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WIRE ELECTRICAL DISCHARGE MACHINING OF THIN Ti6Al4V PLATES: ROUGH MACHINING ASSESSMENT

Fred AMORIM
Pontifical Catholic University of Paraná – PUCPR – Department of Mechanical Engineering
Rua Imaculada Conceição, 1155 – Prado Velho – 80.215-901 – Curitiba – PR – Brazil
e-mail: fred.amorim@pucpr.br

Fabiano REMPEL
Pontifical Catholic University of Paraná – PUCPR – Department of Mechanical Engineering
Rua Imaculada Conceição, 1155 – Prado Velho – 80.215-901 – Curitiba – PR – Brazil

Abstract. *Wire Electrical Discharge Machining (WEDM) is, nowadays, one of the most important production technologies to manufacture very accurate small parts and tools on any electrical conductive material. Titanium and its alloys have been widely used in automobile and aerospace industry and in medical engineering field. This material has advantageous characteristics such as low specific density and mechanical strength similar to that of steel as well as good heat and corrosion-resistance. However, small parts and tools with complex geometrical shapes are difficult to be produced on titanium alloys by both conventional and non-conventional machining technologies. In this first research work an experimental investigation on the influences of wire electrode type and electrical variables when WEDM a thin plate of Ti6Al4V alloy has been carried out. Brass and zinc-coated copper wires were used in rough machining. Interval time, wire run-off speed, discharge duration and dielectric inlet pressure were investigated in order to get adequate process parameter settings. As presented in the paper, the best results for all tested WEDM parameters were attained with zinc-coated copper wire electrode.*

Keywords*: Wire EDM, Ti6Al4V alloy, rough parameter settings.*

1. Introduction

Titanium and its alloys have low specific density and mechanical strength much similar to that of steel. In fact, the ratio between strength and density of titanium alloys is the highest among the metallic materials. This material also has significant characteristics such as good heat and corrosion resistance. For such reasons, for many years titanium and its alloys have been widely used in aerospace and automobile industries. In automobile industry special grades of titanium are used in brakes and exhaust systems. It has also important applications in medical engineering field, because of its high biocompatibility. In this case, examples include joint replacement parts for hip, knee, spine, dental implants, surgical instruments etc, as reported by Deutsch Titan (2004).

However, according to Zhao *et al.* (2002) manufacturing small and deep geometrical shapes onto titanium-based alloys are very difficult by the majority of conventional machining processes. The stiffness of the cutting tool, removal of chips and tool cooling are common problems in conventional machining. It is due to titanium alloys' low thermal conductivity and toughness, as informed by Znidarsic & Junkar (1996).

Recent years have seen that miniaturization has become an increasing demand by a wide variety of industrial products (Taniguchi, 1983). Miniaturized components are a trend in many daily applications such as cameras, watches, audio and video equipment etc. In the case of aerospace engineering very small components machined on special alloys, such as titanium, is a real necessity. Small products can contain more functions in a limited space. Equipment used in medicine such as surgical instruments is another example of miniaturization trend, as well as titanium alloys replacement parts for the human body. However, high precision manufacturing processes are required to accomplish these too sophisticated tasks, e.g. components smaller than 0,5 mm in size, as reported by Masuzawa (2001).

Masuzawa (2000) also states that there are many technologies that can be used to produce small components, because the necessary conditions to machine such parts are very small material removal rate and high precision. At this point can be included electrical discharge machining (EDM), ultrasonic machining (USM), laser beam machining (LBM), ion beam machining (IBM), electron beam machining (EBM) and electrochemical machining (ECM), as expressed in some research works (Snoeys *et al* 1986, Masuzawa, 1991). Each one of those manufacturing processes has its own technical and cost restrictions.

Nevertheless, as remarked by Klocke *et al.* (2004) some WEDM technological constraints are mainly related to the following essential topics: working accuracy, wire electrode material, type of dielectric and its properties and WEDM parameter settings concerning the main and trim cuts for each different work piece material.

In this first work the major objective is the general assessment of rough WEDM performance when cutting a thin Ti6Al4V plate using conventional brass and zinc-coated copper wire electrodes. In addition to this first work, a more extensive research is expected to begin at PUCPR (Curitiba, Brasil) using thinner wires of different types on a conventional WEDM machine. The primary aim is to reach high surface quality, small corner radius and accuracy when WEDM thin walls in small thickness Ti6Al4V plates.

