Efficient dielectric fluid approach in electrodischarge finish machining on the material surface roughness of titanium alloy Ti-621/0.8

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Abstract. This study was developed to reveal the correlation between current intensity and pulse off time with surface roughness of Ti-621/0.8 in fine EDM machining, in a unique manner of dielectric fluid approach. Depth of cut was taken in consideration to be not as high 1 µm due to the fact that good results were taken for more less heights before. In the case of Ti alloy (Ti-621/0.8) bar, EDM machining with low parameters (limited 110 V) is a delicate process, in which reaching SR under 1 µm is a challenge. Cooper and Graphite electrodes were used, die sinker oil dielectric from machine manufacture was used, without thermal modification to workpiece or electrode, just active dielectric compensatory fluid pumping solution with 0.5 MPa.

1. Introduction
The machining of Ti-621/0.8 with conventional machining processes is very difficult because of high toughness and low thermal conductivity. Investigate the effects of cooling time due to pulse off time as prime factor, and peak current intensity as a second factor, of fine machining without using other cooling options, like cryogenically treatment before or in time of processing [1] which provided smooth surface appearance, the cold effect is provided only from the speed and direction of dielectric fluid in the gap area. Regardless of pulse on time which is one of the main factors in MRR (Material Remove Rate), the surface roughness quality is based on efficiency of recasting time of layers [3].

Controlling the thermal proprieties of the Ti-621/0.8 is capital when we have a process in which cooling is allowed less time than heating up on a regime of finish EDM machining with spark temperatures around melting temperature of Ti alloy.

Optimizing input parameters or other means like dielectric approach, is allowing a larger area of applicability in the industry of Ti-621/0.8.

The influence of the workpiece after solidifying and before machining conditions, were made just for reducing the unwanted deforming lines in the workpiece profile, reducing thermal modifications [2] due to classical machining of fabrication in the pre-process of EDM.

Presented experiments are applicable on the workpiece models that will have a distinct simple geometrical surface to be machined on, and a very good dielectric gap circulation.
2. Experimental conditions

The experiments were conducted on a die sinking EDM machine, Model *Fem 110* CNC although, even if kerosene is widely used as dielectric with die sinking machines, at high discharge temperatures, the carbon elements penetrate the electrode surface affecting the normal discharge.

In this study Knuth EDM oil was used, the model provided from the start with the machine.

![Dielectric system management of fluid flowing motion lines.](image)

Figure 1. Dielectric system management of fluid flowing motion lines.

Analyses of dielectric were conducted [5], (using Brookfield DV-e Viscometer) regarding the quality, with temperature around 23°C and viscosity value of 3.07 Centistokes cST or 0.0000307 [m²/s]. For fine machining 2÷3cST is a range accepted for hard steels.

Many preparations and calibrations of process were made for choosing the dielectric system management figure 1, for analysing materials of workpiece and tool electrode as in table 1. Soft abrasive cleaning followed by air pressured cleaning was performed on the circular profile before immersion in dielectric for free of unwanted surface particles.

**Table 1.** Chemical (%) of workpiece and electrode.

| Workpiece Material | Titanium Alloy | High Quality brass (Cu) |
|--------------------|----------------|-------------------------|
| C                  | 0.015          | Cu                      | 99.5                   |
| O                  | 0.106          | Zn                      | 0.175                  |
| N                  | 0.0052         | Cr                      | < 0.0010               |
| Fe                 | 0.04           | Pb                      | 0.0395                 |
| Al                 | 5.32           | Sn                      | 0.0423                 |
| V                  | -              | Fe                      | 0.0837                 |
| Ti                 | Balance        | Ni                      | < 0.0050               |

The graphite [C] electrode was used only on low energy regimes having no need in dividing the plane surface of 20/20 [mm] preparations like [3]. Divided profile and polished surface High-Quality brass electrode was necessary figure 2 due to depth appearance corrosion of tool electrode and workpiece machined surface.
Figure 2. High-Quality brass (Cu) before and after each experiment.

The experimental plan was chosen using Design Expert software. From a total number of 21 machining codes were reduced to 9 experiments by applying the criteria of pulse off time 13, 10 and 7 μs combined with 6, 10, 14 A peak current intensity for the EDM process and input range taken from literature [5].

Parameters that are likely to affect SR and also cause surface changes on the recast layers were identified using a study from the reported results in the literature [1, 4, 3]. Three repetitions for each surface roughness measurement were conducted. The roughness readings were made on Roughness Tester TR-200 (figure 3.) by Namicon Company, with analysing 0.8μm length of surface each. The surface obtained after each EDM process was photo taken using metallurgical microscope IMM 901 by Metkon Company with the 200x amplification factor shown in figures [3-5].

3. Experimental results
The experimental result are listed in table 2 (lowest SR associated to main parameter current intensity I are italics).

