Annals of DAAAM for 2011 & Proceedings of the 22nd International DAAAM Symposium, Volume 22, No. 1, ISSN 1726-9679
ISBN 978-3-901509-83-4, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2011
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Annals & Proceedings of DAAAM International 2011

ELECTROCHEMICAL MICROMACHINING OF TUNGSTEN

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Abstract: *The tendency to make progressively smaller and increasingly complex products is no longer an exclusive demand of the electronics industry. Many fields such as medicine, biomechanical technology, the automotive and the aviation industries are searching for tools and methods to realize micro and nanostructures in various materials. The micro-structuring of very hard materials, like carbides or brittle-hard materials, pose a particularly major challenge for manufacturing technology. For these reasonns the Institute for Production Engineering and Laser Technology of the Vienna University of Technology is working in the field of electrochemical micromachining with ultra short pulses. With the theoretical resolution of 10 nm, this technology enables high precision manufacturing. [Kock M.]*

Keywords: *micromachining, electrochemical, precision, finishing*

1. INTRODUCTION

The ECM process is an electrochemical manufacturing method where an opposing electric voltage for the work piece and the tool is used. So it is possible to machine the tool and the work piece just through a software change to the pulse generator without any set-up time. Only the electrolyte has to be changed to match the material which is to be machined. If it is necessary for a project to machine the tool and the work piece, the simplest way would be to use the same material for the tool and the work piece. The refractory metal, tungsten for example, has very interesting characteristics for the use as tool and work piece material in the process of electrochemical micromachining technologies.

1.1 Characteristics of tungsten

Density:	19.3 g/cm³
Melting point:	3695 °K
Young's modulus:	411 GPa
Strength:	2 GPa
Hardness (Mohs):	7.5

The Young's modulus of tungsten is around twice as high as that of steel, which is an advantage for the stiffness of the parts and allows the products to be produced in a smaller size. Also, the possibility to take the caustic metallic base, sodium hydroxide (NaOH), which is a common and well established base in industry, for the processing electrolyte is another advantage of tungsten. The so produced electrolyte for the manufacturing process would be minimally hazardous and easily available; so far it is a preferable substance for the experimental and industrial use. The lye concentration of 2M NaOH assures a good ratio between machining time and structure precision for most experiments. If the concentration was higher the precision will decrease and the ablation rate will increase; for a less concentrated electrolyte the effects are vice versa.

2. ELECTROCHEMICAL MICROMACHINING OF TUNGSTEN IN 2M NAOH

Due to tungsten's characteristics it is the preferable material in micro manufacturing for products with structural requirements. For example, at the IFT, tungsten is used for the engineering of very small styluses used for high precision measuring machines like a Zeiss F25 coordinate measuring machine. These styluses, with diameters of less than 100 µm, are machined by electrochemical micromachining with a tungsten tool from a tungsten work piece. The problem in having the same material for the tool and the work piece is that generally the electrolyte which is adapted to the work piece material is also able to react with the tool. So it is possible that in some ranges of the different electrochemical parameters, for example the voltage at the tool, the tool dissolves during manufacturing; now the process would experience a kind of wear. With other pairings, for example non-corroding steel as tool material, tungsten as work piece material and NaOH as electrolyte, there is chemically no possibility for any unwanted dissolution. In some cases it is necessary to manufacture the tool and the work piece in the same electrolyte without any time delays.

Figure 1 shows the results of incorrectly choosing the electrochemical parameters. The voltage at the tool should be set so that the tool experiences no wear and that there is no traditional electrochemical ablation through a polarization of the work piece caused by the voltage at the tool. The pictures in Figure 1 show two different tools with diameters of 250 µm. The tool in the left picture has no kind of wear. The right picture shows a tool with wear through a positive tool voltage. The resulting chamfer has the dimensions of 42 x 34 µm after milling a grove with a length of 1000 µm and a depth of 40 µm. With this information it would appear that by setting the voltage at the tool to the negative extreme, it would be possible to avoid that dissolution at the tool, but there is another aspect which narrows the negative range of the voltage. If the voltage at the tool is, for example, -500 mV you might not have wear at the tool but the tool will positively polarize the work piece. If this local polarization is large enough to superimpose the cathodic protective effect, some unwanted dissolution could again appear.

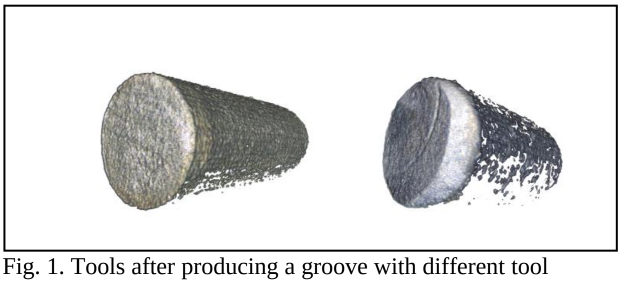

Fig. 1. Tools after producing a groove with different tool voltages Measured with an Alicona Infinite Focus 4G

This time though, the work piece would suffer and traditional problems of electrochemical machining like a strong edge rounding would be witnessed. Another reason again for setting the voltage at the tool very negative is that the dissolved and positive ions coming from the work piece may attach to the tool. So the tool geometry will change, which is undesirable in regard to the manufacturing precision of the process. There is a specific range in which the voltage at the tool has to be set within. In general, this range depends on the materials to be used, the electrolyte and the concentration of the electrolyte. For tungsten in 2M NaOH the voltage at the tool should be between -200 and 100 mV.

