MACHINING OF HIGHLY ORIENTED PYROLITIC GRAPHITE USING WEDM AND THE RESULTING QUALITY OF THE SURFACE

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Highly oriented pyrolytic graphite is a material usually made for specific dimensions, however sometimes the need for altering them may arise. For this reason, it is necessary to choose a suitable technology for machining the material. This study deals with machining a part of highly oriented pyrolytic graphite using wire electrical discharge machining (WEDM). The morphology of the cut and the whole part was then evaluated using both electron and optical microscopy, including microanalysis of chemical composition (EDX). Subsequently, any significant delamination of the surface was studied, with several places differently colored than the rest of the surface.

KEYWORDS

WEDM, electrical discharge machining, highly oriented pyrolytic graphite, quality of surface, Analysis of the chemical composition, HOPG, EDX

1 INTRODUCTION

Wire electrical discharge machining (WEDM), is a nonconventional method of machining, which unlike conventional methods doesn't use mechanical work to remove the material, but electrical energy in form of electrical discharges between two electrodes (wire-workpiece). The principal and schema of the process is shown in Fig. 1. WEDM is a technological process, where the removal of material is achieved by periodically repeated electrical discharges in the presence of dielectric**.** The material is removed by evaporation and melting in the form of globule of debris and then swept away by the dielectric**.** It is possible to work any material that is at least a little conductive [Grote 2009, Jameson 2001].

There are many factors that can significantly affect the quality of the machined material and those can be found using various methods [Matoušek 2009], [Matousek 2010], [Blecha 2011a], [Blecha 2011b]. Even though the settings of the machine are a significant factor, it is primarily the material characteristics of the machined sample that define the resulting quality of the surface. The quality parameters of the surface are influenced by an array of physical and mechanical characteristics of the machined material [Liao 2004].

Highly oriented pyrolytical graphite (HOPG) is a form of graphite belonging to lamellar materials, for his crystallic structure is characterized by the arrangement of carbon atoms in parallel layers [Windholz 1997].

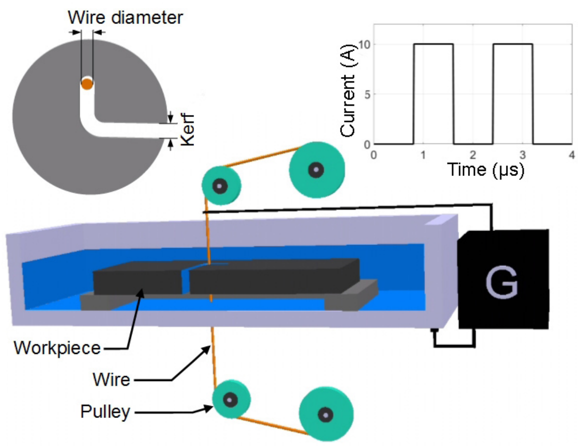

Figure 1. Scheme of the process of wire electrical discharge machining

The sample of highly oriented pyrolytic graphite will be used as a source of carbon atoms in an array used for growth of graphene using molecular epitaxy [Moreau 2010]. The graphene layer made in this manner exhibits the best quality in comparison with other growth methods, for example deposition from gas phase [Henini 2012].

2 EXPERIMENTAL SETUP AND MATERIAL

The sample for the experiment was made from highly oriented pyrolytical graphite. This strange form of graphite is made using chemical vapor deposition (CVD), with the whole process taking place at high temperature 2200 °C, and is based on a reaction of a carbon-rich gas (e.g. methane) with atomic hydrogen in the presence of low amounts of oxygen. HOPG is a polycrystallic material, but its physical properties are close to a monocrystal of graphite. Its usage is significantly limited by the size of the layer which can be made without defects. It usually does not surmount 20 mm, which is why HOPG is mainly used to coat optical cables and coating artificial joint substitutes and heart valves in medicine [Pierson 2012]. The sample used for this experiment had dimensions of 10x10x2 mm, ZYB quality, thickness dispersion ±0.2 mm and was supplied by NT-MDT. It was to be machined into a circle shape with diameter of 9 mm.

The WEDM machine used in this study was high precision five axis CNC machine MAKINO EU64. As electrode, brass wire (60 % Cu and 40 % Zn) PENTA CUT E with a diameter of 0.25 mm was used. Samples were immersed in the deionized water which served as dielectric media and also removed debris in the gap between the wire electrode and workpiece during the process. Parameters of setting machine gap voltage, pulse on time, pulse off time, wire feed and discharge current (Tab. 1) were set up as recommended by the machine producer for graphite material with a thickness of 5 mm. The real cutting speed on the basis of these set parameters being 5 mm/min.

