II CONGRESSO NACIONAL DE ENGENHARIA MECÂNICA
II NATIONAL CONGRESS OF MECHANICAL ENGINEERING
12 a 16 de Agosto de 2002 - João Pessoa – PB

INFLUENCE OF THE DUTY FACTOR ON THE DIE-SINKING ELECTRICAL DISCHARGE MACHINING OF AMP 8000 ALUMINUM ALLOY UNDER ROUGH MACHINING

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Abstract. *The use of high-strength aluminium alloys as material for injection molding tools to produce small and medium batches of plastic products as well as prototyping molds is becoming of increasing demand by the tooling industry. These alloys are replacing the traditional use of steel in the cases above because they offer many advantages like very high thermal conductivity associated with good corrosion and wear resistance presenting good machinability in milling and electrical discharge machining operations. Unfortunately there is little technological knowledge on the Electrical Discharge Machining (EDM) of high-strength aluminium alloys, especially about the AMP 8000 alloy. The duty factor, which means the ratio between pulse duration and pulse cycle time, exerts an important role on the performance of EDMachining. This work has carried out an experimental study on the variation of the duty factor in order to analyze its influence on material removal rate and volumetric relative wear under roughing conditions of EDM process. The results showed that high values of duty factor are possible to be applied without bringing instability into the EDM process and with improvement of material removal rate and relative wear.*

keywords: *Die-sinking EDM, aluminium alloy, duty factor, process parameters.*

1. INTRODUCTION

König et al. (1996) report that developments in the field of production engineering are historically dominated by changes in manufacturing processes. They also remark that some primary causes behind these changes are those related to the introduction of new materials and the requirements for increased accuracy and efficiency of the production processes. In this context is relatively rare the case where only one single manufacturing process is suitable to the execution of a specific machining task. For example, this is the case of the production of a plastic injection mold.

Klocke (1998) points out that nowadays the combination of milling and electrical discharge machining (EDM) operations provides one the most important advantages for the production of injection molding tools. He also reports that further potencials for cost reduction along the entire production process of an injection molding tool are found in the use of high-strength aluminium alloys and copper-based alloys.

Erstling (1998) asserts that high-strength aluminium alloys have been widely used as material for prototyping tools and for molding short and medium batches of plastic products. These alloys have some characteristics which make them suitable for many types of molding tools, such as a high thermal conductivity - four to six times higher than the traditional steels - that ensures not only a reduction of the cooling phase of the molding process, but also promotes a better workpiece dimensional control with less tolerance deviation and less warpage, fewer molded-in stresses and a reduced incidence of sink marks. Additional advantages of these alloys are good wear and corrosion resistance against many plastic resins normally used in molding industry. He also points out that other characteristic is the good machinability found in milling operations when high cutting speeds can be applied with lower tooling costs and consequently promoting reduction of machining time. In some cases for milling operations the reduction of machining time is about 60 %, in the cases of turning and drilling 50 % and for EDM approximately 70%.

EDM has advanced to one of the major manufacturing processes applied in die and mold-making industry to generate deep and three-dimensional complex cavities in many different classes of materials in roughing and finishing operations. Examples include precision machining of hardened steels, carbides, ceramic materials and any other that offers the minimum electrical conductivity, as showed in Fig (1). Unfortunately, there is little technological knowledge on EDM parameters for high-strength aluminum alloys as an example is the case of AMP 8000.

