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Research Review and Development Trend of High Temperature Alloy Deep Hole Drilling Tools

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Abstract

High temperature alloy deep hole drilling tool is an important tool for metal deep hole drilling. In this paper, the development status of superalloy deep hole drilling tools is reviewed from the aspects of optimization design of deep hole drilling tools, vibration and stability of deep hole drilling tools, wear and durability of deep hole drilling tools. The shortcomings and problems of current research are pointed out, and the future development trend and research direction are prospected.

Keywords

Deep Hole Drilling Tool; Drilling Tool Optimization; Drilling Tool Vibration; Drilling Tool Wear; Metal Deep Hole Drilling.

1. Introduction

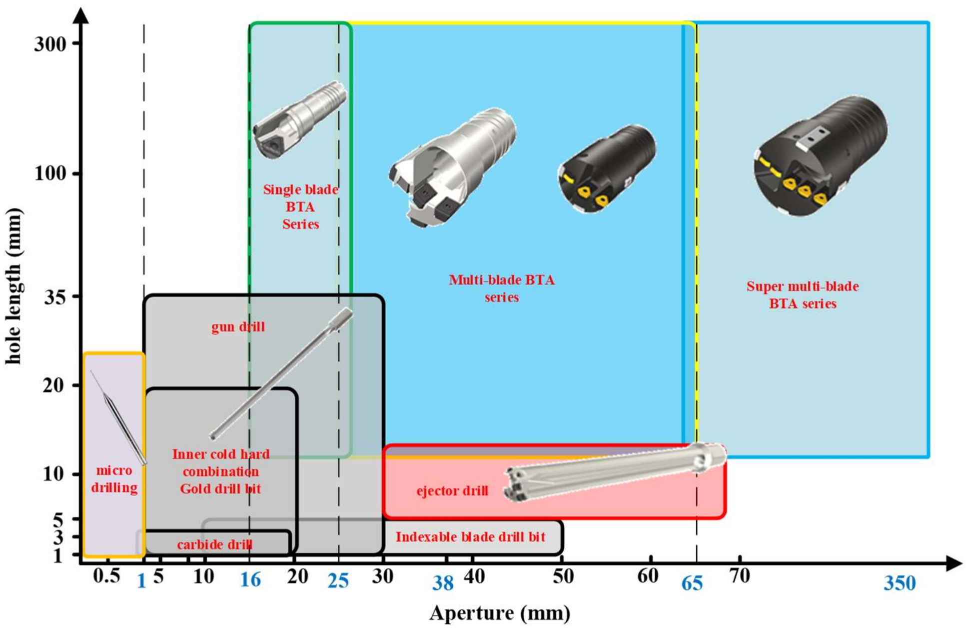

Fig. 1 Hole processing The processing range of each drilling tool

As an important processing method in machining, deep hole drilling is widely used in various fields. Improving the durability of deep hole drilling tools, making the processing quality of deep holes better, and developing high-temperature alloy deep hole drilling tools with better performance are the main research directions of deep hole drilling. In the hole processing, the processing range of the hole is also different (Fig.1). Generally, the hole with the aspect ratio (L / D, L is the hole depth, D is

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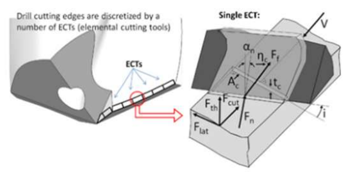
the diameter) less than 5 is called shallow hole processing, the hole with the aspect ratio greater than 50 is called deep hole processing, and the hole with the aspect ratio greater than 100 is called ultra deep hole processing. The deep hole drilling tools mainly include twist drill, gun drill, BTA drill and jet suction drill, among which twist drill, gun drill and BTA drill are the most widely used. As an important branch of the tool field, many scholars at home and abroad have carried out a lot of research on deep hole drilling tools.

The development status of superalloy deep hole drilling tools is reviewed from the aspects of optimization design of deep hole drilling tools, research on vibration and stability of deep hole drilling tools, wear and durability of deep hole drilling tools. The existing technical problems are pointed out, and the future development trend is prospected.

