Research in the field of Polycrystalline Diamond Tools

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Abstract: The multitude of cutting materials already in existence increased further with the appearance of polycrystalline diamond (PCD) some 25 years ago. Ceramic show no chemical affinity to most machining materials, but are very brittle. Natural diamond, the hardest known material, is very wear resistant, but also sensitive to impacts and difficult to shape. The main advantage brought about by the development of polycrystalline diamond is the partial combination of the exceptional hardness of diamond with the toughness of tungsten carbide. This paper is presenting a series of the general considerations on cutting tools which have the cutting surface made of polycrystalline diamond. There are also presented some original results concluded by the author, based on experiments made with the tools mentioned before, which have different design values.

Keywords: polycrystalline diamond, application area, limitation

Received: May 30, 2020. Revised: June 26, 2020. 2nd Revised: August 20, 2020.
Accepted: August 25, 2020. Published: August 26, 2020.

1 Introduction

Diamond and cubic boron nitride are the hardest cutting-materials known. Most of the world's industrial diamond consumption is satisfied by synthetic diamond. The PCD can be manufactured on the same high pressure, high temperature press. The simultaneous application of pressure in the range of 6000 MPa and of temperatures above 1500 ^{0}C, leads to the transformation of the hexagonal crystal lattice characteristic of graphite into a cubic crystal lattice. Under similar conditions the individual crystals as obtained above grow together and form an agglomerate of randomly oriented particles whose hardness is only insignificantly lower than that of single crystal. In the case of polycrystalline diamond, the diamond layer is bonded to a tungsten carbide substrate, during a second synthesis process.

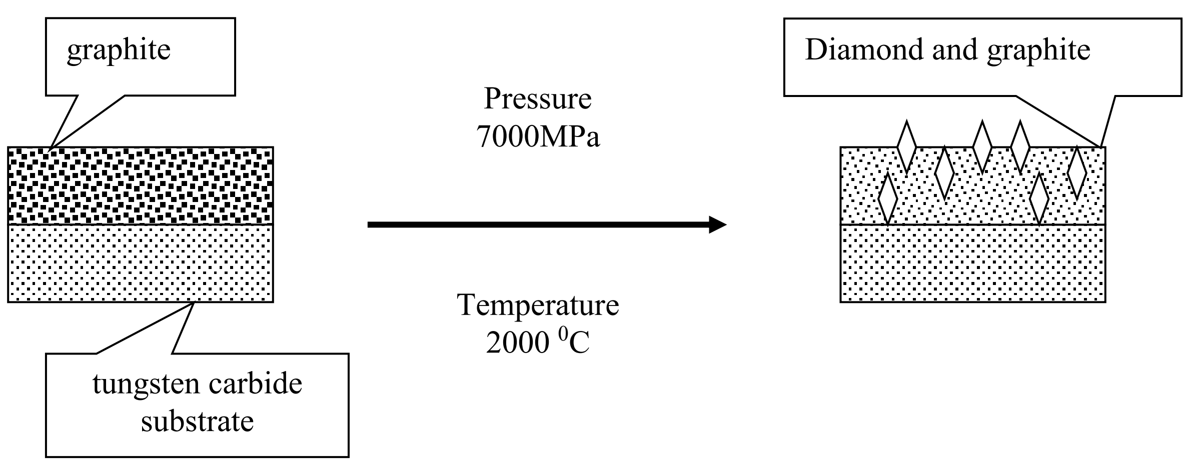

Fig.1 The resultant cutting tips

The resultant cutting tips are isotropic: neither wear resistance nor hardness is directional, and this constitutes a tremendous advantage with respect to single diamond crystals (Fig.1).

Typical applications of polycrystalline diamond are the machining of Aluminum and Aluminum-Si alloys, of cooper, brass and bronze. Due to their high abrasive action, materials such as fiberglass reinforced composites, epoxy resins with quartz fillers, ceramics and pre-sintered carbides cannot be machined satisfactorily with conventional abrasives. The high hardness and toughness of polycrystalline diamond-cutting tips have opened new ways in machining these materials and lead in many cases, to substantially longer tool life and improved surface quality, compared with tungsten carbide or ceramic tools. Polycrystalline cutting materials can be considered superior to tungsten carbide and ceramics in most respects, the only exception being a certain susceptibility to mechanical stresses.

