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The Preparation and Key Technology of the PCBN Cutting Tool Materials Used in the Fine Finishing of Cast Iron Parts

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The formula, the preparation process and the key technologies of the new polycrystalline cubic boron nitride (PCBN) cutting tool materials for Cast Iron Parts in High Speed Finish Machining are introduced in this article. In order to solve the problem of agglomeration of the fine particle powder, the parameters of the wet ball milling as well as the dispersion medium and dispersant are determined by the experimental study. Secondly, by using the advanced detection methods including the X-Ray Diffraction (XRD) analysis and the micro hardness testing, the best parameters of preparation of PCBN materials are developed, which provides a reliable guarantee for the batch quality stability of the tool materials. Finally, the effect of nano whisker on the properties of cutting tools used in the severe intermittent cutting is studied experimentally and the results show that the nano whisker can improve the impact toughness of the tool materials, but its additive amount has the best range. The microstructure and properties of the PCBN cutting tools are analyzed by means of the scanning electron microscopy (SEM), the energy spectrum analysis (EDS) and the micro hardness testing, which indicates that the microstructure of the PCBN tool materials is uniform and compact and the materials of PCBN tool have stable performance. The machining experimental results verify the effectiveness of the adopted key technologies and the prepared PCBN tool materials can meet the requirements of the surface roughness of the iron casting parts for the high-speed finish machining.

1. Introduction

Gray cast iron, as well as nodular cast iron and alloy cast iron is widely used in the automotive industry. For example, the engine block, cylinder head, crankshaft, automobile gearbox, brake drums and so on are made of one of the above materials. Under the requirements of performance improvement and cost reduction, the superhard material cutting tools, which can improve the machining precision and surface quality of the parts and meet the requirements of high speed and high efficiency cutting, have attracted more and more attention.

Polycrystalline cubic boron nitride (PCBN) cutting tool material has advantages of the excellent wear resistance, high hardness as well as excellent chemical stability and impact resistance, so that it has become an indispensable tool in modern machining applications, especially for NC automatic processing in the automotive industry (Su et al., 2016). Therefore, the preparation methods of a kind of fine grain PCBN cutting tools are introduced in this paper, which are mainly used in the fine finishing of cast iron parts, and some key technologies in the preparation process of PCBN tool are studied.

2. Preparation of PCBN cutting tool materials for finish machining of cast iron parts

2.1. Raw materials' formula of PCBN cutting tools

Currently, the raw materials' formula of PCBN cutting tools has two categories. One is composed of a relatively small amount of CBN powder and one or more binders, which is mainly used for the machining of the hardened steel. And the other is consist of a plurality of CBN micro powder and one or more binders, which is mainly used for machining of cast iron parts (Nie and Li, 2016). Now, there are two main trends in the development of PCBN cutting tools. The first is CBN powder used in the raw materials, which is more coarse or finer, and the other is to use binders to increase the impact toughness of PCBN cutting tools (Ma et al., 2016). Under the same content of CBN powder in the raw materials, the coarser the granularity of CBN

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powder is, the better the impact toughness of PCBN cutting tools is, and the poorer the surface finish of the parts machined by this coarse-grained PCBN cutters is. Under the same content of CBN powder in the raw materials, the finer the granularity of CBN powder is, the better the mechanical wear resistance of PCBN cutting tools is, the higher the compressive strength of PCBN cutting tools is, and the better the surface finish of the parts machined by this fine-grained PCBN cutters is. Therefore, the coarse-grained PCBN cutters are used for rough machining, whereas the fine-grained PCBN cutters are mainly employed in final finish machining. However, it is very difficult to mix and sinter raw materials when the fine-grained CBN powder is used to prepare PCBN cutting tools.

Referring to the existing research results (Xie et al., 2013; Zhu et al., 2011), a large number of contrast experiments of the content and particle size of CBN powder and binders are carried out, and finally, a new formula of PCBN cutting tools for finishing of cast iron parts is determined and shown in Table.1.

Table 1: The Formula of PCBN Cutting Tools Material

Material	Granularity/(μm)	Weight Percentage /(wt%)
CBN	<2	90-92
α-Al2O3	<1.5	3-5
Al	1-2	5

2.2. Preparation process of PCBN cutting tool material

The preparation process of PCBN materials is mainly as follows (Ren et al., 2010):

(1) Pretreatment of CBN powder: Washing CBN powder with dilute hydrochloric acid to remove the metal impurity, and then neutralizing with dilute sodium hydroxide solution to remove excess hydrochloric acid. After the removal of the generated water, CBN powder needs to be cleaned with the distilled water and the absolute ethyl alcohol respectively several times in turn and finally dried in a vacuum drying oven to remove the water and ethanol.