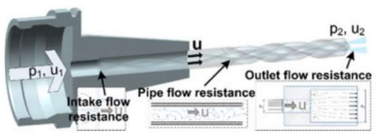
2. Development Status of High Temperature Alloy Deep Hole Drilling at Home and Abroad

2.1 Optimization Design of Deep Hole Drilling Tool

At home and abroad, the optimization of deep hole drilling tools is mainly based on structural optimization and tool parameter optimization. Structural optimization is to optimize the position of the blade, the guide block, the shape of the tool holder, and the chip discharge port. The optimization of tool parameters is mainly aimed at optimizing the geometric parameters of the tool tip and the geometric parameters of the chip outlet.



(a)



(b)

Fig. 2 (a) Drilling mechanics model (b) Flow resistance model

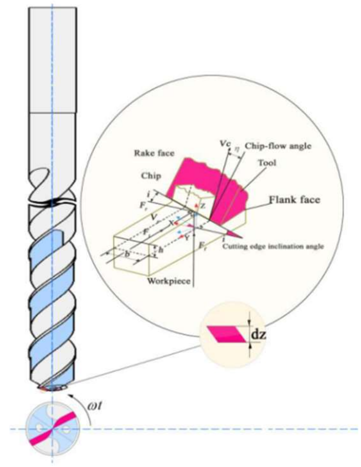


Fig. 3 Mechanical model of twist drill

In the tool tip optimization method, Abele[1] proposes to use fitness and constraint functions to simulate the stiffness and strength, torque and thrust, coolant flow resistance (Fig.2), chip removal capacity and chip removal groove grindability of the twist drill. Combined with the meta-heuristic algorithm, the optimization design of the geometric parameters of the twist drill is realized. Meral[2] uses S / N analysis method and grey correlation analysis method to carry out single-objective and multi-response optimization, and obtains the optimal geometric parameters and cutting parameters of twist drill. Li[3] Aiming at the optimization of geometric parameters of deep hole twist drill, a three-dimensional parametric model is established. Combined with the mathematical principle of multiple nonlinear regression, the tip parameters are optimized by iterative genetic algorithm. However, some scholars have optimized it from the perspective of drilling force. Yueen[4] used the empirical model and geometric model to establish the vector relationship of cutting force (Fig.3), deduced the cutting mechanics formula, and optimized the chisel edge and main cutting edge of twist drill. Wang[5] studied the influence of deep hole structure and drilling process on the drill bit, established the BTA drill model, analyzed the force of cutting edge, tooth edge and guide block, and optimized the tool tip parameters. The reliability of the optimized tool was verified by establishing the cutting model of the cutting port. Zhu[6] deduced the functional relationship between the tooth width and the cutting force of the multi-edge BTA drill bit, and realized the drilling of difficult-to-machine materials by optimizing the width and position of the drill bit.

At present, the mainstream tool optimization method is to establish a simulation model, cut in from different research priorities, improve the tip parameters of specific parts, and verify the feasibility of optimization through drilling experiments. Woon [7] In order to improve the cooling effect of the gun drill, based on the hydrodynamic model of the cutting fluid, the geometric shape and parameters of the nozzle of the gun drill are optimized and designed (Fig.4). The superiority of the kidney-shaped cooling hole is verified by drilling comparative experiments. Shi[8] studied the influence of the tooth position and geometric parameters of the drill bit on drilling, established the mechanical model of the blade and the guide block (Fig.5), verified the feasibility of the model by trial cutting experiment, and optimized the angle of the middle tooth and the inner tooth of the blade. Based on the failure mode of micro-deep hole drilling, Liang[9] established a micro-drilling model, analyzed the factors affecting the stiffness and strength of micro-drilling, and optimized the geometric parameters of the drill tip to enhance the stiffness and strength of micro-deep hole drilling. Zhao Hongbing[10] of Xi 'an Petroleum University optimized the rake angle, clearance angle and offset of the BTA blade, and carried out experiments on drilling titanium alloy with BTA blades of different materials to obtain the best blade parameters and materials. Feng Bin[11] improved the structure of BTA drill, designed a four-stage symmetrical blade structure and a new impact flow channel structure, and analyzed the model from dynamics, fluid characteristics, modal analysis and harmonic response, which provided a theoretical basis for the optimization of BTA drill structure. Professor Wu Xuefeng[12] optimized the structure of the BTA drill, such as the diameter of the BTA drill, the conical surface of the chip outlet, the deflection angle of the outer edge, the rake angle and the back angle of the cutting edge, and the chip removal groove. The cutting process and chip formation process of different teeth in the drilling model were observed, and the influence of different tooth angles on the cutting force and torque was analyzed.