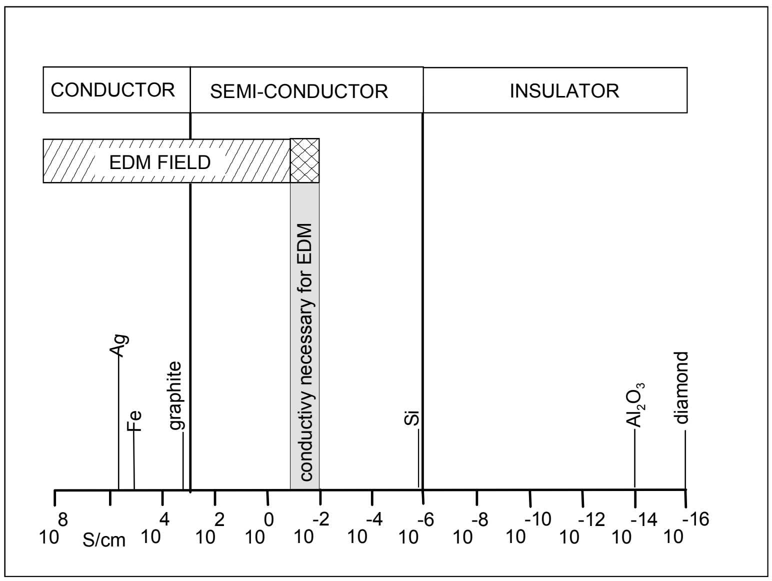

Figure 1. Electrical Conductivity necessary for EDM (König, Klocke & Lenzen, 1996)

Since the development of the process of electrical discharge machining by Lazarenko (1944) various causes for the material removal have been postulated. As informed by König et al. (1975) several models, like for instance the electro-mechanical and the thermo-mechanical theories, have been proposed in order to explain the complex phenomenon of Electrical Discharge Machining (EDM). These two theories like many others are not accepted because the lack of experimental evidences. Currently there is no complete and definite model explaining in all details the different processes that take place during a discharge.

Nowadays, the best supported theory is the thermoelectric phenomenon and according to Van Dijck et al (1974) and other researchers (Zolotych, 1970; Crookall & Khor 1974; Dibitonto et al, 1989 and König & Klocke, 1997), the material removal in electrical discharge machining is associated with the erosive effect produced when spacially and discrete discharges occur between two electrical conductive materials. Sparks of short duration, ranging from 0,1 to approximately 4000 [μs], are generated in a liquid dielectric gap separating tool and workpiece electrodes. The electrical energy released by the generator is responsible to melt a small quantity of material of both electrodes by conduction heat transfer. Subsequently, at the end of the pulse duration a pause time begins and the melted pools are removed by forces which can be of electric, hydrodynamic and thermodynamic nature.

Figure (2), adapted from König & Klocke (1997), briefly presents the phases of a discharge in EDM process. The first one is the ignition phase which represents the lapse corresponding to the occurrence of the breakdown of the high open circuit voltage $\hat{u}_i$ applied across the working gap until the fairly low working voltage u_e, which ranges normally from 15 to 30 [V]. This period is known as ignition delay time t_d. The second phase, which instantaneously occurs right after the first one when the current rapidly increases to the operator specified peak current $\hat{i}_e$, is the formation of a plasma channel surrounded by a vapor bubble. The third phase is the discharge phase, when the high energy and pressure plasma channel is sustained for a period of time t_e causing melting and evaporation of a small amount of material in both electrodes. It is important to remark that little evaporation occurs due to the high plasma pressure. The fourth and last one phase is the collapse of the plasma channel caused by turning off the electric energy which causes the molten material to be violently ejected. At this time, known as interval time t_o, a part of the molten and vaporized material is flushed away by the flow of the dielectric across the gap and the rest is solidified in the recently formed crater and next to the surroundings. During t_o also occurs cooling of the electrodes and the de-ionization of the working gap necessary to promote an adequate dispersion of the successive discharges along the surfaces of the electrodes.

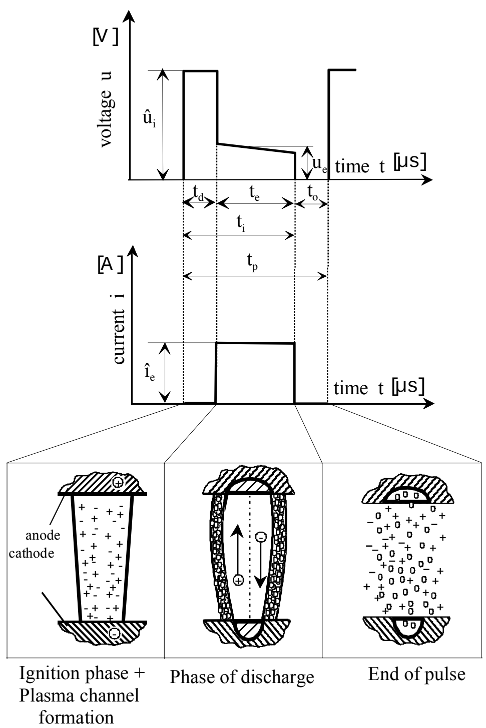

Figure 2. The phases of an electric discharge in EDM (König and Klocke, 1997)

Besides the electric parameters described above others like the polarity of electrodes, the type and condition of flushing, the thermophysical properties of electrodes and the planetary movement of the tool electrode have important effects on the EDM technological results.

