Journal of Manufacturing Science and Mechanical Engineering
ISSN: 2959-989X
DOI: 10.61784/msme240134

MECHANICAL PROCESSING TECHNOLOGY OF ENGINEERING CERAMICS

Todd Magleby
Department of Mechanical Engineering Brigham Young University.

Abstract: Engineering ceramics have many excellent properties such as high hardness, good wear resistance, and stable performance, so they have been widely used in various industries. Based on relevant research by domestic and foreign scholars, new methods of engineering ceramic processing technology have made great progress. Due to the significant hard and brittle characteristics of engineering ceramics, mechanical processing is the most commonly used traditional processing technology. Combining relevant literature and data in recent years, this article explains the successive development of engineering ceramics machining technologies at home and abroad such as high-speed/ultra-high-speed grinding, deep-cut creep-feed grinding, and high-speed deep grinding. In addition, two new processing technologies based on edge fragmentation effect, cutting-push processing and energy-assisted cutting processing, are also explained.
Keywords: Engineering ceramics; Machining technology; Research progress; Energy-assisted cutting

1 INTRODUCTION

Engineering ceramics have excellent properties such as light weight, corrosion resistance, high temperature resistance, small thermal expansion coefficient, thermal shock resistance, self-lubricating ability, wear resistance and low friction coefficient. They have been widely used in the energy engineering industry, automobile industry, Machinery industry, chemical and petroleum industry, aerospace field, metallurgical building materials industry, military engineering and other fields [1, 2].
Engineering ceramic processing technology is usually divided into three categories: special processing technology, composite processing technology and mechanical processing technology. At present, mechanical processing technology is the most widely used in engineering ceramic processing, among which the use of diamond grinding wheels for grinding processing technology is relatively mature. To improve
Many innovative processing concepts and new technologies for efficient grinding have been developed. In view of the fact that the processing process itself is a controllable destruction process of materials, the cutting-push processing technology based on the edge fragmentation effect takes full advantage of defects such as cracks and edge fragmentation. Although many advanced special processing technologies have been developed at home and abroad in the past ten years or so, their processes are imperfect and their processing costs are high, so they have not been widely used. However, energy-assisted cutting technology can improve the machinability of engineering ceramics and has become a hot spot in domestic research.

2 HIGH -EFFICIENCY GRINDING PROCESSING TECHNOLOGY

In 1958, the West German ELB Grinding Machine Company proposed a deep-cut creep-feed grinding method. It is characterized by a slow feed speed and a large amount of back cutting. It is an efficient grinding method [3-5] . G. Werner[6] experimentally studied and derived the grinding force model of deep-cut creep-feed processing, and pointed out that the grinding force of deep-cut creep-feed grinding is 2-4 times that of ordinary grinding processes. Using creep-feed ultrasonic grinding tests, German G. Spur et al. [7] studied the effects of processing parameters on the grinding force, grinding wheel wear, and machined surface roughness of alumina and silicon nitride ceramic materials during processing. conducted comparative analysis. American TW Liao et al. [8, 9] analyzed the grinding wheel wear mechanism and machined surface quality through deep-cut slow-feed grinding tests on alumina. Domestic experts and scholars have also conducted comprehensive and in-depth research on deep-cut slow-feed grinding processing technology. Using creep-feed grinding technology of engineering ceramics, Xu Yanshen, Zhou Canfeng. [10-12] conducted single-factor experiments and orthogonal experiments on characteristic parameters such as grinding force, and pointed out that the grinding force changes with the grinding width. It increases with the increase of workpiece speed and grinding depth, and decreases with the increase of grinding wheel speed, and the integrity of the machined surface is better than that of ordinary grinding. Luo Mingtao et al. [13] pointed out that a considerable part of the grinding heat in deep-cut creep-feed grinding will be taken away by grinding debris. The smaller the workpiece speed and grinding depth, the lower the grinding temperature. Since 2009, the Armored Forces Engineering College [14, 15] has conducted systematic research on the grinding method of small grinding wheels with large axial depth of cut and slow feed. The inner and outer surfaces of the workpiece are cut (the axis of the workpiece is parallel to the axis of the small grinding wheel), and the rotational speed of the workpiece is low. Since the size of the selected grinding wheel is small, there is no need to consider the issue of static balance or dynamic balance, and the cutting resistance encountered during the grinding process is small, the energy consumption is small, and the spindle power requirements of the equipment and machine tools are not high, so there are Helps reduce processing costs.