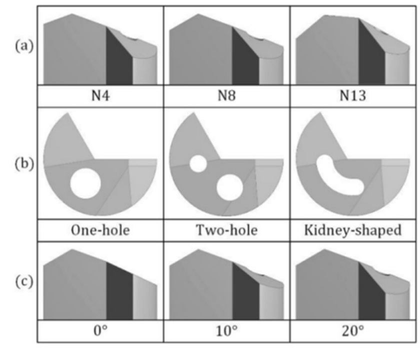


Fig. 4 Gun drill design structure and parameters (a) nose grinding profile ; (b) Coolant hole configuration ; (c) Shoulder elimination angle

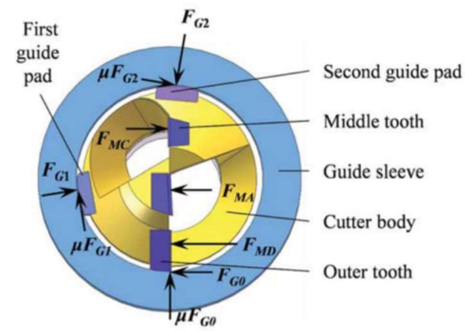


Fig.5 BTA drill mechanics analysis model

In the field of guide block optimization, Li[13] established a contact simulation model between the BTA guide block and the hole wall, compared the actual wear of the guide block, and summarized the change law of the contact stress between the guide block and the hole wall, which provided a reference for the study of the guide block. Based on the mechanical model of BTA drill, Han Xiaolan[14] calculated the stability of the guide block mathematically. From the dynamic and harmonic response analysis model, it is concluded that the arrangement position of the guide block is an important factor affecting the tool vibration and the surface roughness of the aperture.

The problem of chip removal in deep hole drilling has always been a difficult point in deep hole processing. Therefore, solving the problem of chip removal from the tool structure has always been a research hotspot in the optimization of deep hole drilling tools. Biermann[15] used the finite element method to calculate the internal stress of the drill bit in order to solve the problem that the long debris produced by the BTA drill blocked the inside of the tool body, improved the morphology of the chip discharge port, reduced the tool holder material, and enhanced the circulation of the chip (Fig.6). Taking the radius of the front nozzle of Zhang[16] as the optimization object, a three-dimensional flow field model was established, and the optimal radius of the front nozzle was obtained by using the analytic hierarchy process and the fuzzy comprehensive evaluation method. Tnay[17] studied the influence of deflection angle on the cutting outflow rate by establishing the linear and rotational fluid dynamics models of gun drill cuttings, and verified that small shoulder resection can promote the discharge of chips. Domestic scholars have also studied the problem of chip removal. In 2005, Liu Zhaohua[18] first proposed the internal mechanics research of DF jet suction pump, which provided a theoretical basis for the internal fluid mechanics of deep hole cutting tools. Ren[19] used the influence of fluid on the BTA drill to calculate the mechanical relationship between the fluid and the drill shaft, and used the principle of negative pressure chip extraction to achieve high-speed chip discharge, and optimized the throat structure of the jet drill. The effectiveness of the throat structure optimization was verified by drilling simulation experiments. He Caicai[20] added a rotary jet hole at the back end of the throat. Based on the fluid dynamics simulation model, the influence of different jet hole positions, angles and diameters on the chip removal efficiency was observed, and the optimal rotary jet hole parameters were obtained, which provided a scheme for the flow channel design of BTA drill.

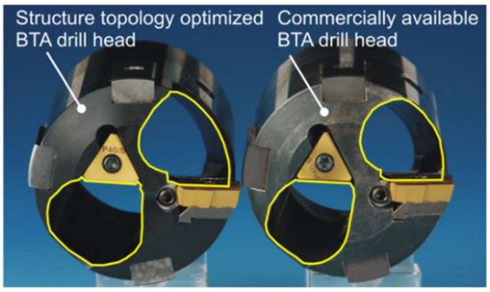


Fig.6 Comparison of topology optimization and commercially available BTA drill bit

From the existing research, although the optimization of deep hole drilling tools has gone through many years of development, and the optimization of the structure and parameters of drilling tools such as tool tip, chip discharge port and guide block is becoming more and more mature, the optimization of small deep hole drilling tools and ultra-large diameter deep hole drilling tools has not been carried out in theory and practice. In-depth research, especially the optimization of deep hole drilling tools with a diameter of less than 1mm and more than 65mm, is still a problem to be solved.

