EXPERIMENTAL RESEARCH ABOUT POLYCRYSTALLINE DIAMOND MACHINING PROCESS

Gheorghe OBACIU, Cristian PISARCIUC
Transilvania University of Brasov, Romania

Abstract: The correct selection of manufacturing conditions is one of the most important aspects to take into consideration in the majority of manufacturing processes and, particularly, in processes related to electrical discharge machining (EDM) of heterogeneous materials. These conditions are determining important characteristics as surface roughness, electrode wear, and material removal rate. The recent development of electrically conductive diamonds has further increased the scale of its applications and possibilities of machinability by nonconventional means.

Keywords: electro discharge machining, PCD, productivity, energy consumption

1. INTRODUCTION

The outstanding quality of diamond as a tool material in engineering applications is due to many of its properties. It is the hardest, most wear-resistant material known, has the greatest thermal conductivity at room temperature, and one of the lowest coefficients of thermal expansion and its excellent friction value is comparable with that of the plastic material PTFE (Teflon).

The use of diamond as an abrasive and as cutting tool material exploiting its great hardness and wear-resistance has been established for a long time and forms the basis for what is today a relatively mature industry.

Polycrystalline diamond (PCD), a diamond like material, is sintered in a composite mass, which for several years already has also been produced by high-pressure synthesis. Polycrystalline diamond is manufactured in a two-stage process consisting of diamond synthesis and high-pressure liquid-phase sintering. The knowledge of the conditions under which natural diamond is formed suggested that diamond could be formed by heating carbon under extreme pressure. This process forms the basis of the so-called high-pressure high-temperature (HPHT) growth technique. This method has been used to produce industrial diamond for several decades. In this process, graphite is compressed in a hydraulic press to tens of thousands of atmospheres (P ~ 50-100 kbar), heated to over 2000-2300 K in the presence of a suitable metal catalyst, and left until diamond crystallises. The diamond crystals, this produced, are used for a wide range of industrial processes, which use the hardness and wear resistance properties of diamond, such as cutting and machining mechanical components, and for polishing and grinding of optics. However, the drawback of the HPHT method is that it still produces diamond in the form of single crystals ranging in size from nanometres to millimetres, and this limits the range of applications for which it can be used. After a second stage, the result is a composite material consisting of diamond crystals embedded in a matrix, which is usually metal (cobalt binder phase).

One of the principal advantages of the EDM process is that machinability is independent of material hardness. However, productivity is highly dependent on the level of workpiece electrical conductivity. The bulk electrical resistivity for PCD is up to 14,700 μΩcm [1]. This value remains fairly constant despite gross differences in product grain size which typically varies from ~2 to ~25 μm. Theoretically, the resistivity of PCD would be expected to be about ~600 μΩcm. The fact that experimental measurements show otherwise suggests that the diamond crystals in the PCD are not completely covered / surrounded by the cobalt, which is understandable in view of the diamond intergrowth evident with PCD products. It is estimated that a high proportion of the cobalt is localised and that what is available as a conductive network incorporates narrow channels, some of which are discontinuous [2].

From electro discharge machining point of view, materials can be classified as homogeneous or heterogeneous. Homogeneous materials can be considered all materials that present a reasonable electrical conductivity (above 10^{-2} S/cm). In this class can be included all pure metals and alloys. Homogeneity assures a unitary characteristic of machining in a way that eroded pieces are in tolerance limits specified by technologist engineer.

In heterogeneous class are included all materials that present a structure resulted by combination of two or more primary materials. This category includes only materials that can be machined by electro discharge means such as ceramics, polycrystalline diamond and diamond alike materials.

2. ELECTRO DISCHARGE MACHINING OF PCD

Majority of machining tests over different sorts of PCD were performed using wire cutting machines. In fact, researchers were focused over cutting optimisation in terms of higher productivity.

