge Machining is, undoubtedly, one of the most important limitations of this process, especially nowadays, while competitiveness between the enormous varieties of machining processes has achieved an unbelievable level of speed and surface finishing. The main objective of this paper was developing a hybrid methodology which combines EDM with high pressured jet of dielectric fluid and abrasive powder. A special device was built to provide the high pressure abrasive jet. Cooper tube shaped tools were used on the experiments and the machined material was a commercial high speed steel (ABNT M2). Kerosene, deionized water and mineral based oil were used as dielectric fluids and the abrasive was SiC (600 mesh), with 3 jet pressures (zero, 25 and 100 bar), and concentration fixed in 30g/l. The results have shown increase of 8 times in MRR when the EDM process is aided by erosive wear. Remarkable gains were still obtained with kerosene and deionized water, both with improvement of surface finishing. This new process, nominated as Abrasive Jet Electrical Discharge Machining (AJEDM), proves to be efficient to increase machining velocity while decreases the surface roughness.

Key-words: Electrical discharge machining; Erosive wear; Abrasive; Deionized water.

PROCESSO DE USINAGEM POR DESCARGAS ELÉTRICAS ASSISTIDO POR DESGASTE EROSIVO

Resumo

Uma das grandes limitações do processo de usinagem por descargas elétricas (EDM) é a baixa taxa de remoção de matéria (TRM). Isto faz com que a EDM perca competitividade para os processos convencionais de usinagem. O objetivo deste trabalho foi o de desenvolver uma metodologia que implementasse a TRM, com o auxílio de um jato erosivo de fluido dielétrico com partículas abrasivas diluídas. Um dispositivo auxiliar, para aplicação do jato erosivo, foi construído. Como ferramenta de usinagem, utilizou-se um cilindro de cobre. O material usinado foi o aço ABNT M2. Como fluidos dielétricos foram usados querosene, água deionizada e óleo mineral. Como abrasivo, foi usado SIC, 600 mesh e concentração de 30g/l. A pressão do jato erosivo foi de 100 bar. Os resultados mostraram que há um aumento de cerca de oito vezes na TRM quando o processo EDM é auxiliado pelo jato de água erosivo. Ganhos significativos também são obtidos com jato de querosene erosivo e jato de óleo mineral erosivo. Este novo processo, denominado AJEDM, é um híbrido dos processos EDM e usinagem por jato de água abrasivo (AWJM) e se mostrou eficaz no implemento das taxas de remoção de matéria do processo EDM.

Palavras-chave: Usinagem por descargas elétricas; Desgaste erosivo; Abrasivo; Água deionizada.

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1 INTRODUCTION

In the past decades, the technological advance of the machining processes have been reached by the Hybrid Machining Process (HMP)'s development and industrial application, which matches the work material in different physical and chemical actions, which is used in the conventional processes and can be associated to one non-traditional processes or more, such as the Electrical Discharge Machining (EDM), Electrochemical Machining (ECM) and the Laser-Beam Machining (LBM). The great reason for the hybrid machining development is to make use of the combined advantages and avoid or reduce the adverse effects individually shown by the constituents.[1-2]

The hybrid processes work based on the synergetic effect, which is defined by two or more agents working together to produce a result not obtainable by any of the agents independently. As results of these associations, can be obtained better machining speeds, a improvement in the machined tools, a decrease of the overcut, a significant betterment of the superficial finishing, and, in some cases, a decrease of the HAZ (Heat Affected Zone), besides smaller length and concentration of cracks and smaller layer of recast thickness, specially on surfaces machined by EDM.[3]

In the die-sink EDM, one of the greatest difficulties is the process speed of metal removal, once the biggest part of the material cast by the spark is recast in the surface. In order to increase the process performance, a more efficient flushing system was proposed, which uses a dielectric fluid jet with suspended abrasive particles.[4-5] The main purpose of this work is to evaluate the improvement in the EDM process speed. Additionally, the superficial modifications caused by the ABNT M2 high speed steel machined by a hybrid process, associating the Electrical Discharge Machining with the Abrasive Jet Electrical-Discharge Machining (AJEDM), with the uniqueness of using deionized water as a replacement for the hydrocarbon fluids in EDM. This dielectric has some advantages, including low cost, storing and handling safety and ecological appeal.