Table 2. Experimental results.

| Experiment Number | Peak current intensity I A | Pulse Off Time μs | High-Quality brass tool electrode Cu | Graphite tool electrode C |
|-------------------|---------------------------|------------------|--------------------------------------|--------------------------|
|                   |                           |                  | Surface Roughness Ra μm               | Average Ra μm            | Surface Roughness Ra μm | Average Ra μm |
| 1                 | 6                         | 13               | 2.302                                | 2.417                    |                          |              |
|                   |                           |                  | 2.437                                |                          |                          |              |
|                   |                           |                  | 2.512                                |                          |                          |              |
| 2                 | 6                         | 10               | 1.253                                | 1.389(6)                 |                          |              |
|                   |                           |                  | 1.72                                 |                          |                          |              |
|                   |                           |                  | 1.196                                |                          |                          |              |
| 3                 | 6                         | 7                | [ italic ]                           |                          | 0.744                    | 0.890(6)     |
|                   |                           |                  |                                      |                          | 0.871                    |              |
|                   |                           |                  |                                      |                          | 1.057                    |              |
| 4                 | 10                        | 13               | 2.471                                | 2.535(6)                 |                          |              |
|                   |                           |                  | 2.542                                |                          |                          |              |
|                   |                           |                  | 2.594                                |                          |                          |              |
| 5                 | 10                        | 10               | 1.655                                | 1.638                    |                          |              |
|                   |                           |                  | 1.648                                |                          |                          |              |
|       | 6      | 7      | 1.611 | 1.413 | 1.474(3) |
|-------|--------|--------|-------|-------|----------|
| Current | 10     | 1.487  | 1.523 |
| Pulse off time | 7 µs    | 3.643  | 3.604 |
| Pulse on time | 5 µs    | 3.578  |
| Cu electrode |         |        |
| Experiment 5 |        |        |
| Current | 8      | 2.208  | 2.485 |
| Pulse off time | 10 µs  | 3.608(3) |
| Pulse on time | 7 µs    |        |
| Cu electrode |         |        |
| Experiment 5 |        |        |
| Current | 9      | 2.262(3) | 2.786 |
| Pulse off time | 7 µs    |        |
| Pulse on time | 10 µs  |        |
| Cu electrode |         |        |
| Experiment 5 |        |        |

Smallest pulse off time is recommended to be used only for finishing stages, very long machining times average 6 hour were recorded for the depth width of 1µm compared to usual timed EDM.

Optical microscopy captions for 200x Ti alloy machined were prepared and chose randomly from machined surface, images are from measurement program of IMM 901 for interpretation by specialists of craters that were chose to be measured, presented as follow:

**Figure 3.** Current of 6 A, pulse off time of 7 µs , pulse on time of 5 µs and C electrode for experiment.

**Figure 4.** Current of 10 A, pulse off time of 10 µs , pulse on time of 7 µs and Cu electrode for experiment 5.

It is considered almost free of debris, craters 0.37±0.8 µm were in normal values compared to SR of 0.890(6) µm, with a usual arrangement of craters, average distance between them of 0.6003µm.

The sparks created craters of low depths < craters diameter, which proves a better recast layer.
Figure 5. Current of 14 A, pulse off time of 13 µs, pulse on time of 24 µs and Cu electrode for experiment 7.

With major debris diameter found around 0.1603 µm, craters 0.35÷2.5 µm were in normal values compared to SR of 3.608(3) µm with a compact arrangement of craters, average distance between them of 1.006µm.

Cracks were not taken into consideration in measurement of craters due to its atypical forms creation.

Individual contributions on SR are presented for all peak current intensity and pulse off time input levels in figure 8. Each experiment is being represented as a dot.

Figure 6. Modifications of SR which depends on Peak current intensity and pulse off time.

Significant decrease in SR was observed in all cases with decrease of energy of EDM, with the presence of low pulse off time, in which case the pulse on time correlated values were also less than 22÷24 µs to the lowest of 5÷6 µs.

Pulse off time is vital for SR if well combined with dielectric fluid pressure (ex. low fluid pressure for low sparks conditions, conditions associated with low peak current intensity or/and low pulse off time). The combined influences of input parameters are presented 3D in figure 7 (the lower the cubic pieces are the finest was the machining process).
4. Conclusions

With the most idealistic environment that consists in: simple geometry Ti-621/0.8 round bar, entire machined surface was dielectric refreshed on each electric contact due to efficient dielectric fluid approach, divided Cu electrode before each experiment, expected results have been reached as follow. Almost free of debris surface roughness was obtained with the pulse off time 7 µs and the pulse on time 5 µs in graphite electrode case.

The graphite electrode used cannot handle well higher peak currents intensity over 10A in fine machining of Titanium alloy (Ti-621/0.8) even if pulse off time used is low, due to his low electrical conductivity compared to High-Quality brass.

Lowering the pulse off time and expecting only to lower SR in the case of graphite is not mandatory as experiment no. 9 was recorded, in which the SR predictive pattern changed dramatically.

In the machining process of finishing with EDM, choosing the 10 µs pulse off time ensures productivity with Cu and C electrodes on Ti-621/0.8 Ti alloy.

The SR predictive pattern on Ti-621/0.8 Ti alloy is applicable only in Cu electrode fine EDM machining.

References

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