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Research into EDM of Beryllium Foil

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Abstract. This paper concerns with a machining experiment on the beryllium sample by electrical discharge machining (EDM), and the experiment proves the machinability in beryllium foil machining of EDM. A brass electrode was chosen for the machining, and the relationship between the tool wear and the process condition was revealed. By the alternation of the positive polarity machining and the negative polarity machining, the tool wear caused by electric erosion was furthest controlled. The foil with a thickness of (0.05~0.06) mm was achieved, and the R_a of (0.18~0.20) μm and the P-V value of 0.78 μm were measured through white-light interference.

1. Introduction

As one kind of rare metal material, beryllium is acknowledged as 'the material of space era' and plays unsubstitutable role in inertia navigation, nuclear reactor, spaceflight, et al owing to its outstanding intrinsic material properties (shown in Table 1) [1]. Nevertheless, because of the high rigidity and the brittleness, conventional machining technologies including turning and milling are approaching poor machining with cracks and rupture (see Fig. 1) [2].

Table 1 The structural properties of Be

Material	Young's modulus （GPa）	Density （g/cm^3）	Thermal expansion coefficient （$10^{-6}/K$）
Be	300	1.84	11.5

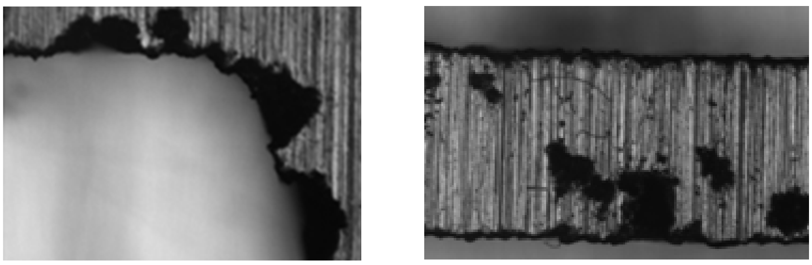

Figure l Cracks of Be in conventional machining process

Electrical discharge machining (EDM) is one of the non-conventional machining processes during which the tool and workpiece do not contact each other during the whole process. When the voltage approaches a critical value between the tool electrode and workpiece, a breakdown of the dielectric medium occurs. In this process, numerous electrons move toward the anode and break the dielectric fluid molecules into positive ions and electrons, causing an enormous increase in the electric field strength across the work surface [3]. Therefore, an ionized channel will be created and cause an electrical discharge in the narrowest positions between the tool and the workpiece. The thermal energy is highly enough to melt and vaporize the material from the workpiece, as a result, the material is wiped off by many small craters benefits with uncontact, stressless and flexibility [4] (as seen in Fig. 2).

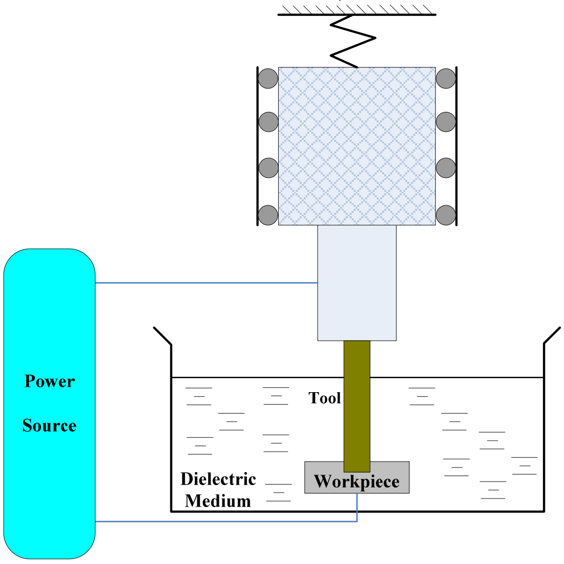

Figure 2 The simplified EDM mechanism

Hence, The present study was carried out from two aspects: (1) For the sake of machining faculty and limit of the EDM process of beryllium workpiece, a 0.05-mm-thick beryllium foil (about 10mm×4mm) was fabricated by EDM; (2) the tool wear, metamorphic layer, surface roughness, and machining precision were analyzed in detail to systematically investigate the relationship between the machining quality and preference of parameters.

