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A Research on the Ultra-precision Polishing Technology of the Abrasive Flow of the Nozzle

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In this paper, the work of the research on ultra-precision polishing technology of the abrasive flow of the nozzle has been done, through theoretical analysis, design and research experiment, the design and development of abrasive flow polishing equipment and related research work of process test have been completed, solving the technical problems of abrasive preparation. A lot of cost for enterprises has been saved, which is of great significance to the further research of abrasive flow polishing small holes.

1. Introduction

Abrasive particle types which are commonly used have: silicon carbide, cubic boron nitride, Aluminium oxide, etc.
Silicon carbide is also known as emery or refractory sand, at present, silicon carbide of China's industrial production is divided into black silicon carbide and green silicon carbide, they are six square crystals with the specific gravity of 3.25 - 3.20, and micro-hardness is 2840 332Okg/mm'. Silicon carbide is formed by using quartz sand and petroleum coke (or coal coke), wood chips (need to add salt to produce green silicon carbide) and other raw materials to be smelted in the resistance furnace through the high temperature. Its hardness is between corundum and diamond, and its mechanical strength is higher than corundum, brittle and sharp. Green silicon carbide, containing SIC of more than 7%, is mainly used as grinding hard gold tools (Ji and Tang, 2010). Another one is black silicon carbide, has metallic lustre and contains SIC of more than 95%, whose strength is larger than that of the green silicon carbide, but the hardness is lower, is mainly used as grinding cast iron and non-metallic materials (Rajesh and Kozak, 2004).
Cubic boron nitride is synthetized of hexagonal boron nitride and catalyst under high temperature and high pressure, and is a new type of high-tech products after the advent of artificial diamond. It has such excellent properties as high hardness, thermal stability and chemical inertia, good infrared property and wider band gap, its hardness is second only to diamond, but the thermal stability is much higher than that of diamond, and has greater chemical stability to metallic elements of iron series (Williams, 2008). Cubic boron nitride has two kinds of single crystal and polycrystalline sintered body. Single crystal is made from hexagonal boron nitride and catalyst within the pressure of 3000 - SO00Mp and the temperature of 800℃ - 1900℃. A typical catalyst material is selected from alkali metal, alkaline earth metal, tin, lead, antimony and their nitrides. Crystal forms of cubic boron nitride crystal have tetrahedral truncated cone, octahedron, distorted crystal and crystals, etc. Cubic boron nitride produced by industry has black, amber colour and surface plated metal, and the particle size is usually below plus M. It has better thermal stability than diamond and chemical inertia to the iron group metal, which is used to manufacture the abrasive tool, and suitable for processing hard and tough material, such as high speed steel, tool steel, die steel, bearing steel, nickel and cobalt base alloy, chilled cast iron, etc.. When cubic boron nitride abrasive tools are used for grinding steel, most of the high grinding ratio and the machined surface quality can be obtained. Grinding performance of cubic boron nitride abrasive tool is very good, which not only can process hard grinding materials and improve productivity, but also effectively improve the grinding quality of the workpiece (Li and Hao, 2012). The use of cubic boron nitride is a major contribution to metal processing, which has resulted in a revolutionary change in grinding, and is the second leap of grinding technology (Yin and Ramesh, 2004).

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Pure alumina is a white amorphous powder, commonly known as alum, with the density of 3.9 4.09/cm^3, melting point of 2050℃ and boiling point of 2980℃, it does not dissolve in water and is the amphoteric oxide, it can soluble in inorganic acid and alkaline solution, which has four kinds of allotropes, namely, knife alumina, J alumina, alumina, alumina, and has two varieties of Type A and Type R, and can be extracted from bauxite mine in industry. A type of alumina crystal existing in the nature is called corundum which often presents different colours due to containing different impurities. Corundum generally presents grey with blue or yellow, has a glass or metallic lustre, the hardness is second only to diamond and silicon carbide, and can resist high temperature (Williams, 2006). Corundum sand containing iron oxides is dark grey and dark black, often used as grinding material, used to make all kinds of abrasive paper, grinding wheel, grinding stone, also used for processing optical instruments and some metal products. Because the output of natural corundum is in short supply, in industry, often pure a-type alumina powder in high temperature electric furnace is sintered into artificial corundum, also known as fused corundum. It can withstand a high temperature of over 1800℃, is a raw material for the manufacture of advanced special refractory materials, has the characteristics of high mechanical strength, good thermal shock resistance, strong corrosion resistance, small thermal expansion coefficient, etc., used for manufacturing combustion chamber liner of rocket engine, nozzle, protective cover for radar antenna, atomic reactor materials, senior high -frequency insulating ceramics, high temperature heating elements, protection tube of the thermocouple, all kinds of furnace liner of high temperature furnaces, etc.. Artificial corundum is also used for the manufacture of precision instrument bearings and metal wire drawing tools (Zhang and Ding, 2014).