2.2 Research on Vibration and Stability of Deep Hole Drilling Tool

The vibration problem of deep hole drilling tool during drilling has always been the focus and difficulty in deep hole processing. The mechanism of deep hole drilling vibration, the suppression of drilling tool vibration, the detection and prediction of drilling tool vibration are the three main directions of deep hole drilling vibration and stability research at this stage.

The research on the vibration mechanism of deep hole drilling has always been an important subject of deep hole drilling vibration. In the study of the vibration principle of basic deep hole drilling, Li Bomin[21] analyzed the relationship between feed rate, cutting speed, cutting fluid flow, workpiece material and torsional vibration from the mechanical model and torsional vibration motion equation

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in 1986, aiming at the problem of torsional vibration of drill pipe, which provided a reference for the study of drilling tool vibration. Chin[22] established the lateral and axial motion equations of BTA drill based on Euler beam theory. Through drilling experiments, the consistency of the motion equations between the natural frequency and the vibration mode of the theory and experiment was verified, which provided a mathematical basis for dynamic chatter. In the BTA drilling experiment, Weinert[23] observed that the chatter of the tool is composed of the chatter state without chatter and one of the three torsional natural frequencies. Through the finite element analysis, it is found that the vibration state transition of the drilling tool is formed by the drilling-related modal damping, which provides theoretical support for the deep hole drilling tool chatter model. Based on dynamic and statics, Chen Yanling[24] established the basic equation of drill pipe dynamics, micro-differentiated the drill pipe, established the differential equation of torsional vibration of the drill pipe, and analyzed the law of torsional vibration of the drill pipe, which provides a theoretical basis for the application of torsional vibration damper. In the research method of deep drilling vibration, Mehrabadi[25] studied the problem of deep hole drilling chatter from damping and gyroscopic effects. The eigenvalue of the frequency domain equation is used to analyze the boundary of the critical cutting radial width. The trajectory of the drilling tool is simulated by numerical method, and the influence of the drilling tool chatter on the hole quality is analyzed. Kong[26] used the nonlinear dynamic response method to establish the drilling shaft system model for the multi-span supporting rotary drill pipe, calculated the dynamic equation of the shaft, and simplified the model by the shooting integration method. The periodic dynamic behavior of the deep hole system (Fig.7) and the drilling in the unstable region were numerically studied. Ema[27] analyzed the flutter stability of deep hole drilling from the motion equation.