2 EXPERIMENTAL

In this study, ABNT M2 high speed steel bars were machined. The EDM experiments were conducted with the operational parameters specified in Table 1.

Table 1. Parameters of the equipment for conducting experiments

Data / Regimen	
Pulse time (T_{ON})	300 [μs]
Pulse percentage (DT)	90 [%]
Current	5 [A]
Voltage	15 [V]

The tool geometry is tubular, and requires an internal flushing system according to Figure 1. Specially in hole boring operations, a disadvantage of the flushing system by injection compared to the internal suction of the tool, as mentioned by McGeough,[4] is the taper generated by the lateral discharges between the tool and the work piece created by the dragging of eroded particles, which emerge from the bottom of the hole to the surface, and also depends on the frontal area of the electrode, on the injection pressure, and on the contamination level of the dielectric fluid.[5-6]

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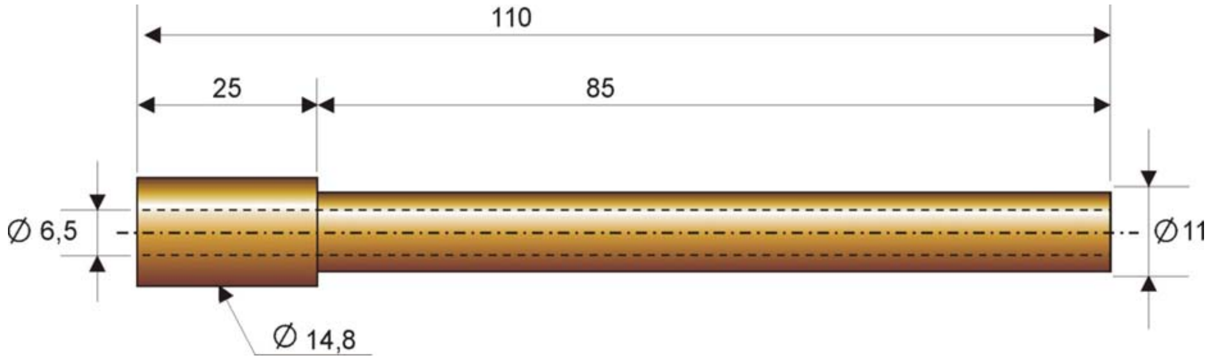

Figure 1. Copper tool geometry used in the experiments.

To make the erosive jet insertion feasible, was adapted a pump to the die-sink EDM equipment in order to inject dielectric fluid under pressure. Thus, were joined the thermal effect of the discharges with the erosive effect of the dielectric fluid with abrasive. The scheme shown in Figure 2 presents the modifications necessary to turn the low pressure auxiliary system into a high pressure one. The settings of the High Pressure Pump are on Table 2.