2. Selection of abrasive particle size selection

The most commonly used abrasive particle size has 60#, 150#, 240#, W10 and so on; the relationship between abrasive particle size and material removal rate is shown in Figure 1.

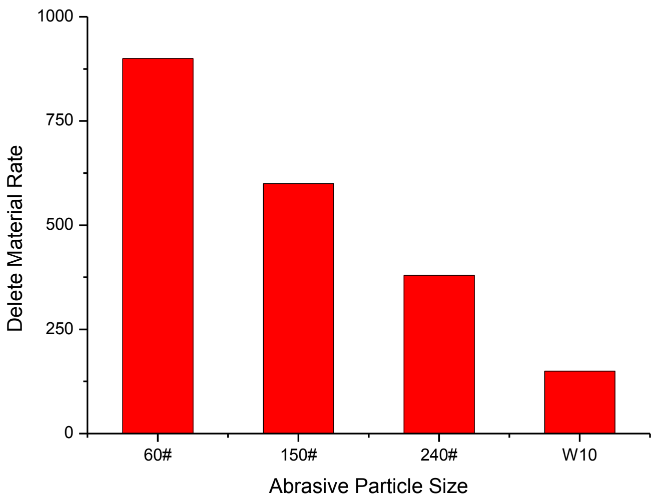

Figure 1 The relationship between the abrasive particle size and the material removal rate

It can be seen that the larger the abrasive particle sizes, the higher the squeezing efficiency is. But when the gap is smaller and the particle size of selected particles is too large, particles will be difficult to squeeze through the channel as a result of producing the "bridge" phenomenon; instead, the squeezing efficiency is reduced. If the roughness value before processing is larger and the particle size of selected particles is too small, then the squeezing efficiency will be reduced and squeezing time will be increased, not only can the surface quality reach the requirements, but also the shape accuracy will reduce, and the surface roughness value of the larger particle size after processing is relatively large. Therefore, the particle size of abrasive particles should be selected according to the requirements of roughness before squeezing, roughness after squeezing and the size of the gap of the channel, and before formal processing; particles should be filtrated with stainless steel mesh and undergoes homogenization treatment.

Usually, when polishing is the main, the thinner abrasive particles should be selected, when deburring and rounding are the main, coarser abrasive particles should be selected. Considering the nozzle orifice diameter must be 0.15mm, as well as the polishing efficiency and quality, the particle size of the selected abrasive particles should be 1200#.

3. Analysis for abrasive content

Abrasive particle content has very large effect on the polishing efficiency of abrasive flow, but with the increase of the abrasive content, the flowing of abrasive flow media in the hole will be slow. If at the time of the increase of abrasive, the matrix viscosity is unchanged, then the effect of the content of abrasive particles on the material removal rate is shown in Figure 2.

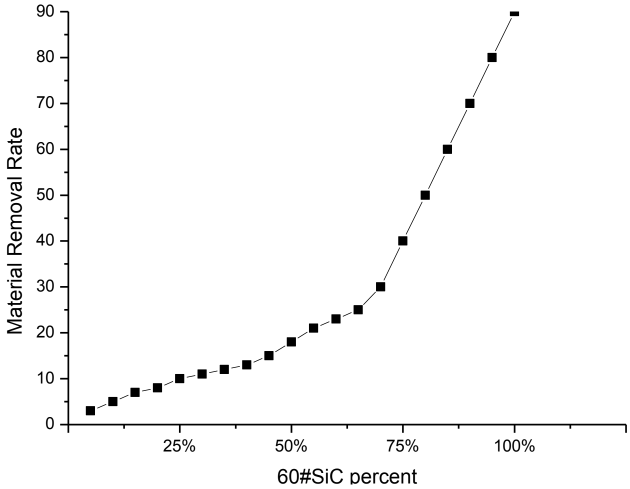

Figure 2: The influence of the abrasive content on the material removal rate

It can be seen from the figure above that the material removal rate of the abrasive ratio of 100% is about 60 times of that of abrasive ratio10%. However, the increase of the content of abrasive particles will reduce the flow of abrasives; moreover, the nozzle orifice diameter is very small, more content of abrasive particles but will affect the polishing efficiency.

