Evaluation of WEDM performance characteristics of Inconel 718 with coated and uncoated wires

Luca Watanabe Reolon, Fred Lacerda Amorim*
Pontifical University Catholic of Paraná, Curitiba, PR, Brazil
**lucawreolon@gmail.com*

INTRODUCTION

Nickel-based superalloys are high thermal and mechanical resistant materials widely used in chemical, energy and aerospace industries, using Inconel (IN 718) in most of cases, to produce intricate shapes such as turbines and engine components. However, such mechanical properties as high creep resistance and intricate geometries can lead to difficulty in machining.

Wire electrical discharge machining (WEDM) appears as an alternative to conventional machining processes, which normally presents several processing difficulties due to the Inconel mechanical properties. WEDM is controlled by a computational system that allows machining any geometrically complex shapes with high productivity. In WEDM the material removal process is driven by a series of discrete sparks between the workpiece and the wire electrode, generating material erosion [1]. The wire is fed through the workpiece and a dielectric fluid is applied under high pressure. There is no contact between wire and workpiece, eliminating mechanical stresses during machining. A plasma channel is created and promotes high temperatures, about 8000-12000°C. Therefore, WEDM due to its thermal-electric nature of material removal is a process that directly affects workpiece surface integrity including: chemical composition, microhardness, microstructure and topography [2].

Considering the aforementioned arguments, this work aims to evaluate the WEDM machining performance of Inconel 718 under rough cutting conditions, as well as to analyze the morphological characteristics of the recast layer and kerf width by varying machining parameters.

Table 1. Inconel 718 workpiece nominal chemical composition.

Element	Ni	Cr	Mo	Fe	Nb	Co	Mn	Al	Ti
wt.%	53	18.8	3.5	Bal.	6	<1	<0.2	0.7	0.9

EXPERIMENTAL PROCEDURES

The experiments were conducted on a five-axis Robofil 290 Charmilles WEDM machine with deionized water as dielectric fluid. In a IN 718 workpiece rough cuts varying the process parameters were made with 30 mm long straight cuts, spaced 2 mm of each other. Zinc diffused copper wire (CuZn coating, 900 N/mm2 tensile, 1.5% elongation) and uncoated brass wire (CuZn 63/37%, 500 N/mm2 tensile, 20% elongation) electrodes of 0.25 mm diameter were employed. To determine the WEDM process performance, the following variables were analyzed:

- Discharge duration t_e [µs]: the period of time of the current flow through the working gap after breakdown;
- Interval time t_0 [µs]: time between two successive discharges;
- Wire run-off speed W_S [m/min]: velocity of the wire in its longitudinal direction.

The experiments were three times replicated using the process conditions shown in Table 2.

For metallographical studies, samples were sanded successively from 500 to 2400 Grit with Struers SiC sandpapers, and polished with 0.25 µm Al_2O_3. The polished samples were etched with Kallings reagent (2 g CuCl + 40 ml hydrochloric acid +60 ml of 95% ethanol) for approximately 10 minutes to reveal the microstructure. A VEGA3 Tescan scanning electron microscope (SEM) was used to analyze the samples surfaces and to measure kerf width. This device is equipped with an energy-dispersive x-ray detector (EDS) by Oxford Instruments, which was used to analyze the chemical composition.

Table 2. WEDM process parameters used for the experiments.

Parameter	**Level**				
Discharge duration [µs]	0.8	0.9	1.0	1.1	1.2
Interval time [µs]	22	18	14	11	8
Wire run-off speed [m/min]	10	8	6	4	2