The concept of high-speed/ultra-high-speed machining was first proposed worldwide in the Salomon curve published by Dr. Carl. J. Salomon [16] in Germany in 1931. Generally, the grinding wheel linear speed reaching 45 m/s and 150 m/s can be used as the critical point value to define ordinary grinding, high-speed grinding and ultra-high-speed grinding. High-speed/ultra-high-speed grinding processing technology developed earlier and rapidly in European and American countries. In 1979, PGWerner et al. [17] from the University of Bremen predicted the rationality of high-efficiency deep grinding zones. In 1983, the University of Bremen and Guhring Automation cooperated to create the world's first machine tool that can be used for efficient deep grinding. The rated power is 60 kW, the spindle speed can reach r/min, and the circumferential linear speed of the grinding wheel can reach 209 m/s. In 2000, S. Malkin et al. [18] from the United States realized the grinding of silicon nitride ceramics using electroplated diamond grinding wheels under the processing condition of a linear speed of 149 m/s. In 1994, the German Junker Company [19, 20] developed high-speed point grinding technology with speeds up to 200 m/s using CBN or artificial diamond grinding wheels. Domestic research on high-speed grinding technology began in 1958. At present, some of the research results of ultra-high-speed grinding technology in key experiments on high-efficiency grinding at Hunan University and other institutions have reached the forefront of the world. Xie Guizhi of Hunan University and others [21, 22] conducted a series of studies on high-speed deep grinding processing technology and pointed out that the grinding depth has little effect on surface damage. Increasing the grinding wheel linear speed and grinding depth will help improve the processing efficiency, but It is not conducive to extending the service life of the grinding wheel. Carrying out high-speed grinding experimental research, Huang et al. [23] pointed out that accelerating the grinding wheel speed can increase the number of abrasive grains participating in grinding per unit time, and the maximum grinding depth of a single abrasive grain becomes shallower, which is conducive to realizing the plasticity of ceramic materials. removal, in addition to improving the machined surface quality of ceramics by reducing grinding depth and workpiece speed.

The material removal rate of deep-cut creep-feed grinding is high, which is conducive to improving production efficiency; and the grinding wheel wear is small, which is conducive to ensuring the stability of the machining accuracy of the workpiece; however, due to the large grinding depth, it is difficult for the grinding fluid to enter the cooling, which The grinding heat is large and the workpiece is easily burned; the large grinding force places high requirements on the rigidity and power of the grinding machine tool. Research on high-speed/ultra-high-speed grinding of engineering ceramic materials at home and abroad often requires increasing the grinding wheel speed and increasing the amount of back cutting, but it has very strict requirements on the strength of the grinding wheel to ensure that it will not break under high-speed rotation; its grinding The force is large, the power of the grinding wheel transmission system and the rigidity of the machine tool are high, and the cost of equipment and other equipment is too high. In the traditional processing method of contact grinding engineering ceramics using machining tools, the tool must be made of materials with a hardness greater than that of engineering ceramics. At the same time, due to the high hardness of ceramic materials, the machining tool is seriously lost during the entire process, making the processing cost higher. .

3 CUTTING-PUSH PROCESSING TECHNOLOGY BASED ON EDGE FRAGMENTATION EFFECT

During the conventional grinding process of engineering ceramics, due to thermal stress, mechanical stress, etc., brittle damages such as grinding surface/subsurface cracks, surface crushing, and edge chipping will occur. They occur randomly and are difficult to control. The defect front forms local stress concentration, which can easily cause the initiation or expansion of cracks within the material, becoming a potential crack source that damages the surface quality and strength performance of ceramic grinding. Because engineering ceramics are very sensitive to defects such as cracks and residual tensile stress, it is generally difficult to control the quality of engineering ceramics during processing. In fact, the processing process itself is a controllable destruction process of materials. Based on this principle, the Armored Corps Engineering College began to study the cutting-push processing technology of engineering ceramics based on the edge fragmentation effect in 2013 [32, 33] . Figure 1 is a schematic diagram of the new technology's processing, and Figure 2 is the actual processing process recorded using high-speed cameras. It is precisely the multiple flanges formed by cutting that increase the number of edges, and crack defects are prefabricated in the grooves, so that the edge crushing effect easily occurs during the processing process, causing the cracks to expand to form chips, thereby achieving surface material removal. Under the combined effects of the external three-dimensional tensile stress field and the relaxation of the free edge surface stress field, the interior of the ceramic material successively undergoes the rapid expansion, penetration and fracture process of prefabricated micro-cracks until the material is broken and removed.