Another variable strictly associated to the electrical parameters and that considerably influences the performance of the EDM process is the duty factor τ, which means the ratio between the pulse duration t_i and the pulse cycle time t_p. This work has carried out an experimental study about the variation of the duty factor and its influence on the results of EDM applied to the AMP 8000 aluminium alloy under roughing conditions.

It has been investigated two important technological aspects of EDMachining performance under roughing machining. The first is the material removal rate V_w, that means the volume of material removed from the workpiece electrode per minute. The second one is the volumetric relative wear ϑ corresponding to the ratio of tool electrode wear rate V_e to material removal rate V_w.

The AMP 8000 is a trademark of a newly released high-strength aluminium alloy produced by ALIMEX Metallhandelsgesellschaft GmbH from Germany. Typical chemical composition of this alloy is 4,3-5,2 % Zn, 2,6-3,7 % Mg, 0,5-1,0 % Cu and the balance aluminium. It has a tensile strength of 590 [MPa] and presents 174 [HB]. The density is approximately 2830 [kg/m^3] and the thermal conductivity is 165 [W/mK].

2. EXPERIMENTAL PROCEDURE

The experiments were performed on a Charmilles ROBOFORM 30 CNC die-sinking electrical discharge machine installed at the Machining Processes Laboratory - LAUS of PUCPR in Curitiba. The ROBOFORM 30 is equipped with an isoenergetic generator, which means that is possible to set the discharge time t_e and to control the ignition delay time t_d as a percentage of t_e. In this work t_d was kept as 25 % of t_e for all the experiments. The AMP 8000 workpieces were square samples 25 [mm] wide and 15 [mm] thick. Electrolytic copper cylindrical bars with a diameter of 20 [mm] and a 4 [mm] central hole were mounted axially in line with workpieces and used as tool electrodes at positive polarity. The Arclean Eletron hydrocarbon dielectric fluid produced by Archem Química ltda was injected under 0,01 [MPa] through the electrode hole providing adequate flushing of particles away from the working gap. The open circuit voltage $\hat{u}_i$ of 200 [V] which provided a stable process was established for the definitive tests after pilot tests with 120 and 160 [V]. The accurate quantification of V_w and ϑ was possible by using a precise balance (resolution = 0,0001 g) to weigh the electrodes before and after an average machining time of 30 minutes. In order to rather improve the flushing conditions an alternation between periods of machining U and periods of tool electrode retraction R with no discharges were introduced, as shown in Fig. (3). The values of U and V were defined after some pre-tests.

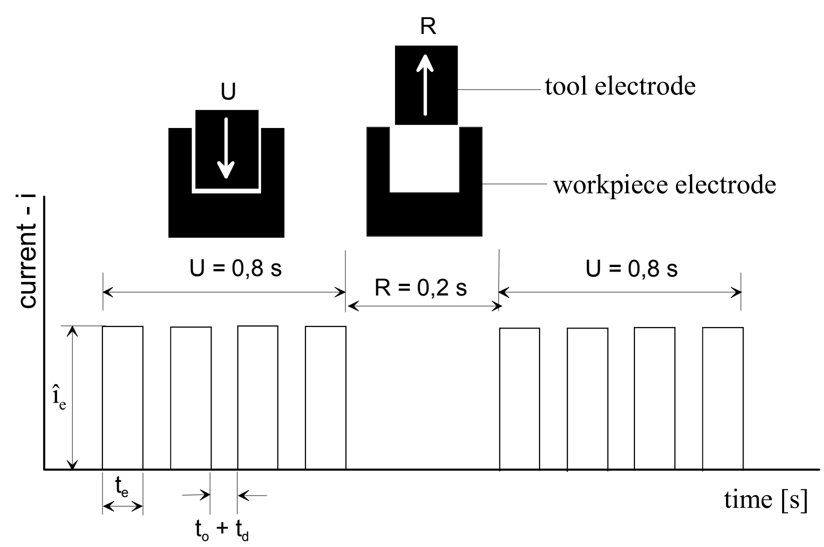

Figure 3. A series of pulses (U) followed by a pause (R)

Table (1) summarizes the electrical parameters established for the experimental investigation. The discharge duration t_e ranging from 25 [μs] to 800 [μs] was suitable for scanning the best results of V_w and ϑ under the roughing conditions possible with 32, 24 and 16 [A] available at the ROBOFORM 30 from LAUS.