2. Experiments

2.1. Equipments

A FORM 1000 electric spark machine (Agie-Charmilles) with the positioning accuracy less than 1μm was utilized as the main machining equipment (Fig. 3). In addition, a metallurgical microscope equipped with video system was used for optical micrographics of the samples.

Figure 3 The FORM 1000 electric spark machine

2.2. Samples & electrode

The beryllium samples, with the grade of RJY40 (optical and instrumental) and the diameter of 20 mm, were firstly machined by precision turning. After the preform machining, the thickness of the wafer-shaped beryllium foil was control to be 0.80 mm to avoid plane warp, thus a machining allowance of about 0.75 mm was left for the subsequent electrical discharge machining. Furthermore,

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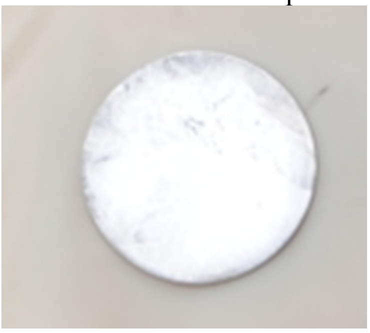
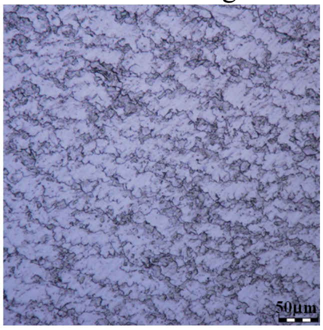
a brass electrode, which had two obtuse angles in side elevation to avoid tool wear caused by electrode melting, was chosen as the tool. The sample and the electrode are shown in Fig. 4.



(a) the sample



(b) micro-morphology of the sample surface

(c) the brass electrode

Figure 4 The beryllium sample & the brass electrode

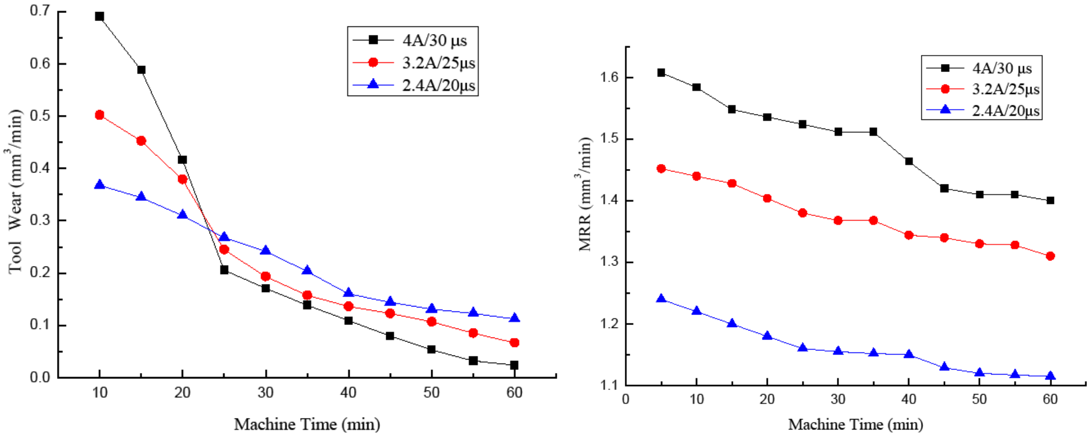
2.3. *Experiments*

Electrical discharge machining (EDM) is uncontact and stressless, there is almost no cutting force exerting on the workpiece. Thus, it is convenient for fixing the sample on a plane surface by epoxy resin glue. Notably, the glue must be coated along the margin carefully in case of insulation on the bottom of the beryllium sample. In view of the counterpoise between efficiency and surface quality, the mechanic process was divided into the rough machining and finish machining.