In order to establish working parameters for PCD EDM, initially was assumed that the mechanism of removal is similar to ceramics [3, 4]. Although being similar in structure, PCD based materials present a higher thermal conductivity attributable to outstanding capabilities of diamond particle.
Although diamond is not electrically conductive, PCD manufactured with cobalt as binding phase have adequate electrical conductivity (this should be above 10^{-2} S/cm) for EDM. EDMing PCD, like EDMing, carbide, is much slower than cutting steel. Cutting speed for PCD depends upon the amount of cobalt that has been sintered with the diamond crystals and the particle size of PCD. Large particles of PCD require very high voltage to be cut. In addition, some power supplies cut PCD better than others. It is noticed that elevated removal rates are obtained by use of higher pulse voltage generators. This a consequence of a bigger discharge channel that has to be used in order to avoid short-circuits. Several analyses lead to necessity of using another type of pulse generators, capable to deliver high pulse voltage (over 500 V). Another improvement that can be done, in order to enhance existing machines, is to use a helping pulse over the existing ones.

Some wire EDMachines instead of cutting with DC (direct current) use AC (alternative current). This type of generators allows more heat to be absorbed by the wire instead of the workpiece. Another positive effect is the reduced of the heat-affected zone and eliminates electrolysis [2]. For most purposes, electrolysis does not have any significant effect on the material. However, the elimination of electrolysis is particularly beneficial because it reduces cobalt depletion.

Primary technological parameters, respectively those installed at machine set-up (voltage, amperage, discharging time etc.) are determining the value of energy supplied to discharge channel. At the same time, these parameters are limiting the overall productivity. Secondly, variables such as voltage, current and spark frequency are selected in such way to optimise productivity and workpiece surface roughness without causing undue damage. The thermal nature of the process is such that when sparking PCD, diamond is inevitably transformed into graphite because it is not stable in the presence of oxygen beyond 700^{o} C. In addition, selective erosion of the cobalt phase can occurring producing wholesale loss of diamond grains [5], together with thermal cracking.

The special features in the EDM of PCD result from the structure and material properties of the PCD blanks, in particular its laminar structure as a composite material, the structure of the PCD layer itself and this layer's relatively low electrical conductivity. The latter reduces the productivity and stability of the process. This reduced productivity is due to energy losses arising from the relatively low electrical conductivity of the material. The stability of the process is impaired by a reduction in voltage over the workpiece proportional to the discharge current. The voltage combines with the average working voltage, which serves as the standard variable of the feed rate control loop, and thus leads to an overvaluation of the spark gap. The infeed motion that then follows can lead to process fluctuations. The special characteristics of the shape and topography of surface are due to the laminar structure of the PCD blanks and the structure of the diamond matrix.

In several studies over die sinking erosion of PCD [2] is revealed the possibility for machining such materials in certain conditions, capable of assuring a reasonable productivity and acceptable energetic consumptions.

The tests described in this report were conducted on an Agie Mondostar 20. The machine has a generator which permit a maximum working current of approx. 64 A. Several experiments were performed by using die sinking technology according to following:

- » Workpiece electrode - PCD 020
- » Tool electrode - Copper (–)
- » Dielectric - Synthetic, polymers
- » Discharge current - 1.5, 3 A
- » Impulse time - 40, 60, 120 and 160 μs
- » Break time - 160 and 200 μs
- » Machining time - 4 min.

The PCD workpiece height consists of a thick PCD layer (0.7 mm) on an 8 mm carbide substrate. Tools electrodes were made by copper sheet rectangles with 0.5, 1.0 and 2 mm thickness (figure 1).