Therefore, the selection of the content of abrasive particles in media accounting for about 30% - 50% of the total mass of the abrasives can meet the needs of the nozzle abrasive flow polishing, even though the material removal rate of polishing process is not high, the quality of processing can be ensured by working stroke and processing time, the determination of working stroke and processing time will be discussed in detail in the next chapter.

4. Calculation and selection of process parameters

4.1 Working pressure and abrasive flow rate

Different pressures should be selected for different abrasive flow processing purposes. If only the surface is required to enhance polishing, Pressure cannot be too high, higher pressure should be used for removing burr and fillet. When the work pressure is determined, the deformation of the workpiece which may be caused during machining should be also taken into consideration, so the thin-walled parts should choose the lower pressure. Besides, the effect of abrasive particle hardness and the channel size of the machining workpiece is also large. If the smaller the channel size is and the harder the abrasive particles are, the greater the required work pressure is. In addition to the bigger influence of working pressure, the abrasive flow rate is one of the important factors to determine the machining efficiency, the larger the abrasive flow rate is, the better the processing effect is. The thrust of electric push rod F_{push} =Z0000N, the radius of the abrasive cylinder is r0=40mm, the working pressure generated in the abrasive cylinder is

$$P=\frac{F_{push}}{A_0}=\frac{20000}{\pi\left(0.04\right)^2}\times10^{-6}MPa=3.98MPa \tag{1}$$

According to the continuity equation $v_0A_0=v_1A_1$, the flow rate of abrasive material in the nozzle orifice obtained is.

$$v_1=\frac{A_0}{A_1}v_0 \tag{2}$$

The nozzle diameter is d=0.15mm, so

$$A_1 = 5\pi\left(\frac{d}{2}\right)^2 = 5\times3.14\times\left(\frac{0.15}{2}\right)^2 = 0.088mm^2$$
(3)

Take two speeds of the electric push rod, respectively is V_1=1m/s and v_0'=2mm/s, then substitute them into equation (2), getting two test speeds

$$v_1 = \frac{\pi\times40^2}{0.088}\times10^{-3} = 56.9m/s \quad (4)$$

$$v_2 = \frac{\pi\times40^2}{0.088}\times2\times10^{-3} = 113.8m/s \quad (5)$$

4.2 Working stroke and processing time

Abrasive flow working stroke refers to the distance covered by squeezing abrasives once in the cylinder of the electric push rod pushing the piston during processing. General working stroke is unchanged; only control the number of repetitions. For the orifice like the nozzle orifice, abrasive flow rate is lower; it will take a long time to complete a working stroke. Machining time is one of the important factors to determine the surface quality. The longer the time is, the smaller the surface roughness value is, but the time is too long, instead, the surface roughness value is increased, there appear relatively deep scratches in the same direction as the abrasive flow.

According to the design parameters, a working stroke is 500mm, in the experiment, select two kinds of speed v=1m/s, v0'=2mm/s of electric push rod, then the processing time of a working stroke is completed, respectively is 500s and 250s. Based on the above analysis and calculation, the technological parameters of process test that will be conducted are shown in Table 1:

Table 1: Technological parameters of process test

Number	A	B	C	D	E
Pressure of work	3.69	369	3.69	3.69	3.69
Abrasive fringe	56.2	56.2	113.8	113.8	113.8
Work schedule	500	1000	500	1000	1000
processing time	500	1000	250	500	750

4.3 Test process

Five nozzles are selected in this process test should be conducted according to the technological parameters of Table 1, the specific test procedures are as follows:

(1) Cleaning before test: 0.4-0.6Mpa compressed air should be used to blow off nozzle inner cavity passage to ensure that there are no dust inside the cavity and other impurities.

(2) The nozzle and clamp should be fastened together to the abrasive cylinder reliably and to ensure that it is sealed.

(3) Stroke limit of electric push rod should be set up to ensure the stroke of 500mm, and the control power supply should be installed in place.

(4) The set speed of the electric push rod is v_0=1m/s.

(5) Open the feeding port, put the prepared abrasives in the abrasive cylinder, Close cover plate and fasten it with screws after it is full, The material collecting box is arranged at the front end of the nozzle and completely cover the nozzle in order to ensure the smooth recovery of abrasives.