(2) Mixing raw materials: Adding the raw materials with the correct amount into the ball mill tank in the planetary ball mill according to the weight percentage as shown in table 1 and then mixing by high-energy ball-milling until well combined (Xiao et al., 2016). Because of the existence of superfine powder, the raw material must be mixed by wet ball milling (Zhang et al., 2016).

(3) Drying and granulating: Because the dispersion medium needs to be added into the ball mill tank when adopting the wet milling process, the milled uniformly mixture of the raw materials must be placed in a vacuum drying oven for drying, so as to completely remove the dispersing medium in the powder, and then, be made into the granular powder by the granulation process

(4) Compression molding of the cutting tool blanks: The granulated powder of the raw materials after drying and granulating is pressed into the cutting tool blanks with different shape. Next, place each blank in a carbon mold with the corresponding shape and bond one carbon sheet at each end of the carbon mold with binder so as to assemble the inner synthetic block. Then, place the inner synthetic blocks in a vacuum oven of 300 °C and dry 4H for use.

(5) Assembly of the synthetic blocks: Place two of the dried inner synthetic blocks into the pyrophyllite block, and arrange one metal titanium sheet and one conductive steel ring at both ends in sequence to assemble one synthetic block. Then, place the assembled synthetic blocks in an oven of 150 °C and dry 2H for use.

(6) Sintering under high temperature and high pressure: The dried synthetic blocks are placed in the hexahedron press one at a time and sintered into PCBN blanks for use in the manufacture of PCBN cutters for finish machining of cast iron parts. The sintering parameters are as follows: the synthetic pressure is 6.5GPa; the synthetic temperature is 1650 °C; and the synthetic time is 6-20min (Xie et al., 2014).

3. Key technologies for the preparation of PCBN cutting tools for fine finishing of cast iron parts

3.1 The ball milling process of ultrafine grain powder

High energy ball milling is to make hard spheres exert strong impact on raw materials, and at the same time, grind and stir the materials in order to decrease the activation energy of reaction, refine grain size, enhance the activity of the powder, and improve component uniformity and its sintering ability (Cheng et al., 2016). The ball milling process is divided into two kinds: dry ball milling and wet ball milling. When preparing powder by the dry ball milling process, due to the use of fine particles of raw materials powder, the results showed that the agglomeration of the powder was still observed in the mixed powder, though the milling time increased from the original 8h to 15h, and the micro-hardness varied greatly at different positions of the same sintered PCBN materials. Therefore, the experimental study of the wet ball mill process is carried out for the raw

material of fine grain PCBN tool. The experimental equipment adopts QM-2SP4 planetary ball mill produced by Nanjing NANDA Instrument Co., Ltd., and is equipped with 4 agate jars.
In the experiment, the anhydrous ethanol, deionized water, ethylene glycol, acetone and their mixtures are used as dispersion medium and the polyethylene glycol, polyethyleneimine, poly (methacrylic acid) ammonia as dispersant separately. Material: ball: the dispersion medium takes different combinations such as 1: (2/3/4/5): (0.8/1/1.2/1.5) respectively. At the same time, the comparison experiment is carried out on the charging quantity, the ball quantity, the ball size, the ball mill speed and ball milling time, etc.
Through the experimental study, and considering the intermiscibility and toxicity of dispersion medium and dispersant, environmental protection, and so on, the wet milling process parameters of fine particles of raw material powder are eventually determined as follows: ball mill speed is 360r/min; forward / reverse time period is 5 minutes; the milling time is 8-10h; material: ball: dispersion solution =1:2:0.8. The dispersed solution is mixed by certain proportion of anhydrous ethanol and some dispersing agent.
The SEM diagrams of the raw material powder of the same batch of ingredients by dry ball milling 15h and wet ball milling 10h are shown in Figure 1 separately, from which it can be seen that the agglomeration of fine granular powder is very serious after dry ball milling process, but the agglomeration of powder after the wet ball milling is eliminated.