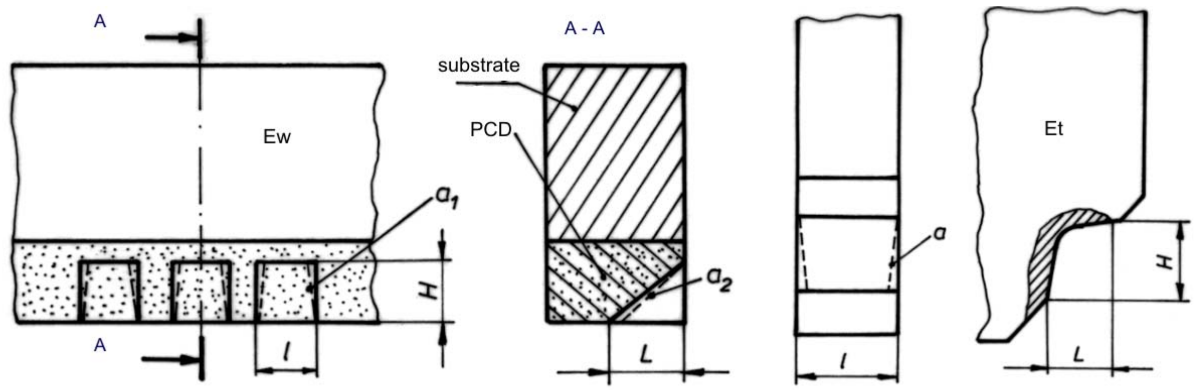

Fig. 1. Electrodes shape

The most important parameter that characterises PCD erosion is productivity. This is calculated with following standard formula Q = V / t [mm3/min], where: Q = productivity, V = volume of material removed from workpiece [mm3] and t = discharging time [min.].

Energetic consumptions are representing the amount of energy consumed to removal a quantity of material from workpiece. Consequently, Wmin is a ratio between the energy used for removal over 1 minute. This energy will include all energetic components such as energy for material removal from work piece and tool electrode, short-circuit pulses, energy necessary from transporting particles etc.

The results of experimental research are presented in figure 2. a. - i.

3. CONCLUSIONS

Investigating the diagrams, several conclusions are arising.

Because of the higher concentration of plasma in case of PCD, with the same energy, is suppose that the quantity of removed material must be higher, compared to other materials, but in effect, this is not the real situation. In case of homogeneous materials, o great amount of energy is loosing in secondary processes, like melting and binding the metallic results to the border of the craters but for PCD that energy cannot be neglected.

For 0.5 and 1 mm electrodes, curves present similar descendent tendencies with the growth of pulse ratio. This is a consequence of low possibilities in expelling the erosion residues. The most significant fact in energetic balance is determined by the growing energy consumed for phenomenon other than those related to electro discharge.

The facts mentioned above are more evident when is observed the erosion with 2 mm electrode. Having the largest surface, the travelling path of eroded particles is elongated. Hence, the productivity registered is the lowest.

In every case, a minimum in central zone of graphics can be ascertained and this has different explications for small and great break time. At lower values, the growth can be a cause of better discharge conditions. For higher values, the growth can be explained only by the fact that more energy is supplied to the discharge channel and as a result, more material is removed.

