PAPER • OPEN ACCESS

Elements of Diamond Tools Development Used in the Technology of Building Materials Processing

To cite this article: Marlena Rajczyk and Pawel Rajczyk 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **471** 052072

IOP Conf. Series: Materials Science and Engineering 471 (2019) 052072 doi:10.1088/1757-899X/471/5/052072

Elements of Diamond Tools Development Used in the Technology of Building Materials Processing

Marlena Rajczyk [1], **Pawel Rajczyk**[2]

[1] ul. Akademicka 3, 42-200 Częstochowa, Czestochowa University of Technology, Poland
[2] Al. Armii Krajowej 19, 42-200 Częstochowa, Czestochowa University of Technology, Poland

mrajczyk@bud.pcz.czest.pl

Abstract. The publication presents a timeline for the development of the industrial application of diamonds in the production of machining tools used for cutting, drilling and surface treatment of stone, concrete and ceramic materials. The development of industrial production of synthetic diamond powders used for the production of diamond segments, which are equipped with technological machining tools, is indicated. The technical parameters of diamonds have directed the technology of their production and the technology of improving their technological features in the field of producing more and more effective grains of synthetic diamonds and working segments. In order to increase the efficiency of work of tools equipped with diamond segments, the analysis was carried out and directions of searching for ways to increase the efficiency of their work were indicated. For this purpose, a model of the work of diamond grain working on a metallic binder was presented, and the methods of increasing the efficiency and quality of machining depending on the design of machining tools and technological parameters of their application were presented.

1. Introduction

In the middle of the 19th century, the construction of a tunnel was carried out in the Swiss Alps, explosives were used in the work process, which were to be placed in the rock slots. To drill these slots, a very effective drilling technique to manufacture tools made of hard steel alloys was used at that time. These structures, however, did not cope with the set tasks of making holes in very hard rock material. This state of affairs caused a significant increase in the costs of the works being carried out, it disturbed the specialist responsible for works, named Loshe. It was in charge of the work related to the tunnel through the rock massif. The specialist responsible for drilling works accidentally discovered, that the diamond witch he wore on his finger leaves scratches on the mineral glass. Commitment in his construction works in the Alps. Insight in the phenomena of his environment made him construct a lace drill at the end of which diamonds were mounted. In the drilling process were abundantly cooled with water. The construction of the drill with a tubular body was mechanically driven from the steam engine. It was this first structure that was the prototype model for many modern tools, where the principle of work remains unchanged till this day. Because diamond is a very expensive mineral, its widespread use was not possible. This resulted in the search for its substitutes and it continued continuously until the mid-twentieth century, ie until in 1955 in the US as a result of the industrial production of diamond powders, which contributed to its widespread availability in the global diamond tool market. Since the beginning of the 21st century, there has been a significant development in the production of synthetic diamond powders, which caused a reduction in production costs.

2. Timeline of the development of diamond tools

The first mention of the diamond is found in the description made by Pliny the Elder named "Historia Naturalis - glow, hardness, the possibility of using diamond for engraving ". Plint the Elder (23-79 years BC) author of an encyclopedia in Latin, discusses natural history, ethnography, art, sculpture, mining, mineralogy. He indicates the practical properties of natural diamonds, with particular emphasis on the fact, that it can be used to engrave in another material. In 1766, Smithson described that the diamond was a form of crystalline elemental carbon, that is how he began his first experiments with diamond synthesis. Closer to our times in the years 1862-1864, practical application for the diamond was indicated by the construction specialist Loshe, who carried out a construction task in the Swiss Alps. He developed a method for the technical use of diamonds in drilling processes. In 1910 Albert Shintt patented in Germany his grinding discs with diamond powders applied to their surfaces. In 1920-1930 in Germany, there was a lot of interest in the use of diamond tools in mechanical processing. From 1940, continuous research into the production of synthetic diamonds began in Germany, the USA, Sweden, Japan and the USSR. The first synthesis of diamonds was carried out by Baltazar Platen in 1953, in Sweden. In 1955, General Eletric conducted the process of diamond synthesis and developed a technology for their production on an industrial scale. In 1965, in Russia, in the laboratory conditions, diamond powder crystals were obtained also in the synthesis process. Synthetic diamonds are known for the technology of their production, HPHT that is decrypted as high pressure and temperature (hight-pressure and hight-temperature) and CVD chemical vapour deposition process. There is also a new method of synthesis performed in a pyrotechnic environment, introduced since the 1990s. The basis of this method was to create nanoparticles in the process of material explosion with carbon content, the product of this method is nano diamond powder particles. Since 2000, research has been carried out on the method involving graphite processing in high-power ultrasonic chambers [1,2].