This new processing method promotes the transformation of crack defects from "harm" to "benefit" under specific conditions, thereby greatly reducing the constraints of traditional ceramic processing that relies on external input of high energy and can only be processed with ultra-high hardness tools. Tools with lower hardness can be processed with less energy consumption. This new technology does not rely on the "cutting" function in the ordinary sense, so there is no requirement for the sharpness of the blade of the pushing tool, and it can even use scrapped turning tools to save costs. This new processing method will help change the current situation of high ceramic processing costs and help promote the widespread use of engineering ceramic materials.

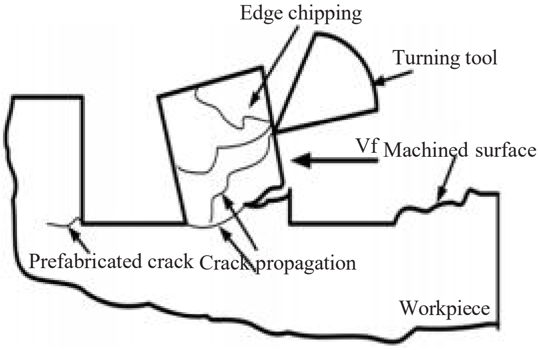

Fig. 1 Processing principle diagram

Fig. 2 High-speed video of the crushing process

4 ENERGY-ASSISTED CUTTING TECHNOLOGY

Ultrasonic vibration-assisted cutting makes full use of the pulse cutting effect caused by vibration, which is beneficial to reducing the friction between the tool and the workpiece in hard cutting, and improving cutting temperature and cutting force. Zhou Zehua, Ye Bangyan and others [24] conducted research on ultrasonic vibration turning systems, using the regular forced vibration of the tool to improve the processability of hard and brittle materials.

In 2003, Wu Zhiyuan et al. [25] of the Armored Forces Engineering Institute used ultrasonic vibration-assisted cutting technology for the turning process of plasma sprayed Al2O3+13%TiO2 ceramic coating. Sufficient experimental research showed that ultrasonic vibration-assisted cutting can be significantly effective. To improve the durability of the tools, their effective cutting time is 4 times that of ordinary turning. Guo Weiguang, Wang Jun, etc. [26, 27] have successively studied ultrasonic vibration-assisted turning and grinding processes, and both have shown that it can better reduce residual cracks on the machined surface and effectively improve the processing quality.

In 1978, SMCopley and M. Bass in the United States were the first to carry out research on laser heating-assisted cutting. They used laser irradiation to material in front of the cutting edge for auxiliary cutting, reducing cutting force, extending tool life, reducing surface roughness, and reducing residual stress. Purdue University in the United States [28, 29] conducted many experiments on Si3N4, mullite and other ceramic materials through comparison, and established a mathematical model and a physical model of three-dimensional instantaneous temperature field transfer. Shin YC et al. [30] conducted laser heating-assisted grinding experiments on ceramics such as silicon nitride, alumina, and zirconia. They can reduce the brittleness and hardness of the material through local preheating of the material, and achieve the brittleness removal direction of the ceramic material. Transformation of plastic removal. Heating-assisted cutting technology has also been a hot topic in the domestic research community in recent years, and scholars have carried out a large number of research experiments. Jin Xiangzhong, Chen Pei and others from Hunan University [31] also successively constructed temperature field mathematical models for the heating areas of silicon nitride ceramics and alumina ceramics during CO2 laser-assisted heating turning, and studied the CO2 laser-assisted heating turning process through a large number of experiments. cutting force, chip shape, tool wear and surface quality after processing. However, the heating-assisted cutting process inevitably leads to an increase in tool temperature, which sometimes leads to serious tool wear. In addition, due to the uneven heating-assisted temperature in the area to be processed, the material of the workpiece softens from the surface to the inside. The degree of cutting gradually weakens, and changes in material hardness cause the tool to receive uneven reaction forces from the workpiece during the cutting process. Therefore, it is necessary to appropriately select the cutting depth to prevent serious wear and tear of the tool tip or even chipping. At the same time, a reasonable selection of the cutting depth is also beneficial. Improve the surface processing quality of the workpiece and prevent surface cracks on the workpiece.