RESULTS

Parameters Optimization

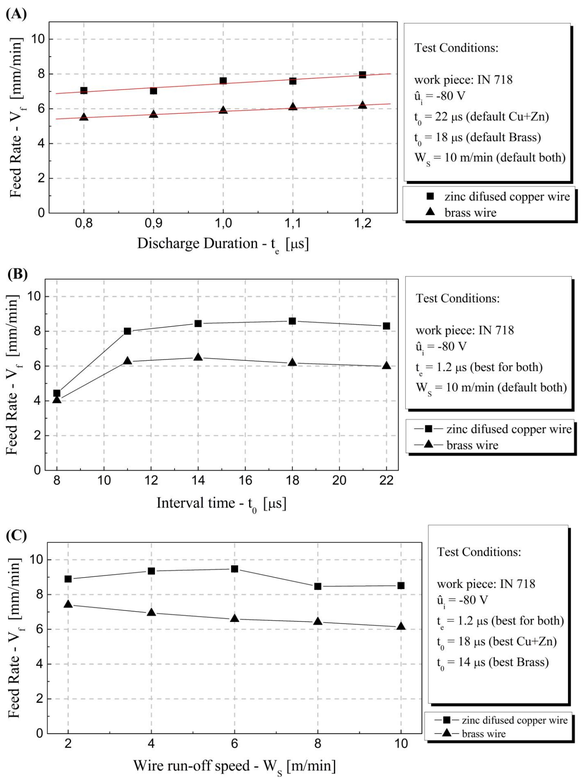

Figure 1. (A) Influence of variation of discharge duration on wire feed rate for uncoated brass and zinc diffused copper wires. (B) Influence of variation of interval time on wire feed rate for both wires. (C) Effect of wire run-off speed on feed rate for both wires.

The results showed in Figure 1 indicate that independently of the process parameters used the best results were obtained for the zinc diffused copper wire. This can be explained because the zinc layer present on copper wire has a lower melting point and much higher vapor pressure. This phenomenon was also observed by Amorim *et al.* [3].

Metallographical Evaluation

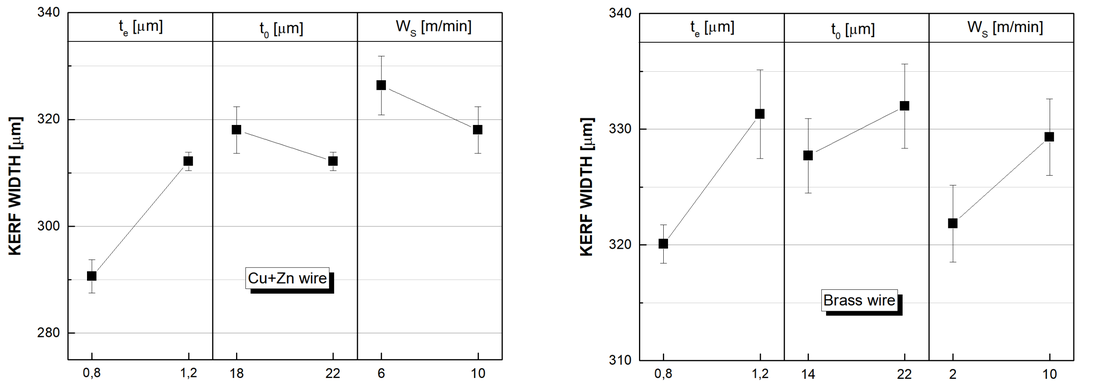

Figure 2. Kerf width for different WEDM process parameters for zinc diffused copper wire and uncoated brass wire.

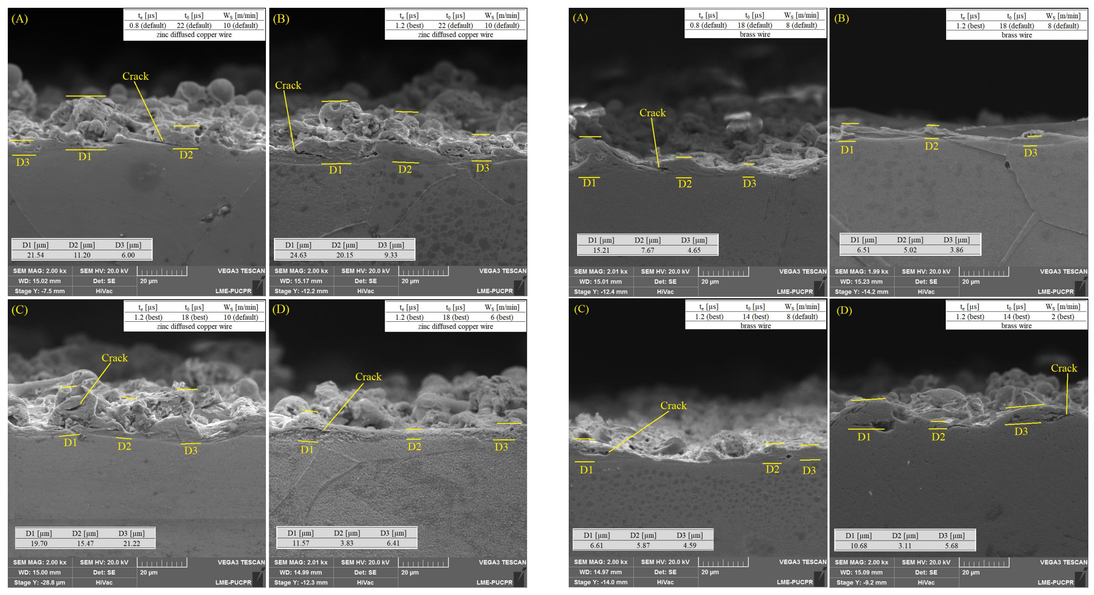

Figure 3. Cross section of different samples machined by zinc diffused copper wire and uncoated brass wire microscopy (SEM) at 2000x magnification.