The most important advantages of PCD are owing to reduced wear, less idle time for tool replacement and adjustment, less waste produced (steady dimensional accuracy guaranteed over long periods of time), better surface quality of work piece due to superior cutting edge stability, higher productivity through higher in feeds and cutting speeds.

2 Researches and experiments

Researches and experiments made in our country with tools shielded with synthetic polycrystalline diamond, has determined orientative working conditions depending on the working material [2] (Table 1):

Table 1 Orientative working conditions depending on the working material

Working material	Vas [m/min]	s [mm/rot]	t [mm]
Al-Si Alloys	200-700	0,02-0,07	0,20-1,0
Copper	300-400	0,02-0,07	0,20-0,80
Brass	300-400	0,02-0,07	0,20-0,50
Plastic material with spun glass	400-500	0,04-0,07	0,50-1,50
Ceramics	150-200	0,02-0,07	0,20-0,50
Hard-cutting alloy	15-40	0,02-0,07	0,10-0,15
Hard metal	80-100	0,02-0,07	0,05-0,15

Optimal parameters of cutting duty for polycrystalline diamond made in other countries are presented in Table 2 and 3.

There can be observed, that, the values of cutting regime alternates between a large scale for every material; the values will adapt to the specific cutting conditions (the tool-machine quality - used for cutting, the given quality of machined surface – etc.).

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Table 2 Optimal parameters of cutting- 1

Working material	Vas [m/min]	s [mm/rot]	t [mm]
Aluminum and alloys	600-3000	0,03-0,30	0,05-1,0
Copper Working material and alloys	300-1000	0,03-0,30	0,05-1,0
Plastics tough rubber, composites	200-1000	0,03-0,30	0,05-1,0
Sintered ceramics	100-300	0,03-0,15	0,05-1,0
Sintered hard alloy	15-40	0,03-0,10	0,05-1,0
Fibrous grained material	2000-4000	0,03-0,10	0,05-1,0

Table 3 Optimal parameters of cutting -2

Working material	Vas [m/min]	s [mm/rot]	t [mm]
Aluminum alloys	600-1200	0,05-0,20	0,10-0,50
Copper alloys	500-1250	0,05-0,15	0,10-1,0
Plastic material shielded with spun	150-1000	0,02-0,25	0,02-0,06
glass	150-500	0,02-0,05	0,01-0,10
Sintered hard cutting alloy	300-1000	0,02-0,10	0,01-0,10
Ceramics-technical			

The elements of cutting regime, cutting speed, feeding and cutting depth, are influencing, also as in case of other cutting machine materials, a series of parameters like the roughness of machined surface, cutting forces, cutting temperature.

The quantity of heat generated during cutting, his intensity, reciprocal position and the interaction of heat flow are determining the working temperature for cutting. On this value depends in a definite way, also the nature and the dynamics of characteristically phenomenon's during cutting, as: plastic flows, cutting force, inner frictions, exterior frictions, wear and tear of tool, vibration of technological system etc. Consequently, the study of heat during cutting process has an importance as much for the forming and sampling splinter as for cutting dynamics.

Since abstracted heat during cutting is generated by the transformation of mechanical work, his sources are becoming, in the process of resulting splinter from the cutting shell, heat sources.

In connection with heat-sources during cutting with polycrystalline diamond, there are no differences between this one and the other tool materials, therefore we may say that the transformation of mechanical work in to heat is carried out in three zones, as we know:

- Shearing zone between the tool and feature;
- Back edge zone, due to the friction between the tool and feature;
- Face side zone, due to the friction between the shaving and tool.

The amplitude and distribution of temperature will be determined by the thermal conductivity and the specific heat of tool-feature couple, as by the position of the heat source, the amount of abstracted heat and the size of heat conduction surface.

As about tools with a diamond polycrystal acting part, in the view of a high performance, these must have, among others, a high rate of transmitting thermal energy with the purpose of maintaining the forming zone of shaving from mechanical and thermical point of view. Especially by increasing, where high demands can appear, the transfer of energy is very important. From a constructive point of view polycrystalline diamond are constituted from many sheets: the polycrystalline diamond sheet DP is fixed on a hard metal sheet WC1 with the help of granite sheet GR.

The half-tool PD+GR+WC1 is fixed with the help of an AG binder, on the trunk of the tool WC2. The sheets mentioned above are very different from thermical point of view [2].
The PCD sheet may have a higher thermal conductivity as 560 W/mK, while at the borders G_R, conductivity is about 1/10 from PD conductivity. The high level of cobalt from the border sheet determines this fact. The binding sheet between the metallic parts has, related to the constituents, a thermal conductivity near 400 W/mK. Table nr.4 is presenting, for comparison, the thermal conductivity of the elements mentioned above, and also of some much known materials used for making cutting tools.