(a) Powder after the dry ball milling for 15 hours (b) Powder after the wet ball milling for 10 hours

Figure 1: The SEM Diagrams of the Raw Material Powder

3.2 Determination of sintering process parameters of PCBN cutting tool materials

The sintering parameters of PCBN materials include sintering pressure, sintering temperature and sintering time (Li et al., 2016). In order to determine the optimal sintering parameters and improve the performance of PCBN cutting tools, it is necessary to comprehensively apply modern detection methods such as XRD analysis and micro hardness detection to study the change rule of the internal phase and properties of PCBN materials with the change of sintering parameters (Zhang and Wang, 2009). Only more scientific determination of the best parameters can provide important guidance for improving the performance of PCBN materials.
The XRD diagram (Xu et al., 2012; Lv et al., 2008) of the materials at different sintering temperatures of Al binder and CBN micro powder is shown in Figure 2. As can be seen from Figure 2, when sintering temperature is 1300°C, the main phase of the sintered body is elementary substance Al, CBN and a small amount of hBN. At this time, there is no obvious reaction between Al and CBN. When the sintering temperature is 1400°C, Al reacts with CBN to form new phases AlN and AlB2, while a small amount of Al exists. When the sintering temperature is 1500°C, the formed phase has no change compared with 1400 °C. Therefore, when the Al binder is used, the sintering temperature can be above 1400 °C.
In the same way, combined with the detection of micro hardness, impact toughness and other parameters, the optimum sintering process parameters of PCBN cutting tool materials of different formulations can be determined according to the results of XRD analysis.

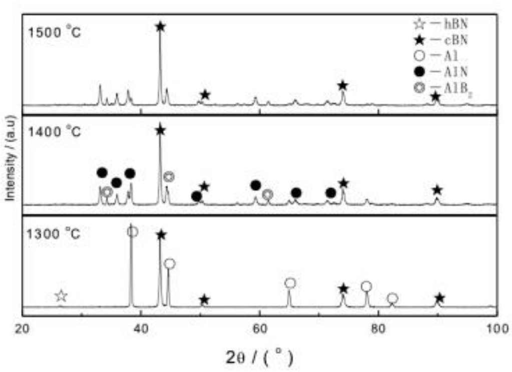


Figure 2: XRD Diagrams of Al Binders and CBN Sintered at Different Temperatures

The SEM and EDS diagram of PCBN materials prepared by the above key techniques are shown respectively in Figure 3 and Figure 4. As can be seen from the SEM diagram, the sintered PCBN cutting tool materials are uniform and compact, and the EDS analysis results show that there are the same elements and the same content of elements in the two regions.

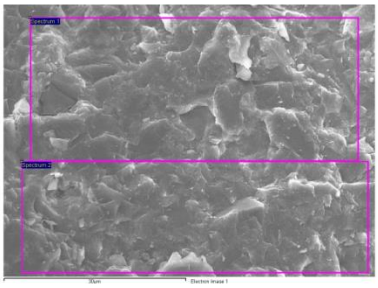


Figure 3: SEM Diagram of PCBN Cutting Tool Material According to Table 1

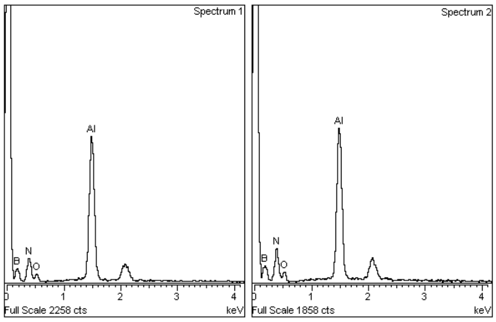


Figure 4: EDS Diagrams of Two Different Regions of the Same PCBN Cutting Tool Material

The prepared PCBN materials are grinded into PCBN cutters of model CNGN120712, and 5 of them are used to test the hardness. The results are shown in table 2. In addition, the micro-hardness of different positions of one of the PCBN blades is detected, and the results are shown in table 3. It can be seen that the micro hardness of the different PCBN cutters and the micro hardness in different positions of the same PCBN cutter are similar, which are prepared by using the wet ball milling and the optimum sintering parameters. It is also proved that the stability of blade quality can be guaranteed by this method.