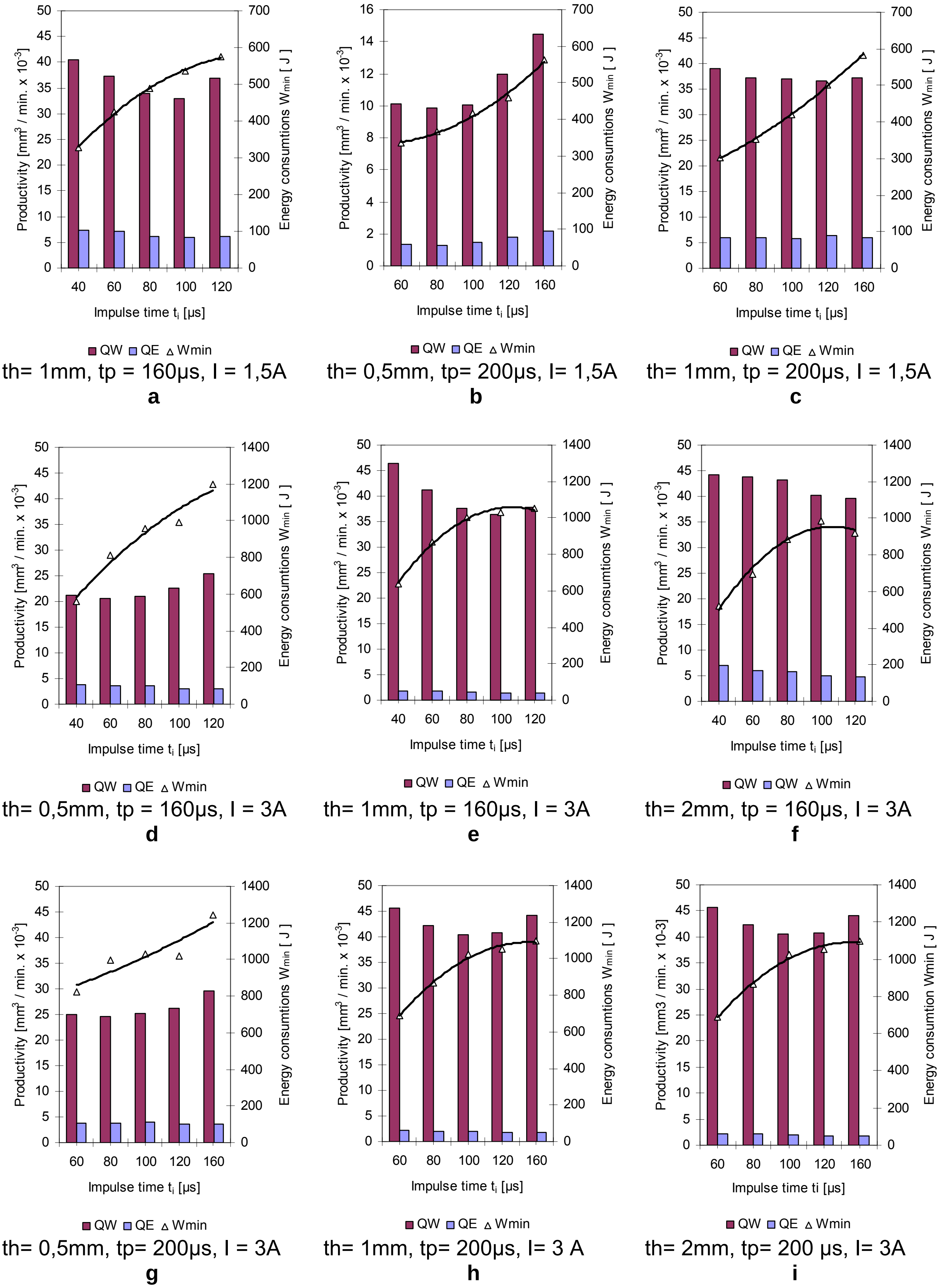

Fig. 2. Graphical results of experimental data at EDM of PCD

This increase of erosion is not equally to those of energy because of the worsen conditions in evacuation residues.

For the greater dimensions of tool electrodes, two effects are balanced and that make the maximum of eroded material to be situated in middle portion of pulse time.

Electro discharge machining of polycrystalline diamond generate two kinds of residues, fact that cannot be observed at homogeneous materials. The relatively bigger ones are diamond crystals and the smaller are residues of binder (cobalt in the present study). The last one is forming a thick film at the surface of PCD, improving the conditions for next discharging. The other noticeable fact, is that the diamond particles present a tendency for graphitisation at temperatures above 800 0C. Those kinds of temperatures are usual at EDM and the thick layer of electro conductive material, at the surface of PCD, conduct only to the growth of short-circuits pulses. Such kind of pulses cannot determine removal of material, contributing only the growth of energetic looses and may be another explanation for high-energy consumptions.

REFERENCES

[1] McLACHLAN, D.S.: Axial and surface
[2] resistivity of Syndite Ultrahard Materials. Technology, Vol.3, pp.34-40, De Beers Industrial Diamond Division, ISBN 0950630810, 1984.
[3] SPUR, G., APPEL, S.:Wire EDM cutting of PCD. Industrial Diamond Review, Vol. 4/1997, pp. 124-130, 1997.
[4] SPUR, G.: Keramikbearbeitung - Schleifen, Honen, Lapen, Abtragen. Carl Hanser Verlag, Munich, Germany, 1989.
[5] PANTEN, U.: Funkenerosive Bearbeitung von elektrisch leichtfähigen Keramiken. PhD Dissertation, TU Aachen, Germany, 1990.
[6] PISARCIUC, C.: Electro-thermal aspects in spark gap at EDM of polycrystalline diamond. PhD Dissertation, Transilvania University of Brasov, Romania, 2003