Table 4 The thermal conductivity of the elements

Material	Poly-crystalline diamond	Metallic carbid	Mineralo-ceramical plate	Cobalt	Alloyd steel with W	Plain carbon steel
Thermal conductivity	560	81	13,5	69	26	48-58

Due to these motifs, even the sheet from PD has a higher thermal conductivity, thermal energy is hardly transmitted from the cutting point to the trunk, and therefore the cutting point of PD will be thermically overstressed.
And also the intermediary sheets GR and WC1 will be thermically over-stressed, because it must carry a large quantity of thermal energy, in these conditions when their conductivity is rather low.
The stability of tools made from polycrystalline diamond is highly influenced by the conditions of energy transmission, especially the transmission from the cutting point to the trunk of the tool.
The contact surface between splinter and tool and, of coarse, the temperature of the tools, is given by the feed - s and the cutting depth - t. But also is very important the cutting speed (Fig.2), because neither during manufacture, nor during machining should the PCD-material be exposed to temperature much above 600 ^{0}C, otherwise severe graphitization and oxidation phenomena occurs.

3 Conclusions

The chemical reactions between ferrous materials, with low carbon content, and diamond, limits the applications field of PCD-cutting tips to the turning and milling of non-ferrous metals and other hard, non-metallic materials. The machining of cobalt, chrome, tungsten and titanium alloys is sometimes, for similar reasons, not successful.
A careful manufacture of the polycrystalline cutting tool is an important prerequisite for good performance in machining. The grinding of these extremely hard and abrasive materials is very difficult and requires a good deal of experience and skill.

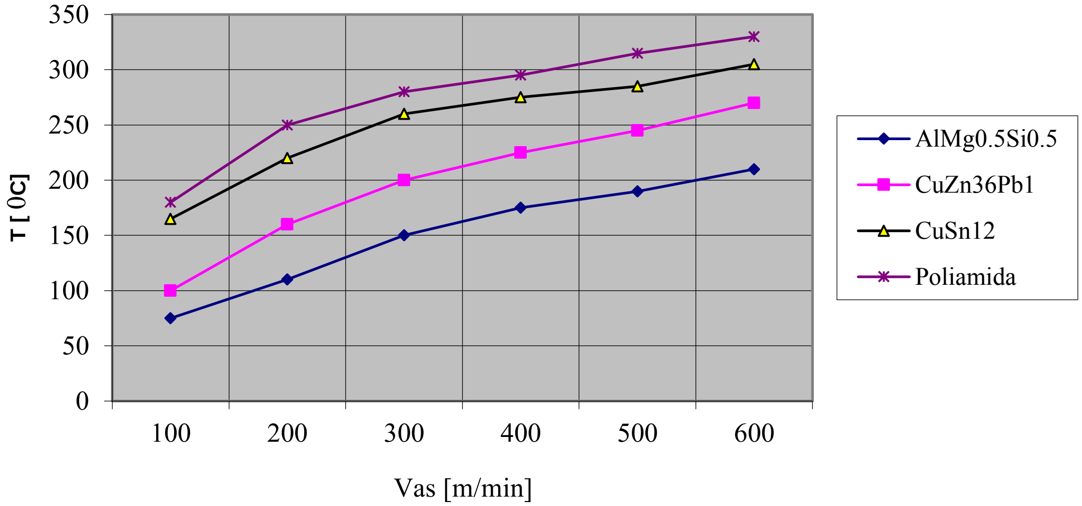

Fig.2 Cutting speed

Before being ground, the polycrystalline inserts are usually brazed on tool holders. Because of diamond's pronounced heat sensitivity, the temperature during the brazing process should not exceed 650-680 ^{0}C. Higher temperatures engender the risk of partial graphitization of the PCD-material with catastrophic consequences for subsequent tool performance.

Finally it should be pointed out, that carefully manufactured PCD-tools do not, by themselves, guarantee superior machining results. Only a comprehensive investigation of all operating conditions will lead to optimal performance. The future user of PCD-tools must be prepared to carry out all necessary adaption on his system to satisfy the requirements of these high performance cutting tools. This often implies substantial modifications and improvements of the machine used, a specially if stability and rigidity of the global system machine/workpiece/cutting tool are found to be insufficient.

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