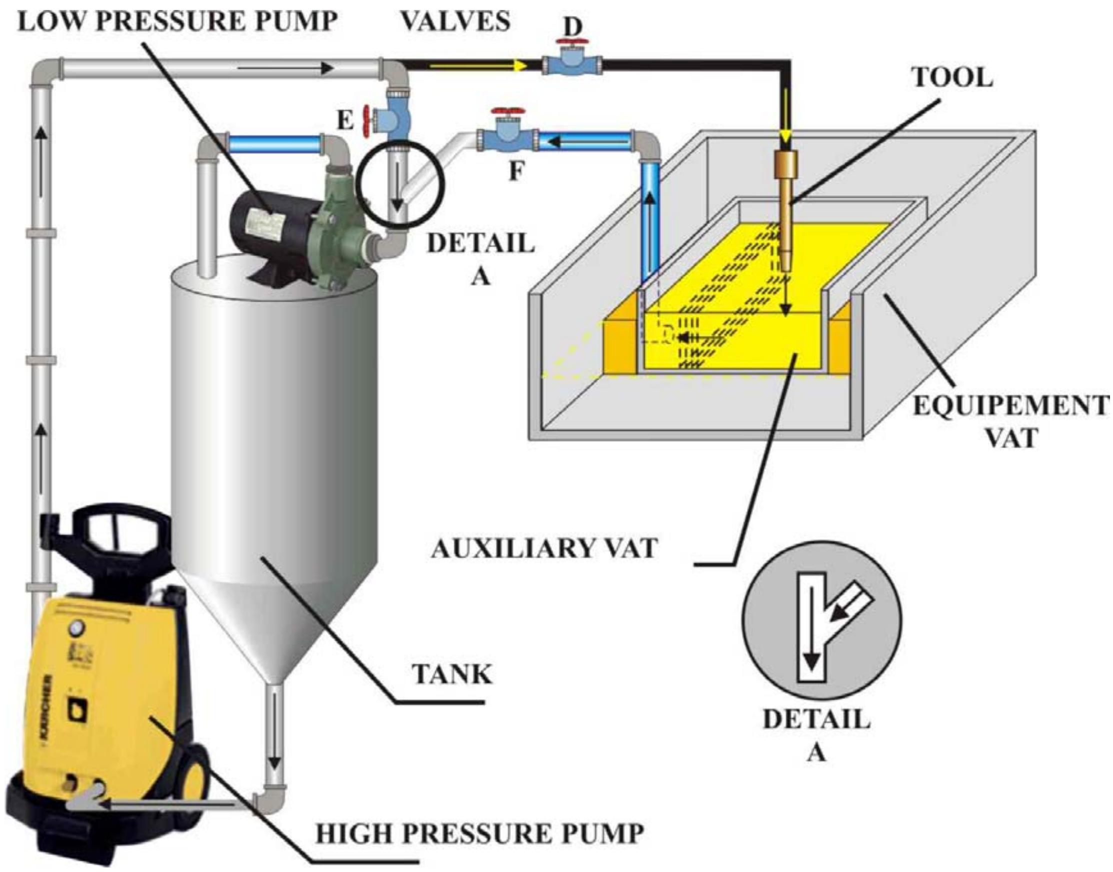

Figure 2. Assembly scheme of the Abrasive Water Jet in EDM machine (high pressure)'s experimental prototype.

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Table 2. Specification of the High Pressure Pump used in the auxiliary system

High Pressure Pump	
Engine Power [Watts]	1100
Voltage [Volts]	220
Pressure [bar]	100
Engine Rotation [rpm]	3450
Flow [liters/min]	42,9

The dielectric fluids used were deodorized kerosene, mineral oil and deionized water, respectively represented by KER, OIL and H2O. For abrasive were used silicon carbide (SiC) with granulometry of 600 mesh and dilution of 30 g/l. For a comparative effect, were conducted experiments with a jet under a pressure of 100 bar with non-abrasive and abrasive fluids. Were conducted at least 3 experiments for each condition.

The machined surfaces' morphology was analyzed with the aid of a scanning electronic microscopy (SEM) and the chemical composition was determined by the EDS technique (equipment coupled with SEM). The Sa roughness was determined by laser interferometry (scanning area = 500 x 100). Others parameters was considered not relevant to this work. The wear of the electrode was visually evaluated. A more consistent analysis must be conducted in the future.

3 RESULTS AND DISCUSSION

The MRR results from the experiments conducted without the use of abrasive are shown in Figure 3, and the experiments conducted with abrasive are shown in Figure 4. The bad performance seen in the water and the best performance in the mineral oil was expected, once were only considered the influence of the fluids' physical and chemical characteristics.

In Figure 4 can be seen that, with the flushing system's improvement, going from static fluid to low pressure fluid, and then to high pressure fluid, the MRR values grow considerably: 85% higher for oil, 40% higher for kerosene, and 42% higher for deionized water. The relative water gain can be explained by its greater fluidity. With a high pressure jet, the flushing system becomes more effective, and the cast particles' removal is improved, regardless the fluid type.