3. Diamond characteristics

Diamond as defined [1] is a thermodynamic, metastable, polymer modification of the chemical element of carbon in nature, where various carbon modifications occur, among which we distinguish: soot, anthracite, graphite, coke and diamond. The differences between the modifications consist in the structure of the crystal lattice, where graphite is flat, while for the diamond spatial tetrahedral as in Figure 1.

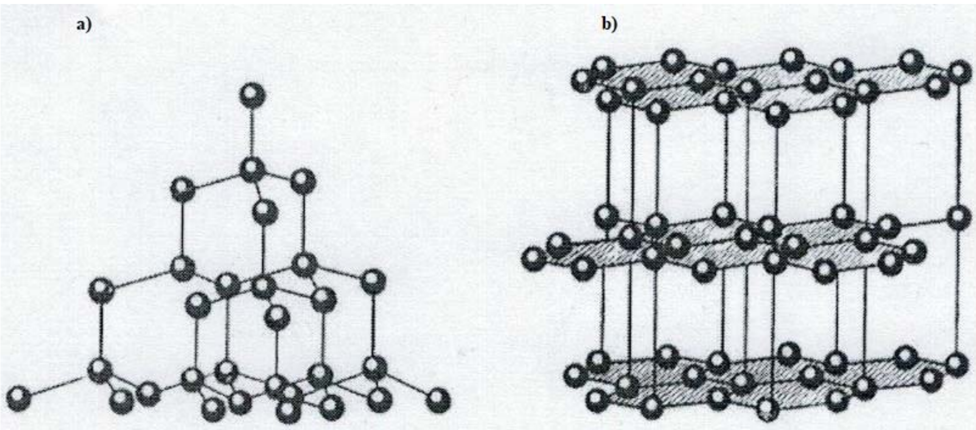

Figure 1. Crystal lattice a) diamond, b) graphite [1]

Diamond is the hardest material found in nature - hardness 10 on the Mesh scale. Due to this characteristic, it is classified as abrasion resistant materials. Diamond is resistant to compression, has high heat conductivity, it is a good electrical insulator, it is resistant to impact, it is brittle, it has a low coefficient of friction, it has the lowest coefficient of thermal expansion and it is biologically inert. At 1000°C, the crystal lattice of the diamond transforms into graphite. Graphite is a stable modification of carbon. A diamond synthetic powders is a basic component for the production of working segments of tools, that are equipped with circular saws, rope saws, cutting chains, lace drills, milling cutters, grinding discs, polishing wheels, diamond needles, diamond eyelets, antiko brushes and other diamond tools. The use of synthetic diamond powders used in the manufacture of segments for machining tools is related to its properties, mainly hardness. Diamond can only be scratched with another diamond. The history of the widespread use of diamond in processing technology, as one can see in the timeline, is not too long. Widespread availability due to the very high price until the middle of the 20th century was limited. From the beginning of the twenty-first century, there has been an increase in the availability of synthetic diamonds, where the major producers of diamond powders and tools had a significant share in this development. In diamond technology, it is extremely important to choose a diamond tool, which is influenced by factors that can be divided into three groups. The first of these are the properties of the material to be processed and the processing conditions. They should be understood primarily as the hardness and abrasive properties of the material being processed, and these processing conditions are: kinematic parameters at which the grain is loaded in the diamond segment binder and the properties of the coolant used. The second group is the properties of the diamond segment. They are the working equipment of the machining tool, among these basic properties there are: hardness, abrasion, concentration of binder modifiers, which is related to the coefficient and degree of heat removal from the diamond segment matrix and the ability to maintain the diamond grain embedded in it time of its effective use. The third group is the properties of synthetic diamond powders, among the features of this abrasive we distinguish: the type of diamond grain depends on the thickness (graininess) of the diamond grain with which the abrasive efficiency is connected, as well as the ability to hold the diamond grain in the binder. The features and determinants presented affect the tool cost as well as the composition and structure of the diamond segment matrix, which mainly concerns segments on metallic adhesives. In recent years, synthetic binders, mainly used for the production of grinding and polishing wheels, are increasingly used in connection with the development of material technologies. Segments in such tools in the scope of their recipe are built, by a set of dependent features, by the type of material processed, which determine the material and geometric properties of the diamond segment matrix [2].