Gap voltage (V)	Pulse on time (μs)	Pulse off time (μs)	Wire feed (m/min)	Discharge current (A)
40	7	66	13	22

Table 1. Machining parameters used in the experiment

3 RESULTS OF EXPERIMENT AND DISCUSSION

The machined surfaces were studied using electron microscope (SEM) LYRA3 supplied by Tescan. This device comes equipped with energy-dispersion detector of X-Rays, which allows for studying the changes in chemical composition of the surface in relation to the WEDM machining. The morphology of the machined surface was studied by light microscopy (LM) using the optical microscope Axio Imager A2m supplied by Zeiss. As a result of an expanding tear in the material, the sample broke into two circle parts circa 1 mm thick. This, however, has not affected the resulting functionality of the parts.

3.1 Analysing the surfaces using SEM

The surface morphology of the sample machined by electro erosion is usually composed of a high number of craters and adhered mixed material from the semi-melted wire electrode and the worked material [Huang 2003, Newton 2009]. But when machined by HOPG, the worked material is not made of craters, but delamination and separation of the WEDM created layer took place, which is observable in Fig. 2. In the process of erosion, the discharge causes evaporation and melting of microscopic particles of the material, which are then swept away by the dielectric from the location of the cut in the form of tiny globule of debris. The quantity of the evaporated and swept material is dependent on multiple factors, those being (apart from others), a set of physical and mechanical properties of the machined material. Only 25 to 75 µm of material gets evaporated from common materials [Kanlayasiri 2007]. In the case of machining pyrolytic graphite, however, evaporation of more than 0.5 mm of material from the diameter of the sample took place.

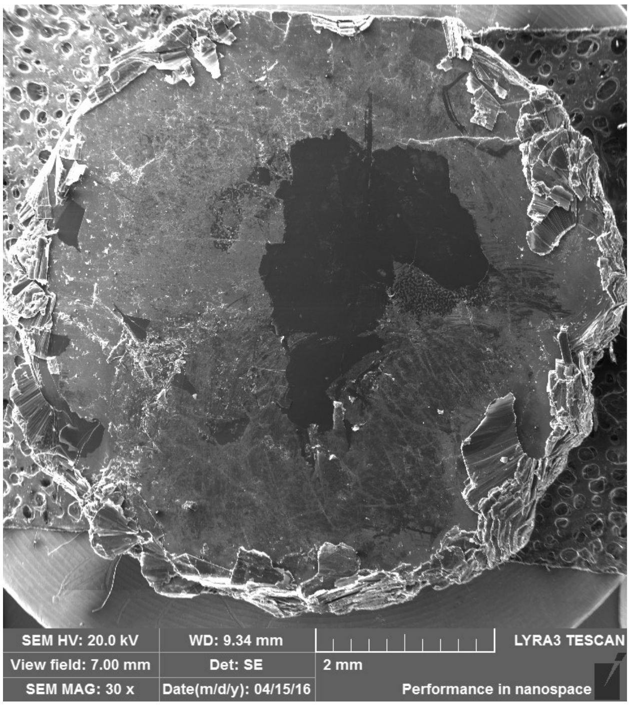

Figure 2. The surface morphology of the entire sample (SEM), 30x magnification

Delamination of the edge after cutting also significantly affected the top, not machined surface of the sample, where local bending of the gouged material took place, observable in Fig. 3.

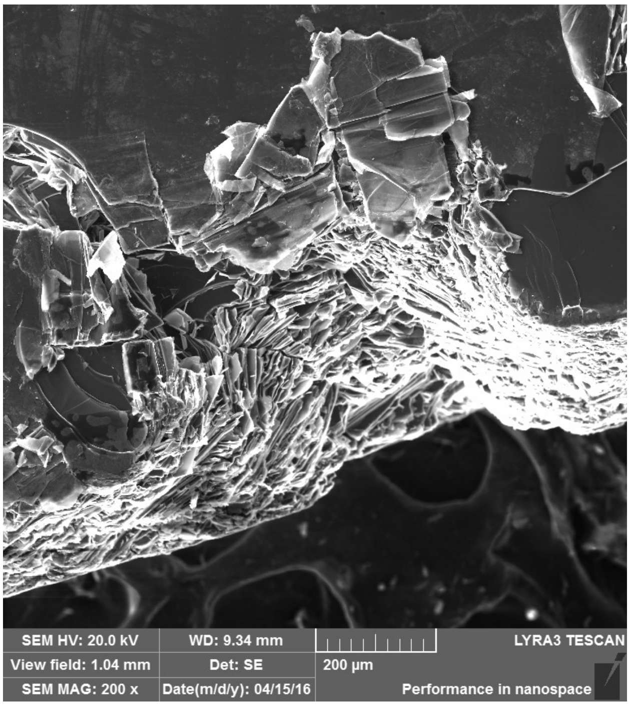

Figure 3. The surface morphology of cut position (SEM), 200x magnification

3.2 EDX microanalysis of chemical composition

Microanalysis of the chemical composition was made for the purpose of observing the intensive difusion actions between the machined material and the wire electrode. This difusion was observed in many materials, such as pure titan [Kumar 2013], stainless steels AISI 440A [Huang 2004], tool alloy steel X210Cr12 [Mouralova 2015] and many more. The local analysis performed on a 1x1.5 mm surface demonstrates that even if difusion between the sample surface and the wire electrode took place, the layer thus created was delaminated and removed from the surface, for no copper or zinc was detected, as shown in Fig. 4 and Table 2. Sodium, detected in amount of 1.4 wt. %, can originate from the anti-corrosive solution commonly added to the dielectric fluid to reduce the oxidation of the worked material during cutting.