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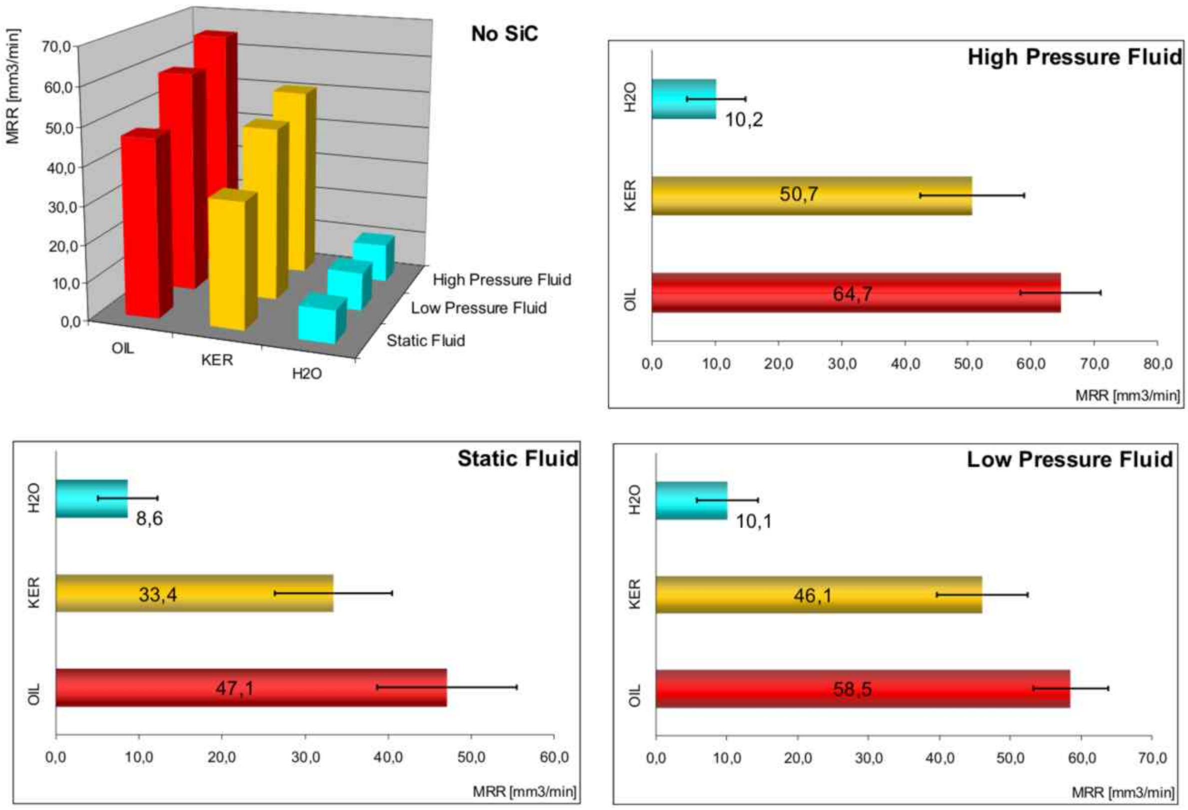

Figure 3. MRR for the samples machined with Oil, Kerosene and Water, without abrasive, with static fluid, low pressure jet and high pressure jet.

The results for the MRR experiments with abrasive powder (SiC) are presented in Figure 5. It can be seen that, when adding the abrasive, the MRR values increased in comparison with the results in the same conditions except for the SiC (Figure 4). The MRR increase was of 277% for oil, 467% for the kerosene, and 800% for the deionized water, comparing the results of high pressure jet with static fluid. It is evident that there was an erosive action of the SiC abrasive particles. The deionized water showed a greater performance percentage gain when compared with the other fluids' MRRs. This result is also explained by the water's greater flow. It also explains the best performance of the kerosene in relation to oil. It can also be seen that the result obtained for the water (88,7 mm^3/min of MMR) is superior to the results in pressure conditions under 100 bar. This indicates that the deionized water can compete with the hydrocarbon based fluids, like oil and kerosene, considering the advantages of the water over these fluids: non-pollutant, non-toxic, renewable and cheaper.

Comparing the results of static fluid, it can be noticed that the simple addition of abrasive improves the MRR values. This effect is due to the density increase of the dielectric fluid, which causes the increase of the environment's resistance to the plasma arc, thus keeping the less disperse discharges and increasing the effectively emanating power over the machined work piece. Regardless the fluid used, it can be noticed the MRR improvement in the three cases (oil, kerosene, and deionized water). However, the dielectric fluid still influences the machining speed; in other words, the abrasive addition improves the process, but it does not put the fluids on the same level.