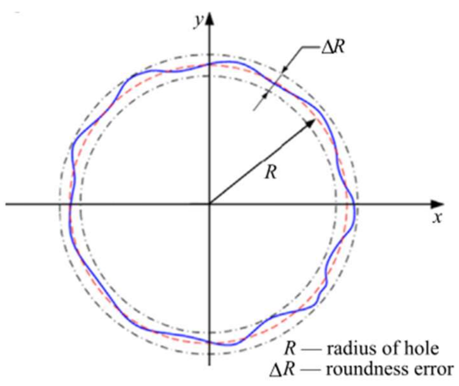

Fig. 7 Periodic motion trajectory of drilling shaft

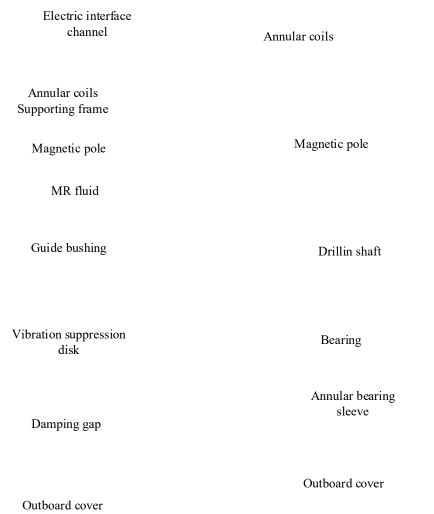

Fig.8 Structure of magnetic fluid damping damper

It is also an important research direction in recent years to study the relationship between deep drilling vibration and tool, cutting parameters, processing quality and cutting environment. Zhao[28] studied the influence of cutting fluid eddy current on the vibration of BTA drilling. By establishing the vibration model of liquid-solid coupling, it is analyzed that the Coriolis effect is the main reason for the eddy current of the cutting fluid in the drilling wall, which provides a new research basis for the vibration of deep hole drilling tools. Volz[29] focused on the influence of the width of the secondary flank on the lateral vibration of the deep-hole twist drill. Yuan Zhongyu[30] analyzed the causes of chatter caused by speed and displacement from the mechanical characteristics. Based on the two-degree-of-freedom chatter dynamics model, it is concluded that reducing the cutting speed and cutting thickness can reduce the vibration. Li Bo[31] focused on the longitudinal vibration, torsional vibration, lateral vibration and coupling vibration of BTA drill pipe under the condition of minimal quantity lubrication. The numerical simulation analysis of the model was carried out, and the influence of cutting fluid and drill pipe length on vibration was summarized. The trajectory function of dynamic cutting force and roundness morphology of BTA drill is calculated by Kong Lingfei[32].Compared with the actual tool vibration trajectory, the influence of drilling tool vibration on the roundness morphology of hole is analyzed.

Suppressing the vibration of deep hole drilling tools is a key problem to be solved in deep drilling. In 1994, Lv Ming[33] of Taiyuan University of Technology used feedback control damper to reduce vibration, which solved the problem of deep hole center offset and roundness in actual processing. Moradi[34] used a tunable shock absorber to suppress the vibration of deep-hole drilling tools. The effect of using general shock absorber to suppress deep hole drilling tools is not obvious. In recent years, more and more scholars have begun to study the design of special shock absorber for deep hole drilling. In 2014, Kong[35] first designed a magnetic fluid damper for deep hole drilling (Fig.8). Pang Junzhong[36] improved the existing dynamic shock absorber. By studying the characteristics of the shock absorber, the parameter range of the shock absorber with the best damping effect was obtained. Based on giant magnetostrictive actuator, Li[37] designed a vibration control system. Qiu[38] designed an electrorheological fluid damper with different working conditions to suppress the chatter of deep hole drilling tools. Yuan Guan[39] designed a hybrid mode magnetorheological damper. Through deep hole drilling experiments, it was observed that the magnetorheological damper can effectively improve the damping effect in semi-active control and control the current in a reasonable range. Li Chao[40] established a variable stiffness / damping tool system, and proposed a tool vibration suppression algorithm based on independent modal space characteristics. The feasibility of vibration reduction of variable stiffness / damping tool system was verified by experiments. On the basis of Li Chao 's vibration suppression algorithm, Cao[41] proposed a sensor / damper position optimization algorithm, and verified the effectiveness of the sensor / damper position optimization algorithm in static modal control experiments and dynamic modal drilling experiments. In recent years, Kong[42] has optimized the position of the damper and the sensor on the basis of previous research. Through theoretical calculation and experimental results, the optimal sensor position is obtained and the resistance is verified.The use of auxiliary support is also a way to solve the vibration of the drilling tool. Zhang Xiaofei[43] of North University of China has studied the auxiliary support to reduce the vibration of the drill pipe. By establishing the multi-centroid vibration model of the long-span deep hole drill pipe system, the optimal position of the auxiliary support point of the drill pipe is analyzed. The experimental results show that the theoretical optimal position can effectively reduce the vibration of the drilling tool.

The vibration monitoring and prediction of deep hole drilling tool is an important guarantee to prevent the vibration of deep drilling from affecting the processing quality. In the field of real-time monitoring. Messaoud[44] proposed an online monitoring scheme based on exponential autoregressive time series model for the first time, which realized the online monitoring from stable drilling to chatter. Subsequently, Xiao[45] proposed a deep hole drilling condition monitoring scheme based on pseudo non-binary second-generation wavelet, and verified the effectiveness of the monitoring scheme in drilling experiments. Uekita[46] used the method of chatter and transient vibration identification based on time-frequency analysis, established the monitoring technology of deep hole drilling process, created a system based on short-time Fourier transform and time-frequency domain spectral kurtosis analysis, and used the accelerometer signal to determine the chatter information. Si Yue[47] used wavelet transform to decompose the vibration signal of the drilling tool, and used the vortex vibration detection method based on EWT and rotating frequency high frequency signal to realize the vortex vibration detection of specific deep hole drilling tools. In the field of deep drilling vibration prediction, Li[48] developed a semi-active neural network controller based on ER / MR damper, which realized the prediction and control of deep hole machining vibration. Ulas[49] collected the vibration values of drilling tools under different cutting parameters and bit parameters, and established a vibration prediction model based on artificial neural network. The reliability of the model was verified according to the experimental results.