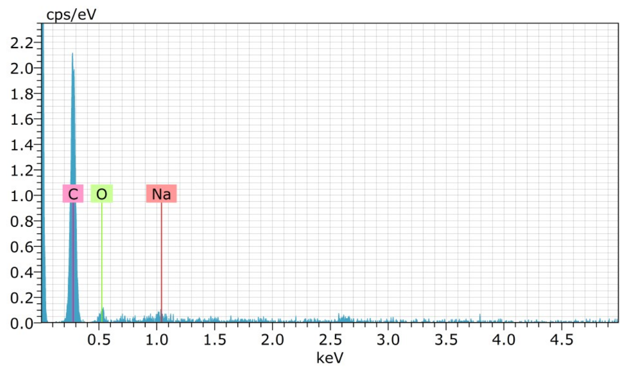

Figure 4. EDX analysis of the machined surface

C (wt%)	O (wt%)	Na (wt%)
89.7	8.9	1.4

Table 2. Measurement of Chemical composition on the workpiece surface

3.3 Surface morphology analysis using light microscopy

The morphology of the surface and its significant delamination in the location of the cut was also studied using light microscopy and is demonstrated in Fig. 5.

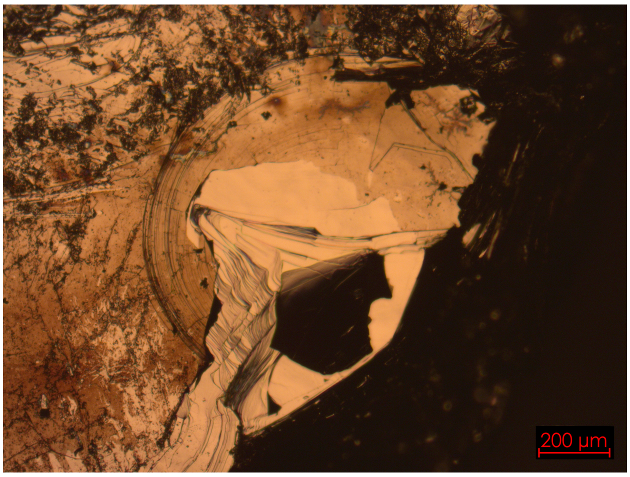

Figure 5. Morphology of the laminated surface edge of the sample

Individual very thin layers of the machined materials were delaminated from the surface in the process, granting the machined surface atypical morphology (for a surface machined by WEDM), made of individual layers. In the surroundings of the cut area, differently colored (than the rest of the surface) locations can be found. This is caused by different reflectance of light from the layers that were partly nipped from the original surface and are differently angled now (see Fig. 6). This hypothesis was confirmed by the local chemical composition analysis, which did not prove any difference in chemical composition in these locations.