2.3.1. EDM conditions in rough machining

Because more than 90% machining allowance was taken out by the rough machining, the efficiency and the electrode tool wear control were preferentially considered as the main factors in the process [5]. In the roughing regime, it was critical to guarantee the precision by decreasing tool wear.

The MRR (material removel rate) was introduced and researched in the process. Foremost, the relatively lower machining energy (current intensity (I(A))×on-time (td (ms))) was used for reducing the generation of the virulent gaseous beryllium (See Fig. 5). Furthermore, tool wear was enhanced along with the increasing machining energy, therefore, the negative polarity, meaning that the sample was connected with the cathode, was chosen to prevent the electrode tool from being worn. In the experiment, when the machining energy was intensive enough, the sample surface appeared to be covered with a black layer caused by hydrocarbon oil decomposing. This black layer was composed of carbon and decreased the tool wear radically[6]. The results obtained for the tool wear and the MRR when using negative polarity are plotted in Fig. 5 as a function of machine time.



(a)the tool wear (b) the MRR

Figure 5 The tool wear and the MRR obtained for roughing regime

The Figure. 5(a) demonstrates that the electrode wore severely at the beginning of the discharging, then slowed down sharply after about (15~25) mins. The reason of this phenomenon comes from two aspects: the first is the shape of the electrode tool. Properly speaking, the interelectrode electric field aroused collision ionization, the ions rushed at the sharpness margin of the electrode tool in advance, causing the rapid fringe melting of the electrode within 20 mins. Moreover, the high temperature decompounded the hydrocarbon oil since the discharging began, then the black carbon layer grew thick enough in less than 25 mins, preventing further electrode tool from melting down. Ultimately, under the shield of the protective layer, the tool wear turned slower as the process continued. Notably, the higher the machining energy was, the faster the tool wear rate descended.

The homologous trend came from the MRR of the sample, and the MRR slowed down as the machine process carried on. Comparing with the tool wear, the difference could be manifest among the decline process which was slower than tool wear. The reason for this phenomenon is that only a few of carbon was sedimented on the sample surface acting as the positive polarity [7]. As the growth of the carbon layer continued, it became thick and cavitary inside, depressing the electrode conductivity and the ions moving[8]. Finally, the MRR reduced prominently at the end of the discharging (Fig.5(b)).

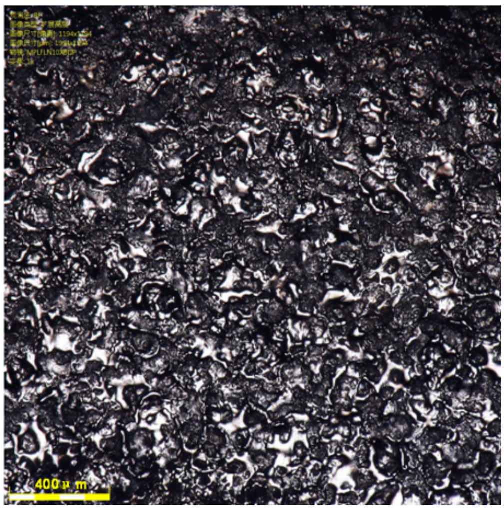


Figure 6 The beryllium sample surface after rough machining

The micrograph of the beryllium sample surface after rough machining is shown in Fig. 6. As can be seen, the black and hollow area is full of carbon granules which restrained the material removel from the beryllium sample. Although the carbon granules could not be washed off by insulating oil, in the experiment the samples were rinsed out to reveal machining surface using ultrasonic.

2.3.2.EDM conditions in finish machining

With the ultrasonic technology, a clean metallic surface with a roughness of R_a =5.8 μm was obtained after rough machining (3.2A×25μs). Before the finish machining, there was still about (0.05~0.06)mm machining allowance left to be removed. To guarantee the precision of the finish surface, the tool wear should be controlled as least as possible.

As the beryllium sample with the crystalline grain size of about (5~10) μm was made from powder metallurgy, it was inclined to perform the intergranular fracture during the machining process. Finally, the finish machining was carried out by the following two steps:

1) To avoid the tool wear, the finish machining (discharging parameter: 2.0A×25μs) was performed in the negative polarity until the machining allowance was less than (0.03~0.04) mm. In particular, a durative on-line machining allowance inspection was put up in case of feedrate distortion caused by electrode wear.