4. Model of diamond segment grain performance

In the case of diamond segments made of diamond powders on a metallic bond, the basic properties are the hardness of the adhesive and its abrasiveness, related to the hardness of the processed material. Defined as the ability to hold the diamond grain in the binder structure. For abrasive grains operating at a specific kinematic load, they should be selected so that the diamond grains in the segment structure work out the effective abrasiveness capacity of the so-called critical abrasive capacity of the abrasive grain in the diamond segment binder as in Figure 2. [3].

The behaviour of the effective abrasive power of a diamond tool for treating mineral surfaces is determined by the index of abrasiveness of the working segment layer, which depends on the properties of the segment binder. Literature analysis [4,5] shows, that abrasive wear of diamond grain occurs as a result of: high-temperature friction together with the material being processed. The output of the segment work process consisting of: particles of processed material, particles of the segment binder subjected to friction along with fragments of crushed particles of diamond grains and coolant forming together a "pulpe". The key factor in the assessment of the phenomenon affecting the maintenance of grain in the segment binder is: hardness of the processed material, kinematic parameters of the machine, brand and volume of diamond powder in the abrasive segment, including the coating for refining the diamond grain, e.g. titanium + cobalt, nano parameters of the coating and the thickness of their coating impact on the processes occurring during the operation of the diamond segment.

The mechanism of maintaining the abrasive grain in the binder at the kinematic load of the tool indicates that the fatigue changes in the grain seating pattern in a given type of binder are determined by the strength limit of the binder that holds the grain. This parameter is defined as (σ_z), which depends on the strength of the material, including the limit of thermal resistance and the hardness of the binder, suitable for specific quantities of tool load cycles at given kinematic parameters.

The hypothetical method reflects the principle of determining the strength of grain deposition in the binder matrix is presented in Figure 2. The model of the process for keeping diamond grain in the binder - the diamond segment matrix is presented [3].

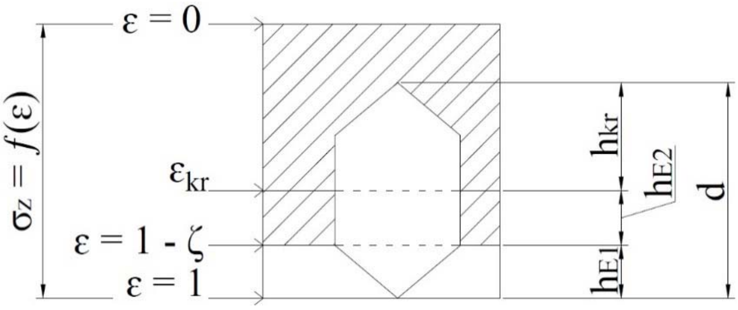

Figure 2. Model for keeping diamond grain in the segment binder [3]

The diamond grain holding force (σ_z) is a function of the depth of the grain embedding in the binder $\sigma_z = f(\varepsilon)$, where ε is the ratio of the depth of the grain location to its size. The dependence determining the critical depth of grain embedding in the binder, which allows the grain to be kept in the segment, is determined by the following formula:

$$h_{kr} = \varepsilon \cdot d \tag{1}$$

where: d – diamond grain diameter.

From the data presented as in Figure 1, it appears that the abrasive segment self-sharpening process occurs at the level of h_{E1}, which is determined by the following formula:

$$h_{E1} = \zeta \cdot d \tag{2}$$

where: ζ - is the relative height of grain protrusion in the diamond segment.

Grain can efficiently work in the segment matrix at the level of h_{E2}, which can be determined from the formula:

$$h_{E2} = d - h_{kr} - h_{E1} \tag{3}$$

The coefficient of using diamond grain can be represented by relative parameters:

$$\eta = \varepsilon - \varepsilon_{kr} - \zeta \tag{4}$$

where: η - coefficient of diamond grain utilization, ε_{kr} - critical relative depth of grain embedding in the binder.

The wear process is related to the number of cycles of interaction (C_{odz}) on the elementary working surface of the diamond segment. For a given machining process, it is possible to determine the coefficient of keeping diamond grain during its operation in the abrasive segment, which we determine from the formula:

$$K_{uzd} = \frac{\eta}{C_{odz}} \quad (5)$$

Introduction of the concept of the ability to maintain diamond grain in the segment (K_{uzd}) is a parameter useful for assessing the work of abrasive segments of diamond tools. The coefficient of keeping grain in the binder is directly proportional to the grain load, which allows forecasting the maintenance of grain in the segment during its operation [3].

5. Factors shaping the surface quality after treatment with diamond tools

For the surface quality assessment, the parameters characterizing the roughness and condition of the surface layer after processing are used. The following parameters are used to assess the surface roughness:
R_a - average authentic deviation of the profile from the average line [μm],
R_z - average height of profile unevenness in 10 points for the 5 highest and 5 lowest measuring points on the measuring length [μm],
R_{max} - the highest measurement unevenness from the lowest point to the highest measuring point [μm],
T_o - the relative length of the profile line [mm].
Profile measurement is usually carried out with electronic, optical or contact measuring devices, eg Mitutoyo.