(6) Press the electric push rod "push" button (the motor is forward), Electric push rod pushes piston to squeeze abrasive materials which flow through the nozzle orifice after passing through the clamp, the motor automatically stops when the front travel limit is reached, at this moment, press the electric push rod "pull" button (the motor reverses), Electric push rod pulls the piston back to the initial position, At the initial position is provided with the rear travel limit, the motor automatic stops operating, in this way, a working stroke is completed, namely, abrasive flow polishing of Part No. A nozzle orifice is completed.

(7) Remove the part number A and clamp, the Part No. B nozzle and clamp should be fastened together to the abrasive cylinder, steps 5 and 6 has been repeated twice, namely, abrasive flow polishing processing of Part No. B nozzle orifice is completed.

(8) The re-set speed of the electric push rod is v_0'=2mm/s.

(9) Carry out Part No. C, D and E in accordance with the above operation steps in turn, the process parameters of which are set according to Table 1.
(10) After the process tests of the 5 test specimens according to the corresponding parameters are fully completed, the power should turned off, all the abrasive materials in the cylinder should be recovered.
(11) Cleaning test pieces after test: First 0.4-0.6MPa compressed air should be used to blow off the inside and outside surface, most abrasive materials should be recovered, then soak the 3H in the aviation gasoline, the compressed air should be used again to blow away the residues and dry.

4.4 Test

(1) The injection effect of the nozzle which doesn't undergo abrasive flow polishing processing is obviously not good, as is shown in figure, the oil ejected from the oil ejection hole is like flowing out, so atomization is not complete.
(2) Abrasive speeds of Part No. A and B are 56.9m/s, Part No. A undergoes a working stroke polishing, Part No. B undergoes two working stroke polishing. The injection effect of Part No. A is slightly better than that of the nozzle which does not undergo abrasive flow polishing, and is not as good as that of Part No. B after twice processing stroke polishing, but atomization of Part No. B is also not complete.
(3) Abrasive speeds of Part No. C, D and E are 113.8m/s, it has just changed the polishing working stroke of three test pieces. It can be seen from the test chart that the injection effect of Part No. C is basically the same as that of Part No .B, which has not yet reached the best. The injection effect of Part No. D is very good and the atomization is complete, spray pattern also tends to be consistent with the geometric angle. The injection effect of Part No. E is basically the same as that of Part No. D, which has no more significant increase or decrease and the atomization, is also complete.

4.5 Analysis for test results

It can be seen from the above test results that as long as the process parameters are properly controlled, the nozzle undergoing the abrasive flow polishing processing can fully meet the design requirements, injection quality from the nozzle orifice can be greatly improved. By analyzing the test results of these pieces, we can know the results:
(1) Only when it achieves a certain working pressure and abrasive flow rate has achieve cutting action, achieving the purpose of removing burrs of the nozzle orifice and grinding and polishing the nozzle orifice wall.
(2) The abrasive flow polishing equipment dependently designed by us can ensure the required working pressure and abrasive flow rate.
(3) Under the circumstance of a certain working pressure and the same working stroke, it can be known from comparison of test pieces A and C, test pieces B and D that the greater the abrasive flow rate is, the better the processing effect is.
(4) under the condition of a certain working pressure and the same abrasive speed, the more working stroke is, namely, the longer the processing time is, the better the processing effect is. However, it can be known from comparison of test pieces D and E that when the processing time reaches a certain degree, the polishing effect is not very obvious.
(5) It can be known according to above analysis that the optimal processing parameters for the abrasive flow polishing of the nozzle: Working pressure is 3.98MPa. Abrasive flow rate is 113.8m/s. Working stroke is 500mmx2. Processing time is 500s.

5. Conclusion

In this paper, the work of the research on ultra-precision polishing technology of the abrasive flow of the nozzle has been done, through theoretical analysis, design and research experiment, the design and development of abrasive flow polishing equipment and related research work of process test have been completed, solving the technical problems of abrasive preparation. A lot of cost for enterprises has been saved, which is of great significance to the further research of abrasive flow polishing small holes.
The main conclusions obtained of this research are as follows:
(1) Through theoretical analysis of abrasive flow polishing processing technology, the pressure distribution model, velocity distribution model of abrasives in nozzle orifice and the force analysis model of abrasive particles are established, and in theory, flow characteristics of abrasive materials in small holes are analysed and its rule is grasped.
(2) Through detection and analysis after the process test, the process parameters of abrasive flow polishing processing are determined: The working pressure is 3.98MPa, the abrasive flow rate is 113.8m/s, the working stroke is 500mmx2 and the processing time is 500s, and the determination of these parameters provides the data support for the research of the polishing processing technology of the subsequent abrasive flow.

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