Table 2: *Micro Hardness Test Data of PCBN Tool Materials*

The blade number	1	2	3	4	5
Micro hardness/HV	2956	3079	2972	3008	3043

Table 3: Micro Hardness Detection Data of Different Locations of the Same PCBN Blade

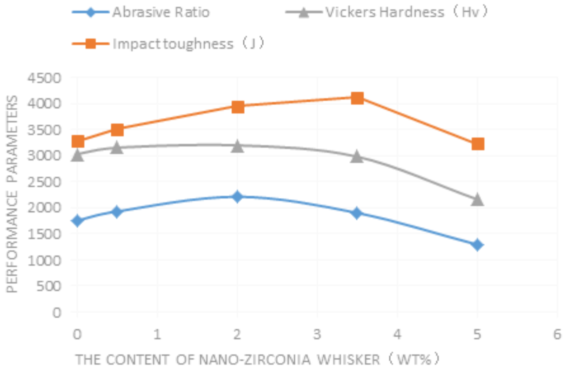
No. of the different positions of the same PCBN blade	1	2	3
Micro hardness/HV	2956	2983	2930

3.3 Toughening measures of PCBN cutting tool materials

The PCBN material with high content and fine particle CBN is brittle, especially in the interrupted cutting, and it may lead to the chipping of the cutting edge and even the breakage of the whole cutting blade. Therefore, it is necessary to study the toughening measures of the PCBN cutting tools (Yang, 2015).

To study the toughening effect of PCBN cutting tool (Zhang, 2015), mix the raw materials according to the formula, as shown in table 1, and add and mix the nano Zirconium Oxide whisker (diameter <300nm, length diameter ratio between 4-10) with different proportions of weight into the mixed raw material. And then sinter at high temperature and high pressure, and after that, the abrasive ratio, the Vivtorinox hardness and impact toughness of the resulting PCBN cutting tool materials are shown in Figure 5.

As illustrated in Figure 5, nano zirconia whisker has great influence on performance of PCBN materials, especially has the greater influence on the impact toughness of PCBN cutting tools. However, the performance of PCBN cutting tool materials is not linear increase with the adding amount of nano zirconia whisker, but there is an optimal range. With the content increase of nano zirconia whisker, the vickers hardness and impact toughness of PCBN cutter are improved accordingly. When the content of nano zirconia whisker is increased to a certain value, the vickers hardness reaches its maximum, but the impact toughness does not reach the optimum value, which only reaches its maximum when the content of the nano zirconia whisker continues to increase to another proportional value. The change of wear ratio with whisker content is the same as that of vickers hardness. Therefore, the addition ratio of nano zirconia whisker should be considered and tested comprehensively according to the material composition, the material to be machined and the cutting state, the performance requirements and the cost of the cutting tools. When in continuous cutting, a small amount of nano zirconia whisker can be added to make PCBN cutting tools have the highest hardness. When in intermittent processing, more nano zirconia whisker can be added to make PCBN tools have the best impact toughness. Figure 6 shows the SEM diagram of the PCBN cutting tool material added with zirconia nanocrystalline whisker.



Symbols: (♦) Abrasive Ratio; (▲) Vickers Hardness(Hv); (■) impact toughness(J)

Figure 5: Relationship Curves between Zirconia Whisker Content and Performance Parameters

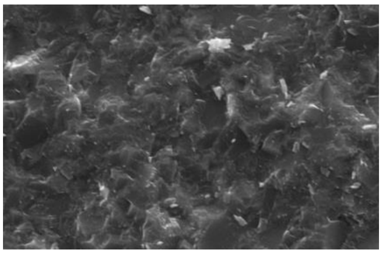


Figure 6: SEM Diagram of the PCBN Tool Material Added Zirconia Nanocrystalline Whisker

4. Machining test of PCBN tool material

The machined workpiece is the brake disc of the automobile, whose material is HT250 and hardness is HBS187-241. The inner and outer surface of the part need to be finish machined. The outer end part is the discontinuous cutting and the rest of the surface is continuous fine turning. The experimental cutting parameters are: linear velocity vc= 400m/min; cutting depth αp= 0.3mm; and the feed f = 0.05-0.3 mm/r.
Cutting experimental results show that the PCBN cutting tools prepared by the method in this paper can be used in the finish machining of the automobile brake disc to ensure the drawing requirement of surface roughness Ra1.6, and by changing the cutting parameters, the machined surface roughness of the parts can reach the processing quality between Ra1.6 and Ra0.4.