2. Experimental Procedures

The experimental tests were accomplished on a Charmilles Robofil 290 CNC conventional WEDM machine. Brass and zinc-coated copper wire electrodes with 0,25 mm diameter value were used. The following variables were investigated:

- Interval time t_o [µs]: the time between two successive voltage pulses;
- Wire run-off speed W_s [m/min]: This represents the velocity of the wire in its longitudinal direction. The continued wire run-off motion is necessary to compensate the erosion wear.
- Discharge duration t_e [µs]: the period of time of the current flow through the working gap after breakdown.
- Dielectric inlet pressure p_{in} [bar]: the pressure of the dielectric fluid pumped into the working gap through the upper and lower nozzles of the machine heads.

Figure 1 depicts the roots of a wire EDM operation. The work piece material is fixed on the machine table while the wire electrode moves according to a programmed path producing the contour of the work piece. In modern CNC WEDM machines five axes can be programmed to be simultaneously moved (X, Y, U, V, Z). The contour of the work piece is normally produced by one main or rough cut, followed by a sequence of two or more trim cuts. The trim cuts are employed in order to approach or reach the final accuracy and surface quality of the work piece.

In this work, the above process parameters were varied to analyze their influences on the wire feed rate V_f [mm/min] for a rough WEDM regime. For each one of the parameter settings three tests were executed. 20 mm long straight rough cuts, spaced of 2 mm from each other, were made into a 1 mm thick Ti6Al4V plate. De-ionized water (15 µS) was used as dielectric fluid for all the experiments. The wire pre-tensioning force F_d = 10 N was applied to the wire between the brake pulley and the feeding pulley to compensate the wire deflection caused by process forces.

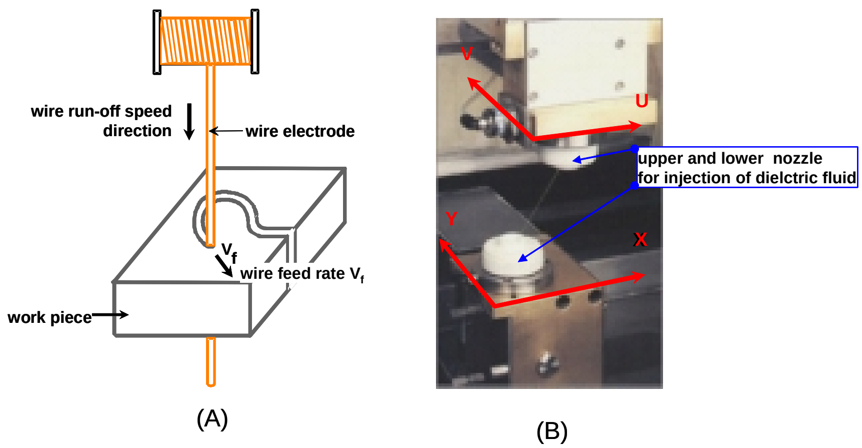

Figure 1. (A) schematic picture of a WEDM operation method and (B) WEDMachine depicting the nozzles to inject the de-ionized water dielectric, by Amorim & Teixeira (2005).

3. Results

The major objective of a wire EDM main cut is to promote high material removal rate [mm^2/min] or high wire feed rate V_f [mm/min] with the wire eroding through its full diameter. According to Prohaszka *et. al*. (1997) the ideal wire electrode must have three important characteristics: high electrical conductivity, sufficient mechanical strength and to be able to promote optimum spark formation and flushing conditions. Nevertheless, the electrical variables are also very important for WEDM performance. Figure 2 presents the influence of interval time t_o on the wire feed rate $V_{f..}$

For the zinc-coated copper wire it can be seen a considerable increase of V_f when the interval time t_o is reduced from 24,8 µs to 13,2 µs, that represents the best value of $t_{o.}$ The reduction of t_o has promoted higher values of V_f because the pulse cycle period was reduced, therefore increasing the discharge frequencies while adequate WEDM stability was maintained, i.e, not much occurrences of short-circuits and arc-discharges. The maximum feed rate of about V_f = 44 mm/min was reached.

When WEDM with brass wire a similar behavior can be noticed, but the intensity of the influence of t_o in V_f is not the same as that of zinc-coated copper. For brass wire the best interval time (t_o = 13,2 µs) promoted 23 mm/min of feed rate value, much lower than that of coated copper wire.