Table 1. Experimental machining parameters

Current intensity $\hat{i}_e$ [A]	Duty factor τ	Discharge time t_e [µs]	Interval time t_o [µs]
32; 24; 16	0,5	25; 50; 100; 200; 400; 800	25; 50; 100; 200; 400; 800
	0,7		12,8; 25; 50; 100; 200; 400
	0,8		6,4; 12,8; 25; 50; 100; 200

3. RESULTS AND DISCUSSION

In rough conditions of EDM the main aim is to achieve the highest material removal rate V_w with low level of volumetric relative wear ϑ. For this reason the duty factor τ is chosen to be as high as possible. The conventional action to elevate the value of τ is reducing the interval time t_o in relation to the pulse time ($t_i = t_e+t_d$). With this procedure an increase of discharge frequency occurs which normally promotes better rates of V_w and lower ϑ.

Figure (4) presents the results obtained for the material removal rate with three different levels of duty factor under 32 [A] of discharge current. The initial value of $\tau = 0{,}5$, which means $t_i = t_o$, was chosen because the good stability normally observed on EDM operations. Smaller values of duty factor ($t_i < t_o$) would lead to very low discharge frequency consequently decreasing the material removal rate. Another important aspect regarding the choice of small values of τ is associated with the low level of contamination concentration across the working gap. According to Schumacher (1990) some concentration of sub-microscopic particles, fibers or moisture drops in the working gap can reduce the ignition delay time t_d because these particles arrange themselves in such a way that a kind of a bridge is probably to occur intensifying the electric field, which by its turn quickly fire another discharge. It is also observed an increase of the working gap facilitating the coarse eroded material to be flushed away.

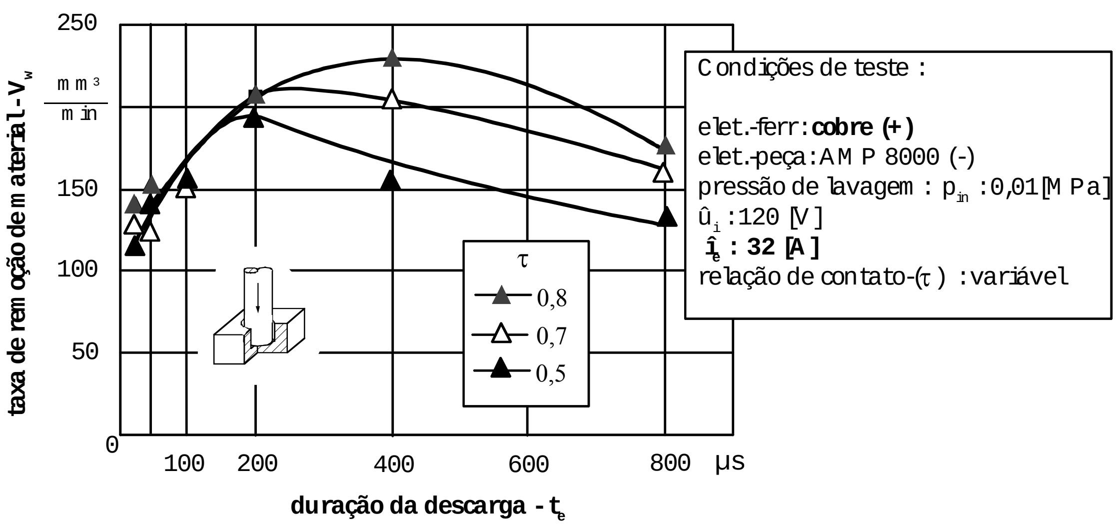

Figure 4. Variation of duty factor for 32 [A] of discharge current ($\hat{i}_e$)

The behavior of material removal rate for each one different level of duty factor is clearly seen from Fig.(4), which shows that as the discharge time t_e increases, V_w also increases up to a maximum value for a specific optimum t_e. Beyond this point V_w starts decreasing rapidly. The explanation for the V_w behavior after its maximum point is concerned to the very high plasma diameter expansion due to the long discharge time t_e that diminishes pressure and energy of the plasma channel over the molten material of the electrodes. As a consequence this phenomenon brings instability to the process lowering the material removal rate.