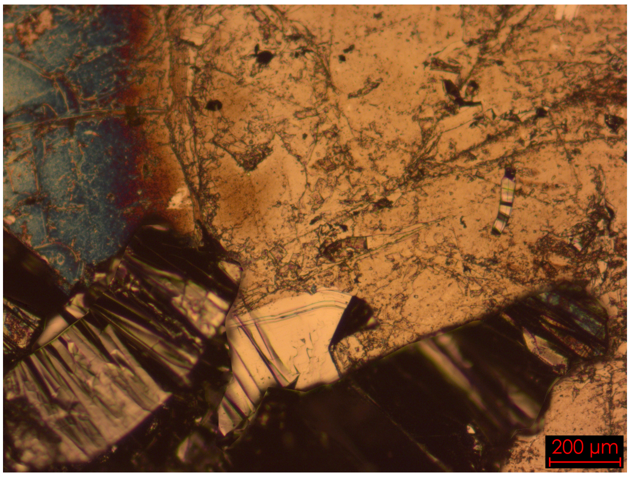

Figure 6. Morphology of the laminated surface edge of the sample

4 CONCLUSIONS

Highly oriented pyrolytic graphite is a material usual made using CVD technology to match specific dimensions and shape. However, in some applications instances, the need for altering this shape can arise. To match this need, wire electrical discharge machining was used. The demanded shape was a 9 mm diameter circle, but due to extreme evaporation, sweeping and delamination of the material was the resulting diameter only 8 mm. Subsequently, expanding of a tear occured during the cutting, leading to the breaking of the materials into two pieces 1 mm thick. This breaking, however, had no influence on the resulting functionality of the parts. Surface morphology was studied using both light and electron microscopy. Individual layers were, in some locations, bend, but a majority of the were completely separated. This delamination process also removed a layer of the mixed difunded material from the wire electrode, meaning no copper or zinc from the electrode was detected. Spots with different colour than the rest of the surface were found in the location of the cut during studying the surface morphology using light microscopy. Those places are made of bend lamellae made of the basic material, which are diverted by a certain angle from the rest of the material. Thanks to this tilt, those lamellae reflect light in a different manner than the rest of the sample and create green-blue surfaces in the image. The validity of this hypothesis was confirmed by local analysis of chemical composition, which showed no chemical difference in said areas than in the rest of the sample.

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REFERENCES

[Blecha 2011a] Blecha, P., Blecha, R., Bradac, F. (2011). Integration of Risk Management into the Machinery Design Process. In Mechatronics Springer Berlin Heidelberg, pp. 473-482.

[Blecha 2011b] Blecha, P., & Prostrednik, D. (2011). Influence on the failure probability. Annals of DAAAM & Proceedings, pp. 11-13.

[Grote 2009] Grote, K. H., Antonsson, E. K. (2009). Springer handbook of mechanical engineering (Vol. 10). Springer Science & Business Media, ISBN 9783540491316.

[Henini 2012] Henini, M. (Ed.). (2012). Molecular beam epitaxy: from research to mass production. Newnes, ISBN 9780123878397.

[Huang 2003] Huang, C. A., Hsu, C. C., & Kuo, H. H. (2003). The surface characteristics of P/M high-speed steel (ASP 23) multi-cut with wire electrical discharge machine (WEDM). Journal of Materials Processing Technology, 140(1), pp. 298-302.

[Huang 2004] Huang, C. A., Hsu, F. Y., & Yao, S. J. (2004). Microstructure analysis of the martensitic stainless steel surface fine-cut by the wire electrode discharge machining (WEDM). Materials Science and Engineering: A, 371(1), pp. 119-126.

[Jameson 2001] Jameson E. C. (2001). Electrical discharge machining. ISBN 08-726-3521-X.

[Kanlayasiri 2007] Kanlayasiri, K., & Boonmung, S. (2007). An investigation on effects of wire-EDM machining parameters on surface roughness of newly developed DC53 die steel. Journal of Materials Processing Technology, 187, pp. 26-29.

[Kumar 2013] Kumar, A., Kumar, V., & Kumar, J. (2013). Experimental Investigation on material transfer mechanism in WEDM of pure titanium (Grade-2). Advances in Materials Science and Engineering.

[Liao 2004] Liao, Y. S., Huang, J. T., & Chen, Y. H. (2004). A study to achieve a fine surface finish in Wire-EDM. Journal of Materials Processing Technology, 149(1), pp. 165-171.

[Matousek 2009] Matousek, R., Bednar, J. (2009) Grammatical Evolution: Epsilon Tube in Symbolic Regression Task. In MENDEL 2009, Mendel Journal series. MENDEL. Brno, BUT. pp. 9 - 15. ISBN 978-80-214-3884-2, ISSN 1803-3814.

[Matousek 2010] Matousek R., Bednar J., (2010) Grammatical evolution and STE criterion: Statistical properties of STE objective function, Lecture Notes in Electrical Engineering, vol 68, pp 131–142, doi: 10.1007/978-90-481-9419-3_11.

[Moreau 2010] Moreau, E., Ferrer, F. J., Vignaud, D., Godey, S., & Wallart, X. (2010). Graphene growth by molecular beam epitaxy using a solid carbon source. physica status solidi (a), 207(2), pp. 300-303.

[Mouralova 2015] Mouralova, K. (2015). Modern technologies in wire electrical discharge machining the metal alloys (in Czech) Dissertation work. BUT, Brno, 98p.

[Newton 2009] Newton, T. R., Melkote, S. N., Watkins, T. R., Trejo, R. M., & Reister, L. (2009). Investigation of the effect of process parameters on the formation and characteristics of recast layer in wire-EDM of Inconel 718. Materials Science and Engineering, pp. 208-215.

[Pierson 2012] Pierson, H. O. (2012). Handbook of carbon, graphite, diamonds and fullerenes: processing, properties and applications. Nouyes Publications, ISBN: 0-8155-1339-9.

[Windholz 1997] Windholz, R., & Molian, P. A. (1997). Nanosecond pulsed excimer laser machining of chemical vapour deposited diamond and highly oriented pyrolytic graphite: Part I An experimental investigation. Journal of materials science, 32(16), pp. 4295-4301.

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