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Research Progress on Manufacturing Technology of High Performance Poly Crystalline Diamond Tool

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Abstract

Poly crystalline diamond tool is a kind of super - hard tool with superior performance. The key technology of tool manufacturing includes two aspects: one is the manufacturing of diamond compound sheet, the other is the processing of diamond blade. This paper reviews the research status and progress of these two key technologies.

Keywords

Poly Crystalline Diamond, Cutting Tools, Manufacturing Processes.

1. Introduction

At present, mechanical manufacturing is developing towards green, precision, digital and integration, and manufacturing equipment is the key to development. In manufacturing equipment, cutting tools, as the core components in machining, directly affect the machining accuracy, quality and efficiency. Synthetic poly crystalline diamond composite cutting tool (PCD) is a super hard cutting tool with superior performance. The poly crystalline diamond composite blade has the following advantages :(1) the grains are disorderly arranged, isotropic, without cleavage plane, and the strength, hardness and wear resistance are consistent on different crystal planes; (2) It has high strength and high impact strength due to the support of cemented carbide substrate. It can be used not only for precision cutting and ordinary semi-precision machining, but also for rough and intermittent machining with large cutting quantity, which can improve production efficiency. (3) Can be made into specific shapes to suit the needs of different processing; For example, triangle, herringbone and other special-shaped knife blanks can be cut by EDM, laser cutting, and can also be designed into wrapped, sandwiched and coiled tools; (4) The design can be adapted to the specific use of the tool, such as the choice of fine-grained Poly crystalline diamond tool material, the cutting edge quality of the tool can be improved, while the coarse-grained poly crystalline diamond tool material can improve the durability of the tool.

Poly crystalline diamond tool is not only suitable for the cutting of traditional metal materials, but also can be used in the processing of non-ferrous metal materials, such as copper alloy and aluminum alloy. Non-metallic materials such as stone, wood, composite materials, glass, engineering ceramics processing. In the processing efficiency, cutting speed than hard alloy is an order of magnitude higher, tool life than hard alloy ten times higher, for the processing of hardened parts, but also shorten the process flow.

The manufacturing of Poly crystalline diamond cutter mainly includes two aspects: one is the manufacturing of diamond compound sheet, the other is the processing of diamond blade. The quality and performance of diamond cutting tools are directly affected by the performance of diamond composite sheet and the processing technology of diamond blade. This paper analyzes the research

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progress of these two key technologies in detail according to the current situation of industry development.

2. Manufacturing process of diamond composite sheet

Diamond compact is the diamond micro powder in the shop on cemented carbide substrates, through high temperature and high pressure to make the carbide substrate of Co, Fe and Ni components to the diamond powder layer melt infiltration diffusion of re-crystallization make diamond grains growth, so as to realize the bonding between diamond grains, poly crystalline diamond layer and carbide substrate connection. The equipment of high temperature and high pressure mostly adopts six-sided jacking machine, and the technology of this equipment is in the leading position in the world.

At present, the main defects in the manufacturing of diamond composite sheet are breakage and peeling, which is caused by the difference of physical and chemical properties between diamond and binder in the diamond layer. Therefore, it is the core problem to enhance the wear resistance and heat resistance of the composite sheet and enhance the binding force between the poly crystalline diamond layer and the hard alloy substrate.

2.1 Enhance wear resistance and heat resistance

Because the synthesized poly crystalline diamond layer, especially in the gap of diamond particles, often leaves a part of the metal components of Co, Ni and Fe, which will have harmful effects on diamond composite plates. When the composite sheet is grinding at high speed, the residual metal components will transform the diamond into graphite due to the local temperature increase. Graphitization will expand the diamond volume and reduce the diamond bond force, thus weakening the bonding strength between diamond particles. At present, the main method to solve the wear resistance and heat resistance of the composite sheet is to reduce the content of metal composition in the composite sheet as much as possible in the process of synthesizing poly crystalline diamond composite sheet.