It is observed that electrical discharge machining under τ = 0,5 promoted a maximum V_w of 190 [mm^3/min] for discharge time t_e at 200 [µs]. Increasing the duty factor to 0,7 a little higher value of V_w can be noticed under the same optimum t_e. However, the best material removal rate of approximately 230 [mm^3/min] is achieved for τ = 0,8 and discharge time t_e clearly at 400 [µs]. It must be pointed out that for duty factor of 0,8 a black film on the surface of the workpiece electrode was observed, probably due to the deposition of hydrocarbon dielectric particles that were not flushed away from the gap. On the other hand for τ = 0,5 ($t_i = t_o$) no black film appeared. In both cases the stability of the process was quite normal.

Some tests were carried out with duty factor higher than 0,8 but unsatisfactory results were obtained. It was noticed that much instability was brought into the working gap in either the form of arc discharge pulses or short-circuit pulses. Probably due to insufficient interval time t_o between to successive discharges to evacuate the coarse eroded material and simultaneously de-ionize the working gap. As a consequence the over concentration of dielectric and electrodes byproducts negatively interfered on the occurrence of normal discharges, causing by this time nonuniform wear of the electrodes related to the poor dispersion of discharges along the electrode frontal surfaces, as well as low performance of EDMachining.

The curves of material removal rate V_w for the 24 [A] of discharge current $\hat{i}_e$ and duty factor of 0,5 and 0,8 are presented in Fig. (5). Tests with τ of 0,7 was suppressed because the low difference of V_w obtained in comparison with τ=0,5. It is obvious from Fig. (5) that the highest rate of material removal rate is found for τ=0,8 which promoted V_w around 180 [mm^3/min] for optimum t_e of 100 [µs]. It is due the lower pulse cycle time t_p that caused a considerable increase of discharge frequency. It important to remark that for duty of 0,5 and 0,8 the process was quite stable, but a little better for τ=0,8.