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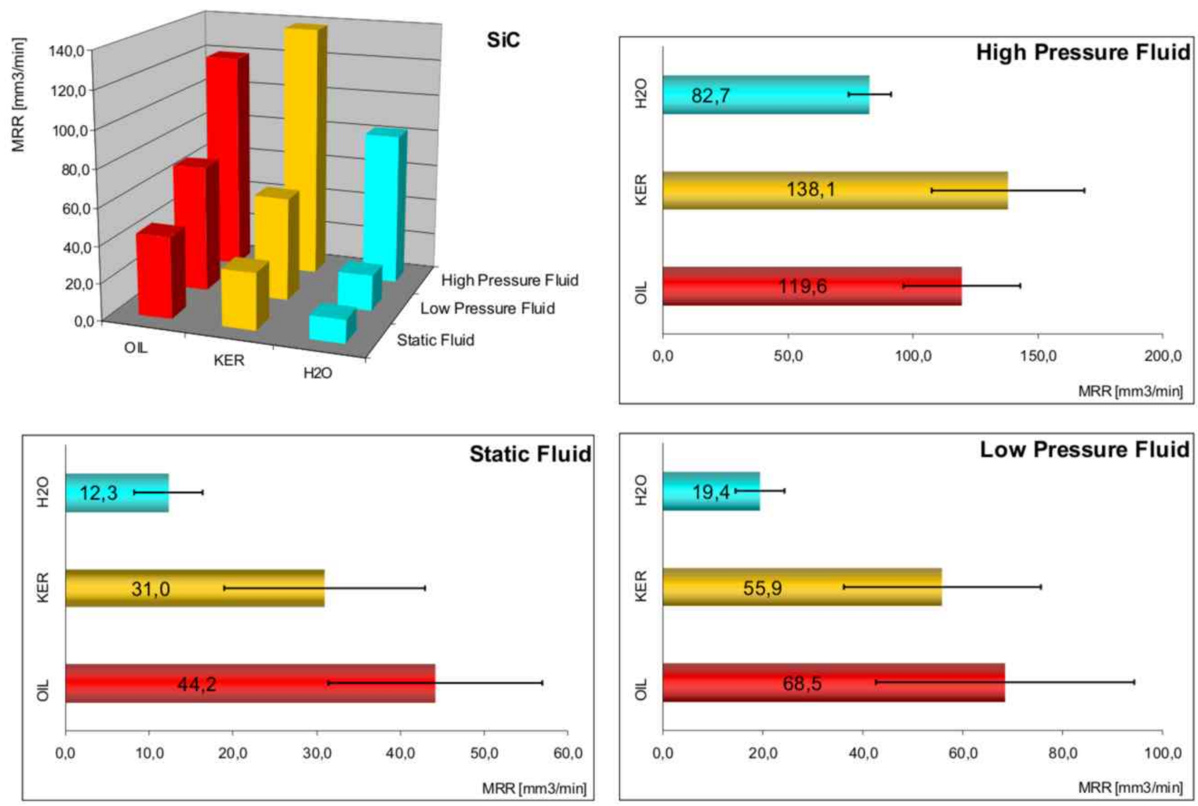

Figure 4. Metal Removal Rate for the samples machined with Oil, kerosene and water, concentration = 30 g/l, granulometry = 600 mesh, static fluid, low and high pressure jets.

In many hybrid cases, besides the contribution of the component processes, a new formulation can occur considering an interaction term of the processes, EDM and AWJM - Abrasive Water Jet Machining:

$$MRR_{TOTAL} = MRR_{EDM} + MRR_{AWJM} + MRR_{(EDM \rightarrow AWJM)} \quad (1)$$

Equation (1) illustrates the synergetic effect in the MRR on the hybrid processes. For the application of this equation, it is necessary to experimentally determine the MRR values (EDM→AWJM), which is the MRR of the EDM process aided by AWJJM. Then, we calculate for the deionized water:

$MRR_{TOTAL} = 80\ mm^3/min$;
$MRR_{EDM} = 11\ mm^3/min$ ► $MRR_{(EDM \rightarrow AWJM)} = 69\ mm^3/min$
$MRR_{AWJM} = 0$

This is the MRR value of the EDM process with the aid of the AWJM process. Total MRR is the Metal Removal Rate of the hybrid process AJEDM. The MRR_{AWJM} is nearly zero, for the parameters used are not enough for the erosion without the sparks (ABNT M2 steel, 100 bar pressure, 600 mesh SiC abrasive, dilution 30 g/l). Therefore, the hybrid process has proved that, in terms of MRR, it is much more efficient than the EDM process, with a performance which is 420% superior than the presented by these processes.