As cobalt is the most commonly used sintering aid, decobalt is usually used to improve the heat resistance of composite sheet. The essence of decobalt is to remove cobalt element in diamond layer. There are three distribution forms of cobalt in diamond: spherical Co particles between diamonds, "Co island", and veined Co distribution [1]. The influence of these three distribution forms on the heat resistance of composite sheet is not the same, among which the Co distribution in the veins has the greatest influence on the tool. From a macro point of view, cobalt is uniformly distributed in diamond composite tablets, so it is difficult to remove. Generally, acid dissolution or electrolysis methods are adopted [2]. The decobalt effect is closely related to the ratio of acid solution. Wang Qianlong et al. mixed inorganic acid such as hydrochloric acid with organic acid such as malic acid and citric acid to get composite acid, and impregnated the composite acid for 48-72h to get the wear resistance of poly crystalline diamond composite tablets about 10 times higher than the original. But acid solution is easy to pollute the environment, how to increase environmental friendliness is the main problem. Another method is the electrolysis method. Cobalt is removed from the diamond composite sheet by an electrolytic solution. The cathode is inert metal and the anode is poly crystalline diamond layer.

Other metals besides cobalt are also considered, such as tungsten. An appropriate amount of tungsten in the composite film is beneficial to wear resistance. Tungsten can strengthen with cobalt in solid solution and form tungsten carbide with diamond. However, excessive tungsten will reduce the wear resistance of polycrystalline diamond composite film. The wear resistance of polycrystalline diamond composite films can also be improved by detungsten treatment of excessive tungsten on the basis of decobalt treatment of polycrystalline diamond composite films.

According to the current research, there are two trends to enhance the wear resistance and heat resistance of the composite sheet: first, the use of other metals, alloys and ceramics to replace part or all Co as the binder, which can effectively improve the thermal stability of the diamond composite

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sheet; Secondly, many holes will be left in the surface layer of PCD after removing the surface layer of cobalt, tungsten and other metals. The presence of these holes will affect the compactness of the POLYcrystalline diamond layer and other metals are needed to fill the holes to increase the bonding strength.

2.2 Enhance interface bonding strength

The shedding of diamond layer is another form of destruction of poly crystalline diamond composite sheet. The bonding between diamond layer and hard alloy is not firm, because the thermal expansion coefficient of metal Co is far greater than that of diamond. At high temperature, the interface between Co and diamond and other metals will produce thermal expansion and cold contraction and oxidation, resulting in thermal cracking, which makes poly crystalline diamond layer become loose. However, the temperature change in the process of processing and working of the composite sheet will generate residual stress inside the composite sheet, which will easily cause the composite sheet to fail. Therefore, strengthening the interface bonding strength and reducing the residual stress are the main means to prevent shedding. Currently, the solutions proposed are as follows.

One is to improve the thermal processing technology, improve the density of the material layer. This is similar to the multi-stage heat treatment method of metal heat treatment. For example, Jiejun et al. prepared poly crystalline diamond composite sheet through the combination of secondary sintering and secondary heat preservation, which not only reduced the thermal stress, but also improved the density of the material layer.

The second is gradient transition design between diamond layer and hard alloy substrate. For example, Shen Jianzhong et al. firstly wet ground the top layer of tungsten cobalt carbide powder, the middle layer of titanium carbide and the bottom layer of vanadium carbide, dried and waxed respectively, and then pressed the functionally graded cemented carbide layer by layer, and then synthesized the poly crystalline composite sheet. The gradient transition of composite composition is beneficial to stress dispersion and avoid stress concentration, and the poly crystalline diamond composite film prepared has better shear strength and impact resistance.

Thirdly, the interface structure between diamond layer and hard alloy is designed non-plane. If some hole structures are designed on the end face of the cemented carbide substrate, the diffusion of diamond particles to the cemented carbide substrate can reduce the thermal expansion coefficient of the cemented carbide substrate, thus reducing the residual stress at the edge of the diamond layer. For example, by setting non-uniform pattern grooves on the upper surface of the hard alloy layer, the interface structure is more complex, which can further improve the bonding holding force between diamond poly crystal and the hard alloy, and slow down and eliminate the anisotropy characteristics of the interface layer. If a variety of chimeric interface structure is designed, of course, several measures can be used in combination, the combined effect is better. The non-planar interface design increases the contact area between the diamond layer and the hard alloy substrate so as to improve the interface bonding strength. It can also realize the distribution of thickness and thickness of diamond layer, which ensures the uniform distribution of stress and improves the service life.