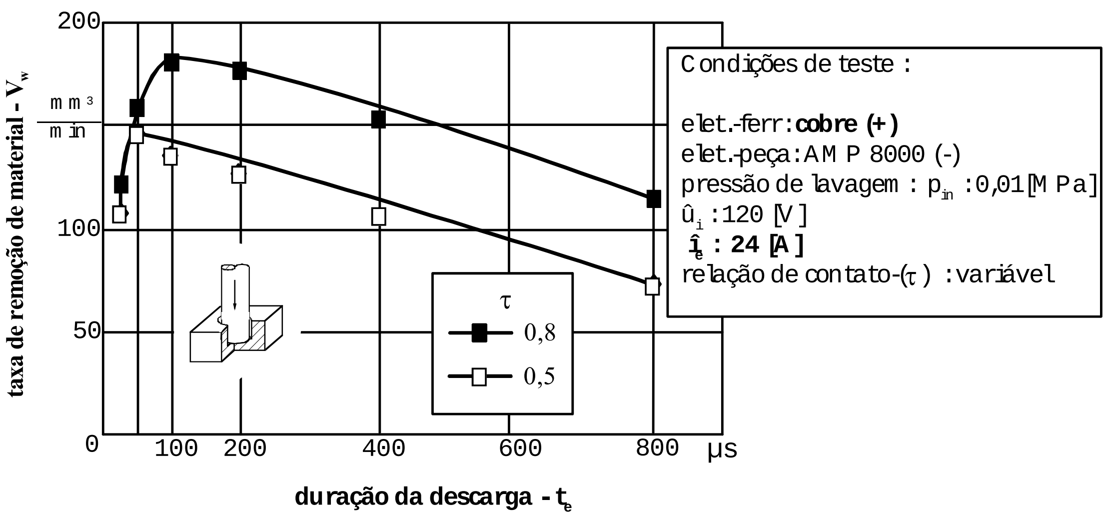

Figure 5. Variation of duty factor for 24 [A] of discharge current $\hat{i}_e$

The results for 16 [A] can be observed in Fig. (6). As occurred to the other discharge currents the duty factor of 0,8 promoted the best results as compared to τ=0,5. The maximum V_w is approximately 110 [mm^3/min] for a clear optimum t_e at 100 [µs] and τ=0,8. For discharge duration longer than the optimum is noticed a deep decreasing of Vw. It is related to the very long discharge duration that causes instability of the plasma channel in two ways. The first is the very fast decreasing of the plasma pressure and the second is the over increase of the plasma channel that consequently promotes a diminishing of the energy density over the surfaces of the electrodes. As consequence the continuation of material melting goes to lower levels.

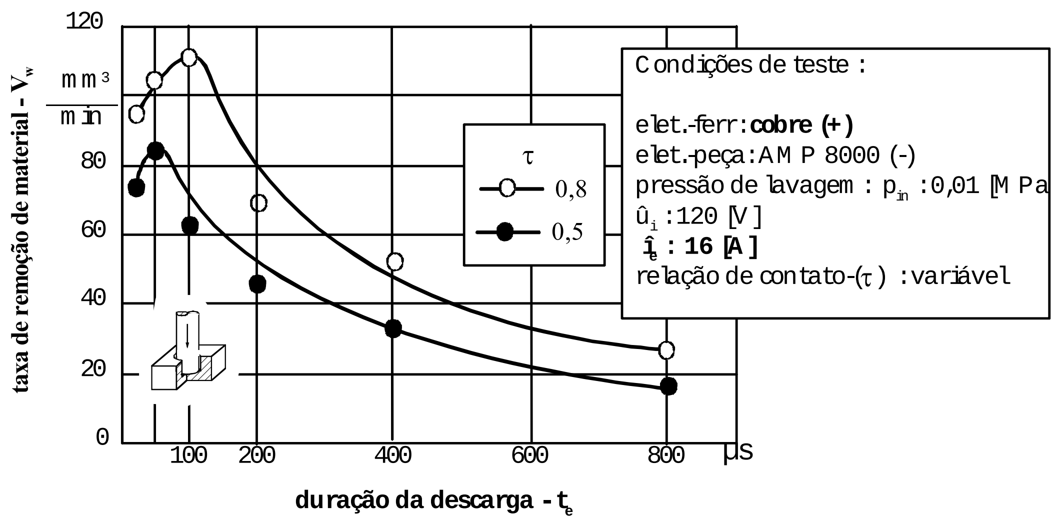

Figure 6. Variation of duty factor for 16 [A] of discharge current ($\hat{i}_e$).

In respect to the volumetric relative wear ϑ the results are presented in Fig. (7) and Fig (8). It can be said that the higher is the discharge current $\hat{i}_e$ the higher is the relative wear when machining with copper electrodes. A possible explanation to this fact is due to the low resistance of copper against the thermally influenced wear.

Another import observation between EDMachining under duty factor (τ) of 0,5 and 0,8 regards to the lower level of volumetric relative wear ϑ achieved to τ=0,8 in comparison to the one obtained for τ of 0,5. This behavior is associated with two aspects. The first one concerns to the higher values of V_w and the second is related to the adhesion of workpiece particles over the surface of the tool-electrode. These two aspects become favorable because of the low interval time t_o that promotes some higher concentration of debris quantity in the working gap.

In general terms, by the analysis of the experiments it is clearly seen that for both values of duty factor (0,5 and 0,8) the volumetric relative wear ϑ is considerably under low levels, which means a good performance of the process.