5. Conclusion

(1) Through a large number of experiments, a kind of PCBN cutting tool materials for fine finishing of cast iron parts are determined, which are made of fine grain CBN and binders. According to this formula, the PCBN cutting tool sintered by high temperature and high pressure can machined the surface of the cast iron parts to reach the surface roughness between Ra1.6-0.4.
(2) According to the determined technological parameters in this paper, the wet ball milling process is used to avoid the agglomeration of fine particle powder. The micro hardness of the different PCBN cutters and the

micro hardness in different positions of the same PCBN cutter are similar, which are prepared by using the wet ball milling process and the optimum parameters, and it is also proved that the stability of blade quality can be guaranteed by this method.
(3) With the aid of XRD analysis and micro hardness testing methods, it is more scientific to determine the optimum sintering parameters of PCBN cutting tools, which can ensure the stability of the performance and quality of PCBN cutting tool materials.
(4) Zirconium oxide nano whisker can improve the performance of PCBN tool materials, especially for the impact toughness of PCBN cutting tool materials, but the adding amount of nano zirconium oxide whisker has a best proportion and needs to be determined accurately through the experiment so as to ensure the best impact toughness for the severe intermittent cutting conditions.

Reference

Cheng M., Liu Y., Wu H., 2016, Effects of parameters of high-energy ball-milling on properties of TiH2 and Mg powder, Materials Science and Engineering of Powder Metallurgy, 21(4), 626-631.
Li Y., Xu H.W., Zhang J., 2016, Effects of Pressure on the Sintering Properties of PCBN Composite and Sintering Mechanism, Chinese Journal of High Pressure Physics, 30(5), 363-368.
Lv R., Liu J., Li Y.J., 2008, High pressure sintering of cubic boron nitride compacts with Al and AlN, Diamond and Related Materials, 17(12), 2062-2066.
Ma Y., Li J., Wang H.L., 2016, High Pressure and High Temperature Sintered PcBN Using Al, B4C and C as Sintering Additive, Key Engineering Materials, 697, 521-525, DOI: 10.4028/www.scientific.net/KEM.697.521.
Nie J.J., Li H., 2016, Development of PCBN Cutting Tool Material for Hardened Steel in High Speed Finish Machining, Tool Engineering, 50(6), 60-63.
Ren Z.H., Zhang R., Wang H.L., 2010, Preparation and Characterization of Polycrystalline Cubic Boron Nitride(PcBN) Compacts by a Pressureless Sintering Process, Advanced Materials Research, 105-106(1), 38-41, DOI: 10.4028/www.scientific.net/AMR.105-106.38.
Su J., Zhang Y.H., Wang D., 2016, Application and Advance in Super-Hard Tool Material, Applied Mechanics and Materials, 84-85, 228-231.
Xiao P., Lv S.L., Wu S.S., 2016, Fabrication of Nano-SiCp/ZL101 Composites by High Energy Ball Milling Combining with Stirring Casting Technology, Special Casting & Nonferrous Alloys, 36(2), 208-211.
Xie H., Feng F., Fang H.J., 2013, Influence of ratios of CBN-TiC-Al on PCBN properties, Diamond & Abrasives Engineering, 33(1), 31-35.
Xie H., Xu H.M., Feng F., 2014, Synthesis and Performance of PCBN for Cutting Tool in φ 51 mm Diameter, Tool Engineering, 48(9), 16-19.
Xu H.L., Wang Y.C., Wan X.D., 2012, Effect of Al content on the microstructure and properties of PcBN compact, Diamond & Abrasives Engineering, 32(1), 1-3+7.
Yang J., 2015, Study of in situ growth nano-whisker ceramic tool, Hebei University of Technology.
Zhang R.H., 2015, Study on particle whisker synergistic toughning ceramic tool material, Hebei University of Technology.
Zhang W.Z., Cai X.L., Hu C., 2016, Research of fracture mechanism and defects of MWCNTs by wet ball milling, Journal of Functional Materials, 47(1), 1163-1168.
Zhang Y.C., Wang M.Z., 2009, Effect of sintering temperature on the structure and properties of polycrystalline cubic boron nitride prepared by SPS, Journal of Materials Processing Technology, 209(1), 355-359, DOI: 10.1016/j.jmatprotec.2008.02.005.
Zhu J.F., Dong Q.M., Peng J., 2011, Effect of Ti(C, N) on properties of PcBN compact, Diamond & Abrasives Engineering, 31(2), 66-69.