Figure 5, morphology of the M2 steel surface machined with water in high pressure, is representative of the samples surfaces' conditions. With the presence of SiC, can be noticed the "soften" of the surface, the decrease of the number of craters

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and bubbles. According to Yih-Fong and Fu-Ghen[7] and Zhao, Meng and Wang,[8] the action of the solid particles stabilize the EDM process, and are capable of improving MRR, roughness and surfaces morphology. Besides, the pressure's increase optimizes the flushing system in the *gap*, improving the removal of recast metal, decreasing the bubble and crater effect that are common in the recast layer of parts machine-made by EDM.

(a) (b)

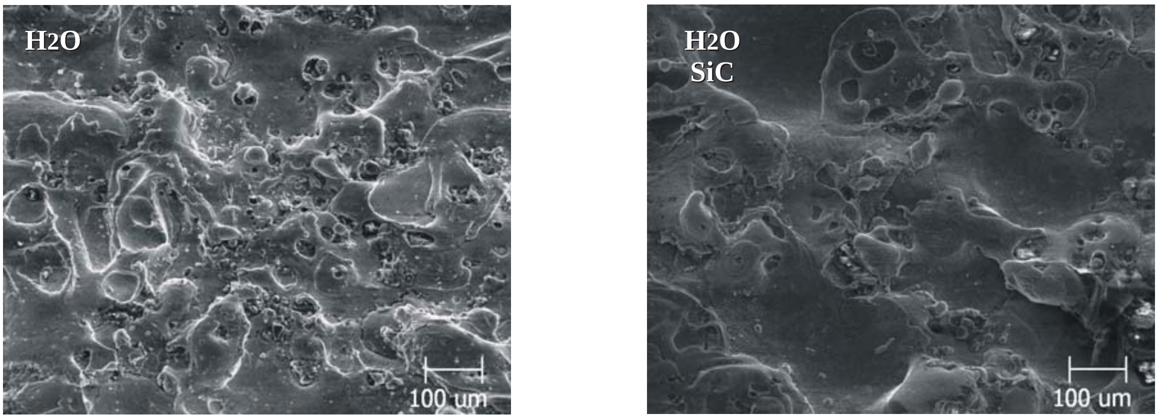

Figure 5. Morphologies generated by scanning electronic microscopy of the surfaces machined with high pressure fluid, deionized water: (a) without abrasive and (b) with abrasive.

The surfaces observed in Figure 6 are typically produced in EDM processes. It cannot be seen characteristics that allow the identification of erosive action of SiC abrasive particles. Thus, it is not possible to identify the active erosion mechanisms. It was conducted a comparative EDS analysis of the machined surfaces. Table 3 presents the results. For the condition of high pressure fluid without the addition of SiC, it cannot be found Si or SiC deposition (not significant). But for the condition of high pressure fluid in dispersion, there was a considerable deposition of Si in the machined surface. These results show that, in the situation in which the SiC was used, there was effective participation of the abrasive particles in the metal removal process.

Table 3. EDS analysis of the machined surfaces with High Pressure Fluid, with and without SiC, regarding the Si deposition (%)

Si (%)	OIL	KER	H2O
No SiC	-	-	-
With SiC	1,36	1,25	1,69

To quantify the improvement of the machined surfaces' quality, was determined the Sa roughness, whose results are shown in Figure 6. It can be noticed that oil presented the best result in all conditions, when compared with the results presented by kerosene and deionized water. The water presented the worst performance, especially when the static fluid was used. Then, we conclude that the increase in the flushing system pressure of the work piece interface decreased the roughness difference of the machined surfaces. This is due to the fact that the flushing system contributes not only to the elevation of the MRRs, but also to the improvement of the superficial finishing of the part.[9-11]

The results for Sa roughness of the samples machined with SiC are shown in Figure 7. It can be noticed that in the condition which the abrasive's erosion action contributes to the material removal, there was a sensitive improvement in the surface

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finishing of the machined samples. For instance, without the addition of SiC and with a high pressure jet, the Sa value with oil was 9,5 μm, while it dropped to 4,91μm with the abrasive.