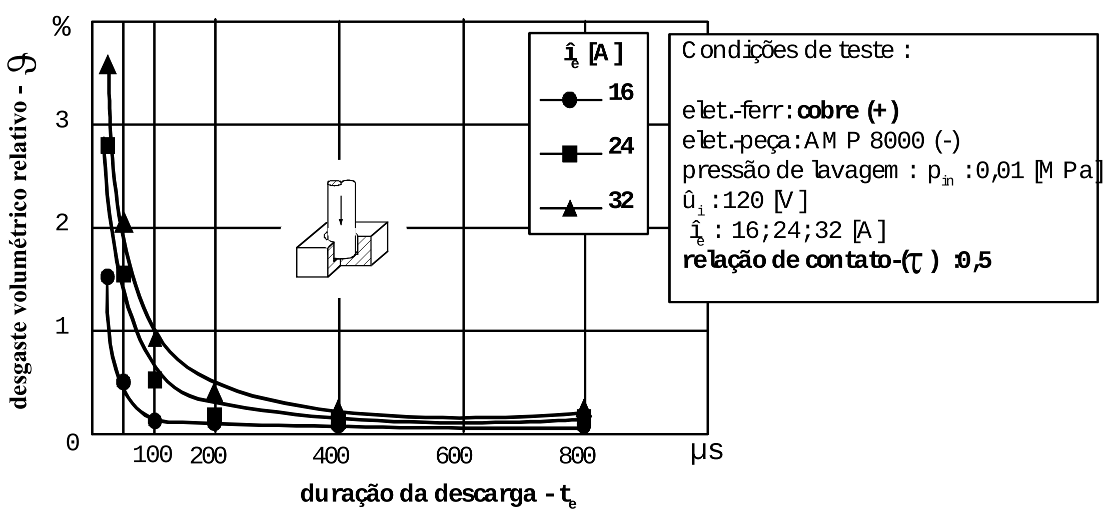

Figure 7. Volumetric relative wear ϑ for duty factor τ of 0,5.

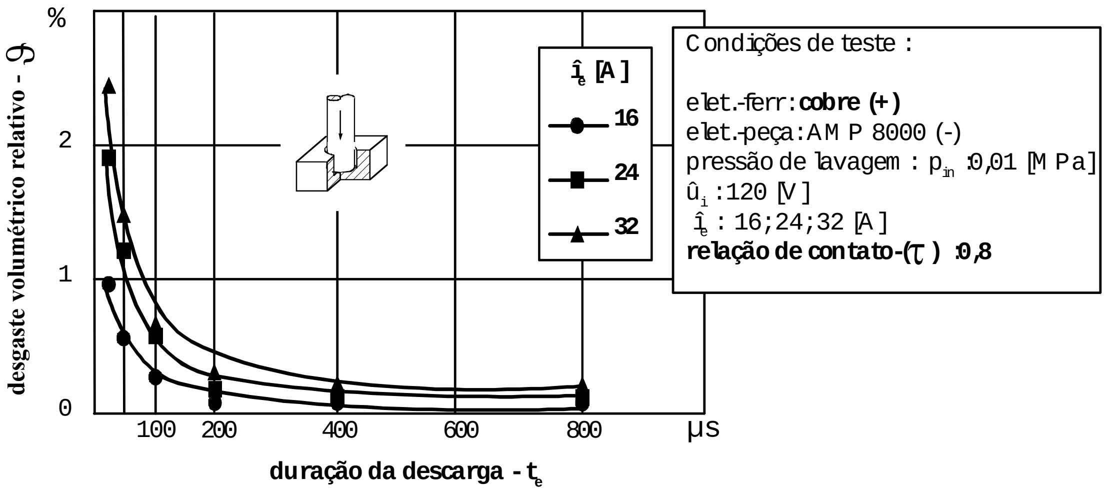

Figure 8. Volumetric relative wear ϑ for duty factor τ of 0,8.

4. CONCLUSIONS

From the results of this experimental investigation the following conclusion can be drawn:

- The elevation of duty factor τ from 0,5 up to 0,8 promoted better results for material removal rate V_w and volumetric relative wear ϑ.
- The maximum material removal rate (V_w = 230 [mm^3/min]) was obtained for a discharge current $\hat{i}_e$ of 32 [A], τ= 0,8 and t_e = 400 [µs].
- The average level of volumetric relative wear ϑ for all the tests is less than 1 % under electrical discharge machining at the optimum discharge duration t_e.
- Irrespectively of the level of duty factor (0,5 or 0,8) the process stability were quite stable.
- When EDM using a duty factor of 0,8 it was observed a presence of a black layer over the surface of workpiece samples. A negative result was found for τ=0,5 ,i.e., no black layer was observed.
- Some tests with duty factor higher than 0,8 promoted an unstable condition with considerable presence of arc discharge pulses or short-circuit pulses.

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