Another phenomenon of traditional electrochemical machining technologies is that of conical shaped flanks after, for example, drilling of a hole. To solve this problem there are a number of different strategies. One possible solution to this problem is to change the form the tool from a simple cylinder to a tool with a thin shaft and a disc at the end. That leads to a longer distance between the shaft of the tool and the work piece so that only the disc surface of the tool is near enough to recharge the electrochemical double layer formed at the work piece. Such tool geometry is used for better localization of the ablation of drilling processes. Another possibility to solve this problem is to separate the drilling process in a strong dissolving and a slight dissolving process. This is possible through different parameter sets and does not need any preparation time at the machine. The finishing part of the process could have amplitude of 2200 mV and a pulse width of 80 ns instead of 2800 mV and 200 ns for the basic part. With this strategy it is possible to outperform the single cycle process with just one parameter set in case of machining precision. Experiments with such a strategy have shown, for example, that the edge rounding decreases to lower than 4 µm and the roughness of the produced surfaces is about Ra 0.06.

Figure 2 shows the effect of the dwelling time during the process. In this experiment a tool with a diameter of 250 µm was positioned 1 µm over the work piece surface. The voltage of the tool was -100 mV, the amplitude of the pulse was 2800 mV and the pulse width was 200 ns. There are eight stop positions visible. On each position from the left to the right end the dwelling time was doubled from 5 s at the first position to 640 s at the last position. With the maximum depth of -7 µm after the dwelling time of 640 seconds this experiment confirmed the relevance of the dwelling time for the manufactured geometry. That is one of the effects, which has to be controlled for an industrial use of the ECM technology.

The most important parametrical relationship in the use of electrochemical micromachining is that between amplitude, pulse width and working gap. [Hamann C: H:] The energy for the process is the integral over the amplitude and the pulse width. Increased energy in the double layer at the work piece leads to a rougher, more powerful process. In this case the appeared working gap is large and the precision of the process is no advantage for the ECM technology. The size of the working gap is the most important benchmark for the precision of the parts and in creating sharp edged geometry.

The working gap for tungsten manufacturing with a cylindrical tool and a diameter of 75 µm in the electrolyte with

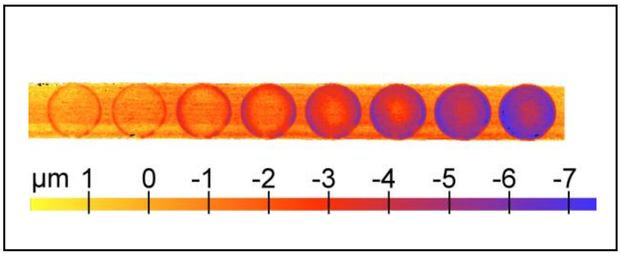

Fig. 2. Effect between dwelling time and material ablation

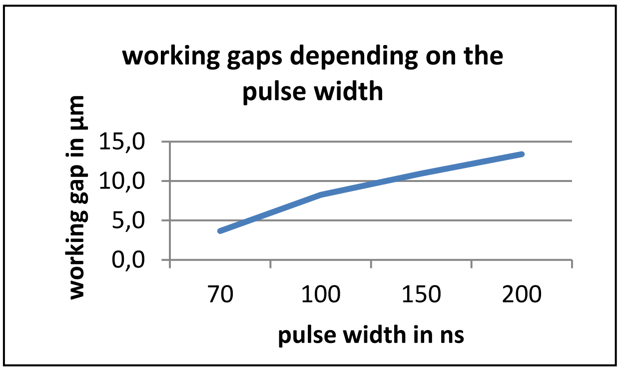

Fig. 3. working gap depending on the pulse width at a pulse amplitude of 2750 mV for a tool with 75 µm diameter in 2M NaOH

2M NaOH, has a range from 2 to over 30 µm. In Figure 3, the graph of the working gap for a pulse amplitude of 2750 mV and a pulse width from 70 to 200 ns is shown. This process would be a rather more dissolving one. If the precision requirements of the product are not met a finishing cycle could help. The finishing with an amplitude of 2200 to 2500 mV and a low pulse width under 100 ns would create a sharper structure.

3. CONCLUSION

The technology of electrochemical micromachining with ultra short pulses has successful displayed the many applications especially for prototype building or for the manufacturing of special products where there is no other technology which can combine a very high precision without any mechanical forces or thermal influences. [Kirchner V.] The characteristics of tungsten are very positive for many micro and nano sized parts and the wider range of application in high end products is foreseeable. Also the application of tungsten for both, the tool and the work piece has positive aspects especially for the use in industry. The occurring electrochemical problems are tradable and a further topic for the Institute of Production Engineering and Laser Technology, as well as the micromachining of many other materials like nickel or non-corroding steels.

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