The methodology for assessing the effectiveness of work tools for surface treatment of building materials is taken from literature [6,7].

The characteristics of a diamond grinding disc, for example, determined by graininess, affect the surface roughness after machining. The greater the granularity, the higher are the surface roughness parameters R_a, where Ra = $\frac{1}{n}\sum(yi)$, $R_z = \frac{W_1+W_2+W_3+W_4+W_5}{5} + \frac{D_1+D_2+D_3+D_4+D_5}{5}$.

The hardness of the diamond segment turns out to be a complex effect on roughness. For specific conditions and parameters of the grinding process, the optimum hardness of the diamond segment matrix is used. This is different to the hardness of the processed material; at which we achieve the most favourable level of roughness parameters. Decreasing or increasing the hardness of diamond segments with regard to the optimal process values, taking into account the hardness of the machining material, results in increased roughness parameters [8].

6. Generally known influence of kinematic parameters shaping the value of surface roughness parameters

The practice of using diamond tools for treating granite surfaces in the general range has shown that when surface treatment (grinding) increase of rotational speed reduces surface roughness. Increasing the forward speed (Vp) increases the surface roughness of the workpiece. Increasing the depth of impact of the disc in the material being processed increases the roughness. An important task is the selection of optimal machining parameters in terms of the characteristics of the processed material, the properties of the machining tool, the selection of kinematic parameters, for the purpose of the forecasted parameters of the quality of the surface to be processed.

Physico-mechanical processing properties of materials largely determine the surface roughness after machining. In the granite grinding process, a lower roughness is achieved, such as for marble processing using diamond segments of similar hardness and granularity of diamond powders in the working segment.

7. Conclusions

The trend of world production of machining tools with the participation of synthetic diamond powders annually reaches a 30% increase, mainly with the participation of Chinese producers.

An important direction in the development of diamond tool production is the improvement of technologies related to the processing of diamond grains in the CVD and PVD systems.

The coefficient of keeping diamond grain in the binder is an important parameter for assessing the properties of the binder from which the segment is made for given parameters of its performance.

The criterion for assessing the quality of the treatment surface is a useful parameter in the selection of granularity, concentration of diamond powder and its hardness, for a selected type of segment used for a specific technical task.

The criterion of the treatment surface quality is also an indicator used in the selection of rational kinematic parameters and the depth of machining of the tool at one pass on the surface being machined.

The selection of the properties of newly designed diamond tools should be strictly defined to the properties of the material to be processed, in order to obtain the expected surface quality, defined by the roughness, taking into account the efficiency of technological processes.

Reference

[1] J. Rajczyk, M. Rajczyk, "Stonework technology", Częstochowa University of Technology, No. 30, Częstochowa, 1997.
[2] M. Knapiński, P. Rajczyk, “Innovative methods for modeling diamond tools for surface grinding of stone”, Innovation in management and production engineering 2018. T.1 (red.) Knosala Ryszard Opole: Publishing House of the Polish Society for Production Management (PTZP), Opole, 2018, pp. 564-574.
[3] P. Rajczyk, “Analysis of the abrasive mechanism for use tools to grinding of mineral material surfaces”, Innovative potential in production engineering and material technology, Częstochowa, 2018, pp. 493-495.
[4] V.A. Konovalov, V.V. Shatokhin, “The relationship between the strength of grain fastening in conjunction with the durability of a diamond-abrasive tool”, VISN, ZDTU, Technical Sciences, 2009, pp. 508-513.
[5] V.A. Konovalov, V.A. Alexandrov, M.D. Levin, “Influence of the diamond holding strength and speed of abrasive wear of a sheaf on working capacity of diamond-abrasive tool”, Synthetic diamonds, Ukraina, 1975, pp. 26-28.
[6] J. Rajczyk, M. Kosiń, “Methodology of analyzing a new geometry design of a friction plate effect on the engineered surfaces”, IET Conference Publications, 2011, pp. 2-177 - 2-180.
[7] J. Rajczyk, Z. Rajczyk, M. Al.-Mashadani, “Systematic motion path of manual floats for concrete Surface”, IET Conference Publications, 2011, pp. 2-171 - 2-176.
[8] J. Rajczyk, “Modelling the geometric structure of concrete work item processing”, Applied Mechanics and Materials, 2013, pp. 638-643.