3. Blade processing technology

The most important aspect that restricts diamond tools is the processing of diamond blades. The processing of diamond blades mainly includes cutting of composite pieces, welding of blades, grinding of blades and other steps. Equipment and processing technology are the root cause of low product quality at present.

3.1 Cutting tool

In order to prepare poly crystalline diamond composite chips into various cutting tools or tools, cutting poly crystalline diamond composite chips is an essential procedure. At present, wedM, laser machining, ultrasonic machining, high pressure water jet and other processing methods are mainly used, among which WEDM and laser cutting are the two most widely used. In the process of EDM

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wire-cutting, there is obvious graphitization on the surface of the diamond layer and serious excessive removal of the cobalt-rich interface between the POLYcrystalline diamond layer and the hard alloy layer, which increases the difficulty of subsequent processing [4]. Compared with laser cutting, edM wirecutting efficiency is low, mainly because of insufficient discharge energy of high-frequency power supply, and due to poor conductivity of diamond particles, wire breakage is very easy to occur in the cutting process, which also leads to low cutting efficiency. However, wire-edM technology can be used to process polycrystalline diamond with high surface quality. Wu Yu et al. conducted cutting experiments on polycrystalline diamond using laser cutting and WIre-edM methods respectively, indicating that wire-edM surface quality is better than laser cutting [5]. Song Mancang et al. studied the specific processing technology of edM wirecut composite sheet, indicating that the precision requirement can be achieved through slow moving wire [6]. In the process of cutting tools, the slow-moving silk cutting machine made by Archshamir of Switzerland can realize the surface roughness value of 0.4um, and has excellent cutting surface integrity, no grinding process is required, which can guarantee the processing quality and efficiency at the same time. Laser machining is characterized by high machining efficiency, good cutting quality and easy control, which provides new flexibility for manufacturing and is an ideal method for cutting polycrystalline diamond composite wafers. Keliang et al. developed a special CNC laser cutting machine for composite slices, which effectively improved the thickness and production efficiency of laser cutting for composite slices.

In general, equipment is the most important factor affecting the cutting tool, the input of equipment will also increase the processing cost; Various processing methods have advantages and disadvantages: for example, abrasive water jet cutting technology is complex, laser cutting cost is high, edM wire cutting speed is slow; How to give consideration to machining quality, efficiency and cost is the core problem in cutting process.

3.2 Tool welding technology

Welding poly crystalline diamond compact refers to cemented carbide substrates and blade welding, this is polycrystalline diamond tool a crucial part of the production process, welding quality is directly related to the life of the cutter, welding produce thermal stress can make the blade welding, due to the heat resistance of the diamond is about 800 ℃, prone to defects such as carbide welding, affect the service life of cutting tools, and performance.

The welding methods of composite sheet include laser welding, vacuum diffusion welding, vacuum brazing and high frequency induction brazing. The laser welding intensity is high, the welding efficiency is high, but the investment is big, the welding cost is high, affects the further promotion. Brazing is a relatively reliable welding method. Vacuum brazing can achieve high welding quality, but there are some problems such as complicated technology and difficult operation. Frequency induction brazing is the most commonly used welding process in the manufacturing of POLYcrystalline diamond tools. High-frequency induction brazing A welding process in which parts are welded together by heating the filler metal to a molten state using the thermal effect of eddy current induction. High frequency induction brazing has high heating temperature, high speed and short heating time, which can complete the heating process in a few seconds. Uniform and selective heating, small deformation of workpiece, and non-contact heating; Good working environment, almost no noise and dust. Due to the limitation of the permissible heating temperature of diamond in POLYcrystalline diamond, the solder filler is mostly silver based. By adding three main elements of Co, Ni and Mn to the base of the solder, the joint strength of the solder is improved [7]. Suitable brazing agent is F500A, F600B and QJ305 brazing agent, etc. These brazing agent can well cooperate with brazing filler metal to weld cemented carbide, diamond polychip and other materials in the temperature range of 600~850℃.