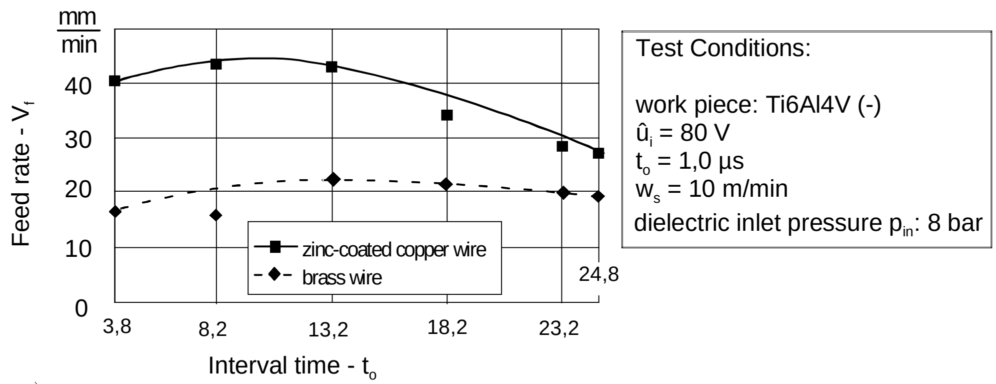

Figure 2. Influence of the variation of interval time t_o on wire feed rate V_f for brass and zinc-coated copper wires.

Prohaszka *et. al*. (1997) also points out that the first commercial wire electrodes were made of uncoated copper because the experience on Die-Sinking EDM. However, copper wears very rapidly under the WEDM electro-thermal conditions and its tension ability is rather poor, resulting in machining instabilities due to a high degree of short-circuits and arc-discharges. Copper also has inconveniences such as high melting point and low vapor pressure rating that contribute to lower the performance of WEDM operations. Later in the early 70's the development of brass alloy wires (63 % Cu, 37 % Zn) with higher tensile strength improved the cutting speed. The addition of zinc also provided a lower melting point and a higher vapor pressure rating to the wire, resulting in cutting speed better than those of uncoated copper wires. However, brass alloy cannot be manufactured with higher values of zinc.

As reported by Convers & Balley (1981), in order to avoid the shortcomings of the aforementioned wires and to rather increase speed and accuracy, coated wire electrodes were introduced in the WEDM market. These wires are normally composed of a brass or copper core that is coated with zinc or ZnO layer of 20 to 30 µm thickness. The coating layer has a much higher vapor pressure rating and a melting point lower than the wire core material. So, when the pulse voltage is applied across the working gap the wire coating is overheated and then evaporated. This phenomenon makes the ionization channel to be faster created. The working gap size also increases, promoting better flushing conditions. The end results are higher cutting speeds and cutting precision when WEDM with coated wires. The above discussion explains the extra improvement performance of zinc-coated copper wire in comparison to uncoated brass wire used in experiments of this work.

Figure 3 shows the variation of wire run-off speed W_s on the results of wire feed rate V_f [mm/min]. In general, for both wire electrodes is clearly seen that W_s (varying from 4 to 10 mm/min) exerts just a few influence on the V_f values. For W_s = 2 mm/min the WEDM process presented some instability, promoting the wire break sometimes. In order to reduce the consumption of wire and to keep a stable machining it is recommended to set W_s = 4 m/min when WEDM thin plates of Ti6Al4V.

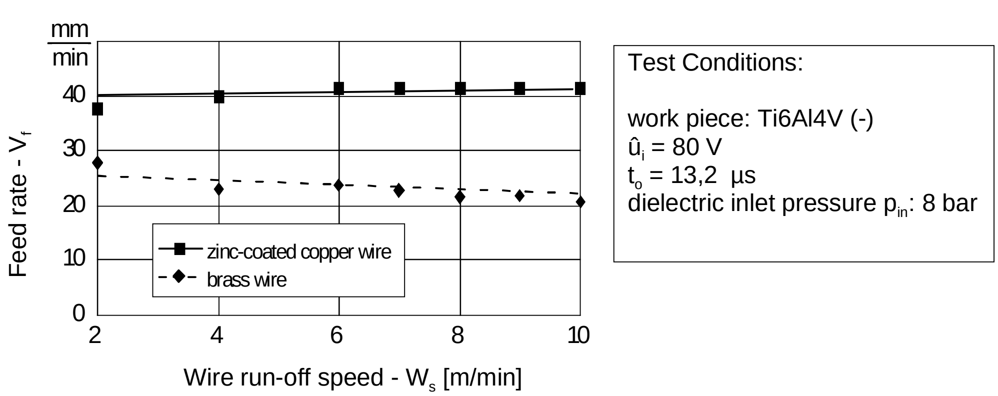

Figure 3. The influence of wire run-off speed W_s on the wire feed rate V_f for brass and zinc-coated copper wires.

The energy ($W_e = u_e . i_e . t_e$ [J]) supplied in the working gap has large influence on the wire feed rate V_f [mm/min] through the contour of the work piece material. The higher W_e the higher V_f. Figure 4 presents the results on the variation of discharge duration t_e over the results of V_f. For both wires the increase of t_e promoted enhanced WEDM performance. Superior values of t_e means that more material will be molten and evaporated in the work piece, yielding better material removal at the end of pulse. The better results for coated copper wire in relation to uncoated brass wire were already explained previously. The optimum discharge duration t_e for both wires is 1,1 µs which promoted the best wire feed rate. Rising the value of t_e beyond 1,1 µs would probably cause the wire break because positive ions from the work piece would erode the wire excessively.