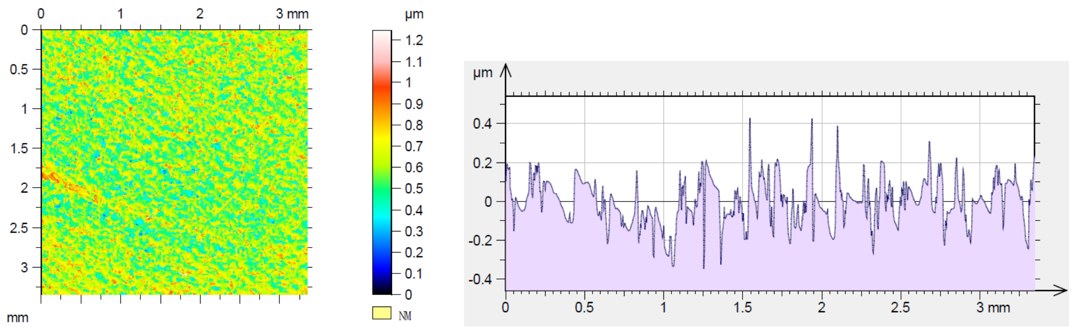
2) A new electrode and the new discharge parameter (1.5A×20μs) were used in the following step. In this step, the positive polarity mode was preferable for a slower tool wear rate. Due to the high-tension point discharge, the peak area of sample was removed prior to the bottom area.

Figure 7 The beryllium sample surface after finish machining

The finish machining surface of beryllium sample is shown in Fig. 7. Comparing with the surface of rough machining in the same scale (Fig. 6), the former one is much more refined in surface roughness and surface accuracy. Meanwhile, the relatively lower machining parameters caused fewer carbon granules, and a polished-like surface was achieved after ultrasonic cleaning.

2.4. Results and discussion

A measurement of surface roughness based on white-light interference was performed. Fig. 8 shows a white-light interference image for the R_a of (0.18~0.20)μm and the *P-V* value of 0.78μm within the approximately 3mm×3mm area on the sample surface.



(a) the surface roughness (b) the surface accuracy

Figure 8 The surface roughness & the surface accuracy based on white-light interference

Furthermore, the cross-sectional microstructure of the thin film with a thickness of about (0.05~0.06)mm is shown in Fig. 9 showing only one or two layers of grains. After ultrasonic cleaning, the EDM denatured layer could be hardly detected, the finish machining surface of the flat part was considerably smooth.

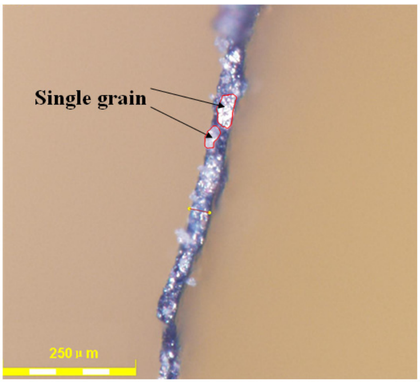


Figure 9 The cross-sectional microstructure of the sample surface.

3. Conclusions

The following conclusions are summarized from the EDM experiments operated on the wafer-shaped beryllium foil:

1) The EDM process was proved to be machinable in beryllium foil machining. The parameters including the thickness of about (0.05~0.06)mm, the R_a of (0.18~0.20)μm and the *P-V* value of 0.78μm within a 3mm×3mm area on the foil sample surface was achieved, even though the individual grain size could be as large as about 5μm.

2) The negative polarity should be used for rough machining to prevent the tool from being worn acutely. Moreover, the positive polarity was chosen for finish machining to smooth the surface.

3) The tool wear ratio appeared to increased along with the machining energy, but sharply decreased with the machining time because the black carbon layer sedimented on its surface. Meanwhile, the black layer could also slow down the MRR for the same reason.

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