In the process of welding, it is necessary to control the technological parameters of welding. Welding temperature, holding time and welding pressure are the main factors affecting welding, among which welding temperature has the greatest influence on welding strength. The best welding temperature is around 750℃, and welding is generally controlled at medium and low temperature. Because of

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carbide shape is very poor, brazing crack is the basic problem in the process of hard alloy welding, by controlling the cooling and heating speed can improve this situation, and of course have welding pretreatment and strengthen treatment after welding, such as rolling mill, using process before welding interlayer and multi-step heating process can improve the welding performance [8]. The surface modification of composite sheets, such as electroplating, electroless plating, molten salt plating, impregnation plating, vacuum deposition, vacuum sputtering and ion implantation, can also improve the welding performance.

3.3 Cutting tool grinding technology

Cutting tool grinding is the most critical factor affecting tool quality, diamond cutting tool hardness is very high, cutting tool grinding difficulty is very high, the technical and equipment requirements are very high. At present, the research on the cutting tool grinding mainly focuses on the cutting tool grinding mechanism and the cutting tool grinding process. It is generally believed that the failure mechanism of diamond materials is mainly micro-brittle crushing and fatigue damage. In the process of grinding the tool, diamond grinding wheel will play the role of carving and sliding, and material removal has many ways of bonding, carving, tribochemical reaction and surface fracture [9]. Current research on mechanism of diamond abrasive friction mainly from laboratory experiments, and the grinding process there is a certain difference in practical engineering, because the actual grinding process produces a large amount of heat makes the material performance change, the differences of the grinding conditions and the influence of heat in the process of grinding on the performance and mechanism needs further research.

Poly crystalline diamond tool cutting edge grinding process mainly includes three kinds of machining methods: mechanical cutting edge grinding, discharge cutting edge grinding and special processing. Mechanical cutting edge grinding is the most widely used diamond cutting tool cutting edge grinding method. The nature of mechanical cutting edge grinding is diamond to diamond grinding. The vibration characteristics and precision of lapping machine, lapping line rate and lapping pressure are the most important factors affecting the lapping precision and wear rate. Edm grinding is the application of edM technology to diamond tool grinding. Discharge blade grinding is a kind of thermal etching processing in essence. It makes use of the instantaneous high temperature generated by discharge to melt and vaporize the tool material, so as to realize the material removal. Compared with the mechanical grinding of diamond wheel, the discharge grinding cost is lower and the processing efficiency is higher. Because the etching process has certain damage to the tool, it has certain influence on the life and precision of the tool. The QWD series machine tools of Vollmer are the most typical ones. The radial runout of the processed multi-blade tool can be controlled within 0.001mm, and the surface roughness of the tool can be ra0.4um. The cutter surface roughness processed by Vectaspark 300 manufactured by Vectaspark in the UK can reach ra0.2um. The domestic CNC100 edM grinder is of vertical structure, and its cutting edge roughness can reach about Ra0.4 m, but its processing efficiency is relatively low [10]. Special processing technology with ultrasonic grinding, laser processing, methods of electrochemical grinding, but the concrete application in diamond tool grinding process is still relatively small, how to combine mechanical grinding method and special grinding process is applied to the engineering practice, at the same time get the grinding efficiency and grinding accuracy is grinding technology research hot spot in the future.

4. Conclusion and Prospect:

Excelsior is the eternal theme of tool manufacturing. Poly crystalline diamond tools are developing towards product serialization, grain refinement, quality optimization and performance homogenization as a whole. The blank size is increasing constantly, and the shape and structure of the tools are diversified. Now the high-end diamond tools are mostly in Europe and the United States. The world famous diamond tool manufacturers include De Beers, GE and Sumitomo Electric. The diamond tools made in China are at the middle and low-end level. Although The output of diamond

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in China ranks the first in the world, the production of diamond products lags far behind that of foreign countries. At present, the most important aspect that restricts diamond tools is the processing of diamond blades. The processing of diamond blade includes multiple steps such as compound cutting, blade welding and blade grinding.

Of course, as a new super hard tool material, poly crystalline diamond will be more and more widely used. The annual global market capacity of diamond tools has exceeded 10 billion US dollars. The continuous introduction of new technologies, new processes and new products has created new market demands for diamond tools. In the future, diamond tools will have a huge market space.

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