5 CONCLUSION

The hard and brittle characteristics of engineering ceramics make it a typical difficult-to-process material, thus becoming a "bottleneck" hindering its development. Driven by market demand in various industries in recent years, it has undoubtedly promoted the rapid further development of ceramic processing technology. Grinding is a typical material finishing method. It has been deeply promoted on hard and brittle materials and the technology has become more mature. Technologies such as high-speed/ultra-high-speed grinding, deep-cut creep-feed grinding, and high-speed deep grinding have been developed. And it will still be the most conventional and reliable processing method for engineering ceramics for a long time in the future, and will continue to promote the increasing progress of related technologies of processing systems such as grinding machine tools and grinding wheels. Grinding processing will increasingly tend to be high-efficiency, high-precision, and low-cost. cost. The cutting-push processing technology based on the edge fragmentation effect provides a high-efficiency, low-cost new mechanical processing method. For the first time, it cleverly utilizes defects such as prefabricated cracks and edge fragmentation effects to consume less energy and is lower than the processed material. Rough machining can be achieved with tools that process the hardness of the material. In order to meet the industry's urgent demand for high precision and high quality of ceramic parts, engineering ceramic surface ultra-precision grinding, grinding and polishing processing technologies have also received attention. In addition to mechanical polishing, elastic emission processing, interface reaction polishing, magnetic fluid polishing, etc. Polishing technology has also been vigorously developed and widely used.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

[1] JOO JK, LEE BHWA, KIM T H. Method of manufacturing multilayer ceramic electronic component: US 14/981, 650. 2015-12-28.
[2] PAWAR K. New tendencies in manufacturing in ceramic industry . International Journal of Ceramics and Ceramic Technology, 2016, 2(1): 18-20.
[3] Ning Xin, Yao Jianguo, Su Jianxiu. Analysis of the influence of nanoceramic grinding depth on surface quality. Aviation Manufacturing Technology, 2015, 16: 96-97.
[4] MOHAMED AO, BAUER R, WARKENTIN A. Application of shallow circumferential grooved wheels to creep-feed grinding. Journal of Materials Processing Tech., 2012, 2013, 213: 700-706.
[5] Wu Zhibin. Bottlenecks and Countermeasures of High-efficiency Grinding. Nanjing: Nanjing University of Aeronautics and Astronautics, 2001.
[6] WERNER G. Influence of work material on grinding force. Annals of the CIRP, 1978, 127(1): 243-248.