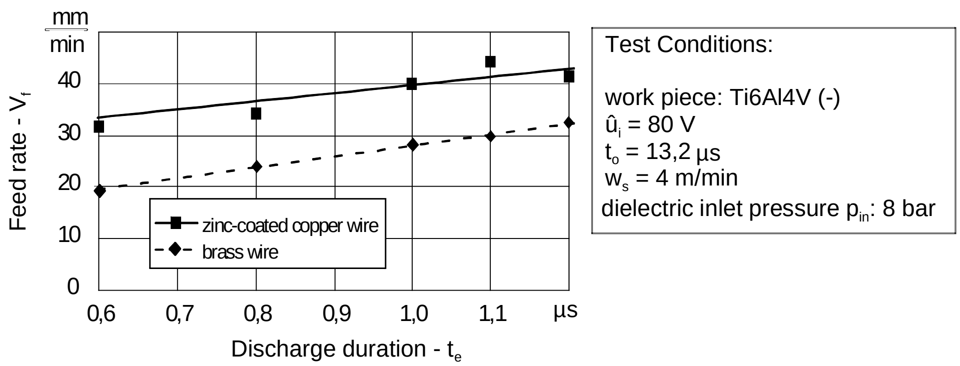

Figure 4. The influence of discharge duration t_e on the wire feed rate V_f for brass and zinc-coated copper wires.

The dielectric fluid is responsible for cooling the wire and work piece, flushing the eroded particles away from the working gap and concentrates the plasma energy. Figure 5 illustrates the influence of the dielectric inlet pressure on the wire feed rate. Tests were carried out from no-pressure flushing to 8 bar pressure flushing. With no-pressure flushing the feed rate is quite slow because the eroded particles are not properly expulsed from the gap. It has occasionally caused wire break and in many times short-circuits, decreasing the V_f values. On the other hand, the use of high pressure (8 bar) flushing is not recommended because deflection of the thin plate can occur at some point in WEDMachining. Further research will be carried out on this influence. However, as regards the present work the authors recommend 3,5 bar dielectric inlet pressure.

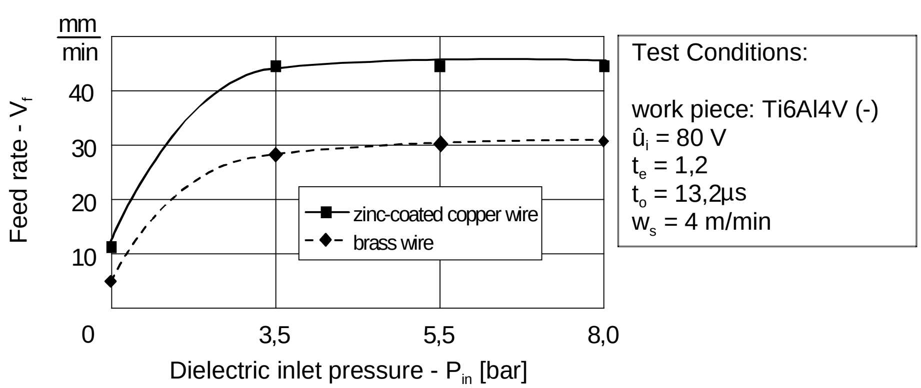

Figure 5. The influence of dielectric inlet pressure P_{in} on the wire feed rate V_f for brass and zinc-coated copper wires.

4. Conclusions

This work has investigated the influence of some electrical variables and wire electrode type on the rough WEDM performance of thin Ti6Al4V plates. From the results and discussions the following conclusions can be summarized:

(a) Zinc-coated copper wire electrodes promoted the best results on the wire feed rate $V_{f.}$ [mm/min]

(b)The wire run-off speed W_s exerts just little influence on V_f when WEDM thin plate of Ti6Al4V. It is recommended to WEDM with W_s = 4 m/min in order to reduce the consumption of wire while providing good process stability.

(c) The increase of discharge duration t_e increases the wire feed rate V_f. The best results for both wire were achieved for t_e = 1,1 µs.

(d) The optimum interval time t_o = 13,2 µs provided the highest wire feed rate V_f for both wire electrodes.

(e) The dielectric inlet pressure P_{in} = 3,5 bar is recommended for good flushing conditions. Future research will be developed on its influence over the thin plate's deflection.

5 Acknowledgements

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6. References

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