Chemical Evaluation

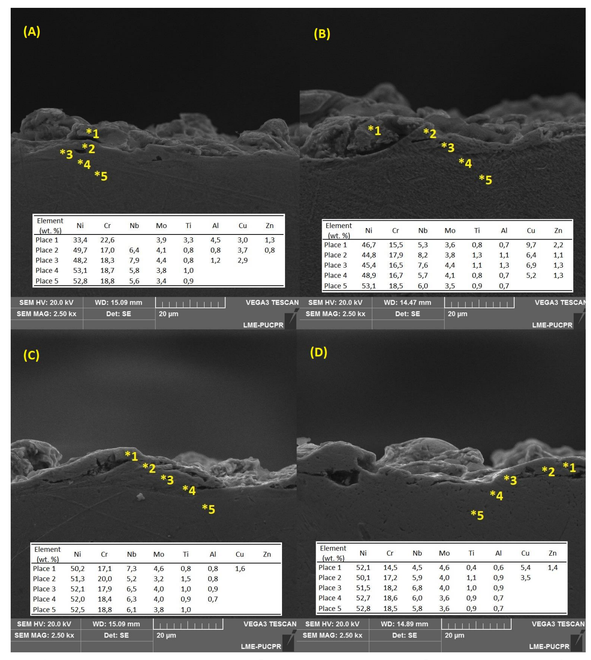

Figure 4. Cross section of microstructure after WEDM and measurements of EDS, SEM 2500x magnification. (A) and (B) machined by Zn diffused Cu wire, (C) and (D) machined by uncoated brass wire.

As can be seen in Figure 2, increasing the value of t_e also increases the kerf width. It is related to the fact that rising t_e a higher amount of energy is delivered to the discharge working gap, which by its turn remove more material of the workpiece, enlarging the kerf for both wires. For t_0 and W_S the results found were opposite comparing the wires. The influence of contamination of the working gap with byproducts, that promotes increase on the number of arcs and short-circuits, resulting unstable process can lead to this opposite behavior dur to different chemical composition. The recast layer was evaluated on Figure 3 and Figure 4.

CONCLUSIONS

In this study, the parametric influence of WEDM on machining IN 718 was investigated using zinc diffused copper wire and uncoated brass wire. From the results the following concludes can be presented:

- By variating the parametric conditions of WEDM its possible to reach a higher feed rate;
- Zinc diffused copper wire presented higher feed rate than uncoated brass wire;
- Increasing the discharge duration t_e also increases the feed rate for both wires;
- There is diffused material of wire in the recast layer of IN 718;
- Cracks were observed on recast layer of WEDM machined surfaces.

REFERENCES

- [1] K. H. Ho, S. T. Newman, S. Rahimifard, and R. D. Allen, "State of the art in wire electrical discharge machining (WEDM)," *Int. J. Mach. Tools Manuf.*, vol. 44, no. 12–13, pp. 1247–1259, 2004.
- [2] K. Mouralova, J. Kovar, L. Klakurkova, and T. Prokes, "Effect of Width of Kerf on Machining Accuracy and Subsurface Layer After WEDM," *J. Mater. Eng. Perform.*, vol. 27, no. 4, pp. 1908–1916, 2018.
- [3] F. Amorim and F. Rempel, "Wire Electrical Discharge Machining Of Thin Ti6Al4V Plates : Rough Machining Assessment," *18th International Congress of Mechanical Engineering.* Ouro Preto, MG Brazil, November 6-11 2005.

AKNOWLEDGMENTS

The author Luca Watanabe Reolon wish to acknowledge Pontifical University Catholic of Paraná for support, especially LAUS and LACEM laboratories. Also Prof. Dr. Paulo Soares and Prof. Dr. Ricardo Torres, Mrs. Luciane Sopchenski Santos and Mrs. Jessica Turola who helped during this research work.