[7] SUR G, HOLL S E. Ultrasonic assisted grinding of ceramics. Journal of Materials Processing Technology, 1996, 62(4): 287- 293.
[8] LIAO T W. Flexural strength of creep feed grinding ceramics: General pattern, ductile-brittle transition and MLP modeling . International Journal of Machine Tools and Manufacture, 1998, 38(4): 251-275.
[9] LIAO TW, LI K, MCSPADDEN S B. Wear of diamond wheels in creep-feed grinding of ceramic materials I: Mechanisms. Wear, 1997, 211(1): 94-103
[10] Zhang Ke, Qi Yufei, Wang He. Finite element simulation and experiment of grinding mechanism of zirconia ceramics. Journal of Shenyang Jianzhu University (Natural Science Edition), 2014, 03: 523- 529.
[11] Shen Jianyun. Analysis of grinding mechanism and thermal characteristics of structural ceramics. Tianjin University, 2004.
[12] Hou Yonggai, Tian Jiugen, Lu Jihong. Research status of grinding processing of zirconia ceramics. Chinese Ceramics, 2014, 09: 6-9.
[13] Bi Xuefeng, Yang Chengsan, Jing Lulu. Experimental study on deep-cut creep-feed grinding burns. Journal of University of Shanghai for Science and Technology, 2014, 03: 303-306.
[14] TIAN XL, GUO F, MAO Y T. Mechanism analysis of high efficiency axial turn-grinding of engineering ceramics. Key Engineering Materials, 2011, 487: 376-380.
[15] GUO F, ZHANG BG, LU H. High efficiency axial deep creep-feed grinding machining technology of engineering ceramics materials. Journal of Wuhan University of Technology-Materials Science Edition, 2012, 27(5): 902-906.
[16] Shang Zhentao, Guo Zongfu, Xie Guizhi. Experimental study on high-speed and ultra-high-speed grinding performance of cermet materials. Manufacturing Technology and Machine Tools, 2012, 07: 144-148.
[17] LAWN BR, MARSHALL D B. Hardness, toughness and brittleness: An indentation analysis. Am Ceram Soc, 1979, 62: 347-351.
[18] Zhao Henghua, Song Tao, Cai Guangqi. Development trends of grinding processing technology. Manufacturing Technology and Machine Tools, 2012, 01: 55-58.
[19] Gong Yadong, Cao Zhenxuan, Liu Yueming. Effect of high-speed point grinding parameters on temperature field and surface hardness. Journal of Northeastern University (Natural Science Edition), 2012, 03: 414-417.
[20] Yu Haitao, Du Ruixue. Application of ultra-high-speed grinding technology in the field of machinery manufacturing. Coal Mining Machinery, 2012, 04: 134-136.
[21] HUANG H. Machining characteristics and surface integrity of yttria stabilized tetragonal zirconiain high speed deep grinding. Materials Science and Engineering, 2003, A345: 155-163
[22] Xie Guizhi. Research on the mechanism and thermal phenomena of high-speed deep grinding of engineering ceramics. Hunan University, 2009.
[23] HUANG H, YIN L, ZHOU L B. High speed grinding of silicon nitride with resin bond diamond wheels. Journal of Materials Processing Technology, 2013, 141: 329-336.
[24] Xie Zhiping, Liu Guoxiao, Liu Guozhong. Research progress of ultrasonic vibration cutting technology. Ordnance Materials Science and Engineering, 2015, 02: 133-136.
[25] Wu Zhiyuan, Liu Guimin, Tian Xinli. Plasma spraying Al2O3+13%TiO2 ceramic coating in ultrasonic vibration turning. New Technology and New Technology, 2003, (6): 13-14. WU ZY, LIU GM, TIAN X L . New Technology & New Process, 2003 (6): 13-14.
[26] Duan Shiwei. Research on static and dynamic mechanical properties and damage characteristics of ceramic materials. University of Science and Technology of China, 2013.
[27] Jiao Feng. Mechanism and experimental research on high-efficiency grinding of ultrasonic-assisted fixed abrasives for engineering ceramics. Shanghai Jiao Tong University, 2008.
[28] REBRO PA, SHIN YC, INCROPERA F P. Laser-assisted machining of reaction sintered mullite ceramics. Journal of Manufacturing Science and Engineering, 2002, 124(4): 875- 885.
[29] TIAN Y, WU B, ANDERSON M. Laser-assisted milling of silicon nitride ceramics and inconel 718. Journal of Manufacturing Science and Engineering, 2008, 130(3): 310131-310139.
[30] TIAN Y, SHIN Y C. Laser-assisted machining of damage-free silicon nitride parts with complex geometric features via in-process control of laser power. Journal of the American Ceramic Society, 2006, 89(11): 3397-3405.
[31] Chen Pei. Research on laser heating-assisted cutting of engineering ceramic materials. Hunan University, 2006.
[32] Tian Xinli, Wang Long, Wang Wanglong. Research on surface characteristics of ceramic push processing based on GLCM and NN. Journal of Intraocular Lenses, 2014, 43(9): 2358-2365.
[33] Tian Xinli, Wang Long, Wang Wanglong. Experimental study on crushing simulation based on edge crushing-driven crack push processing. Journal of Intraocular Lenses, 2014, 43(10): 2726-2731.