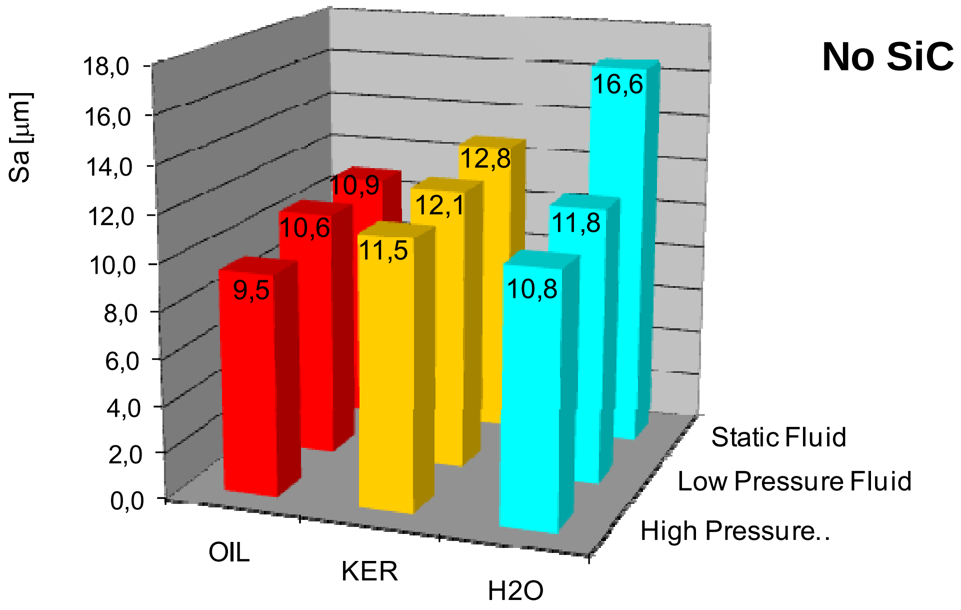

Figure 6. Sa roughness for the samples machined with Oil, Kerosene and Water, without abrasive, with static fluid, low pressure jet and high pressure jet.

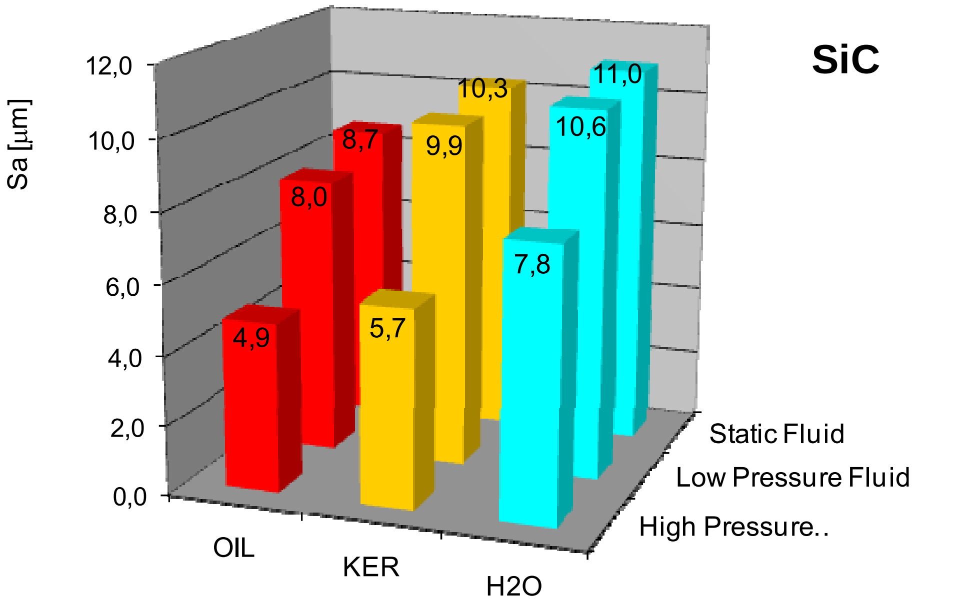

Figure 7. Sa roughness for the samples machined with Oil, Kerosene and Water, with abrasive, with static fluid, low pressure jet and high pressure jet.

The abrasive improves the machining mechanism by the better distribution of the sparks[(8)] and generating impact energy on the surface, thus improving the machining speed and superficial integrity. The erosive effect does not occur in the solidified material, at least in a significant way, but it effectively occurs in the cast material that, by gravity, after the implosion, precipitates again in the already

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machined surface, by the posterior spark. The high pressure abrasive particles remove this layer of cast material during its solidification. This mechanism leverages the EDM process, like a kind of mechanical catalyst.

The sensitive difference in the roughness corroborates the expectation that the AJEDM hybrid process is not only faster, but also generates better quality surfaces.(8)

Related to the copper electrode, can be observed that there was a more distinctive erosion in them when used the erosive fluid jet under high pressure, as showed by figure 8. As there is an erosive action of the particles in the M2 steel work piece, the electrode will also be susceptible to these particles' action. This explains the more distinctive erosion of the electrode.

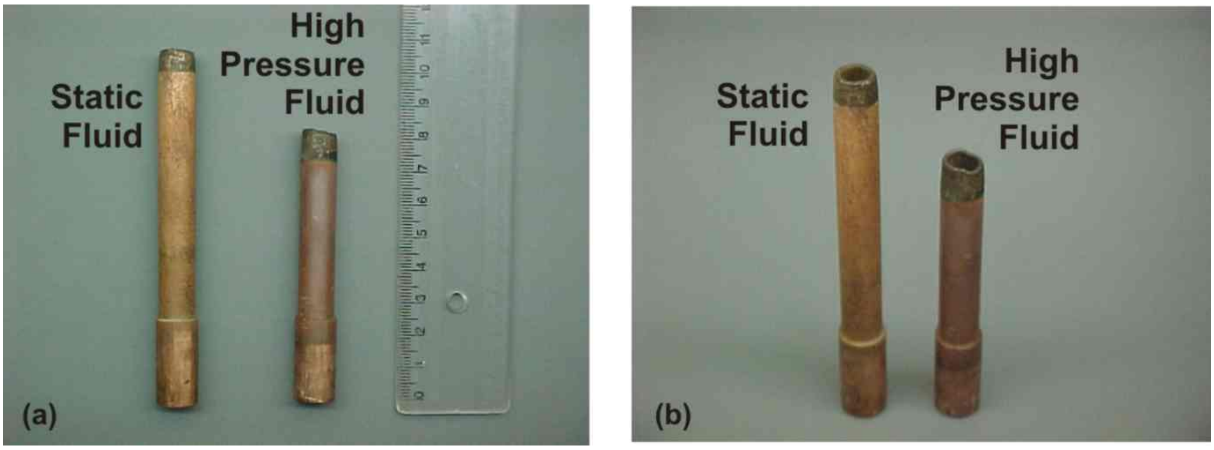

Figure 8. Tooling wear in experiments with deionized water and addition of abrasive: (a) view 1 e (b) view 2.

4 CONCLUSIONS

Based on the results found from the experiments conducted in die-sink EDM process associated with an erosion process by fluid jet (AJEDM), can be concluded that:

- The hybrid process AJEDM is technically viable;
- The flushing system has a fundamental importance in the EDM machining process. The greater the dielectric fluid pressure, the greater is the Metal Removal Rate (MRR) and the smaller is the roughness values. The addition of abrasive particles of SiC improves considerably the roughness values of the work piece machined by EDM;
- In the condition of high pressured fluid and SiC in dispersion, there was a considerable deposition of Si in the machined surface. These results show that, in the situation in which SiC was used, there was effective participation of the abrasive particles in the metal removal;
- The usage of deionized water as dielectric is technically viable in the proposed hybrid process, once the roughness values become compatible with the ones obtained with hydrocarbon and conventional EDM, with the advantage of less cost, greater safety to the operator, and being ecologically viable. However, when it is desired to a less rough surface, the best fluid is the hydrocarbon specific for electroerosion, whose physical and chemical properties show a better efficiency in the AJEDM process;
- In the AJEDM process there is a greater erosion of the copper electrode.

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