From the current research situation at home and abroad, the research on the vibration and stability of deep hole drilling tools is more comprehensive and in-depth, especially in the vibration mechanism and vibration suppression methods. At present, the research of deep drilling vibration is gradually combined with artificial intelligence and machine learning technology. Using the advantages of algorithms to detect and predict the generation of vibration will be the focus of future deep hole drilling tool vibration research.

2.3 Study on Tool Wear and Durability of Deep Hole Drilling

Because deep hole machining requires long-term continuous drilling, it determines that the drilling tool is always in a state of wear and consumption during deep hole machining. Therefore, the wear and durability of deep hole drilling tools is another important research direction. To this end, many universities and research institutes at home and abroad have carried out a series of studies on deep drilling wear and durability, including deep drilling wear mechanism research, advanced drilling technology wear resistance research, drilling tool wear monitoring and prediction research, and achieved fruitful research results.

2.3.1 Research on Tool Wear Mechanism of Deep Hole Drilling

At present, the research on the wear of deep hole drilling tools mainly focuses on the wear mechanism of drilling tools and the influence of internal and external parameters on the wear of drilling tools. Among them, the research on the internal parameters of drilling tools is relatively few, and the research on the wear mechanism of drilling tools and the influence of external parameters on the wear of drilling tools accounts for the majority.

The research on the wear mechanism of deep hole drilling tools is the basic research of drilling tool wear. Many scholars have explained the stages and causes of deep drilling wear from the perspective of wear phenomena and mechanical properties. Wang[50] conducted a gun drilling experiment of aluminum titanium nitride (TiAlN) cemented carbide, analyzed the wear stage of the drilling tool from the drilling torque, and analyzed the causes of different wear mechanisms by observing the chip morphology at different wear stages (Fig.9). By observing the phenomena of burning, adhesive wear, chipping, spalling and cracking of the guide belt when drilling TC4 titanium alloy with gun drill, Xu Ning[51] studied the wear stage of the drilling tool and analyzed the relationship between the wear of the drilling tool and the axial force. Zhu[52] carried out the experiment of drilling nickel-based alloy with YG cemented carbide. Through the observation of the worn drilling tool, it was found that the tool wear and tool chipping were the main forms of BTA drill failure. Han[53] established a mechanical model of drilling tool wear based on drilling force coefficient and drilling effect coefficient. The relationship between drilling tool wear parameters and drilling tool wear effect coefficient was analyzed by response surface method, and the model was verified by drilling experiments, which provided a model basis for drilling tool wear research.

In the study of the wear of drilling tools in the drilling environment, Heinemann[54] compared the wear of the twist drill under the condition of minimum lubrication and discontinuous supply of cutting fluid (Fig.10). Through drilling experiments, it is concluded that the minimum lubrication method can reduce the wear of the drilling tool. Sato[55] focused on the relationship between the temperature of the bottom of the hole and the wear of the drilling tool. The optical fiber infrared radiation pyrometer was used to observe the drilling experiment, and the experimental data under the factors such as the temperature of the bottom of the hole, the wear of the drilling tool, the feed rate, the material, the drilling depth and the cutting environment were obtained. It is concluded that the higher the temperature of the bottom of the hole, the greater the influence on the wear of the drilling tool. Zhu[56] analyzed the influence of drilling temperature on tool wear by establishing the temperature field model of gun drill dry drilling.

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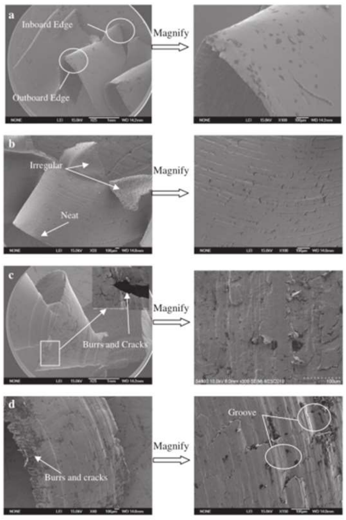

Fig.9 Chip morphology at different wear stages

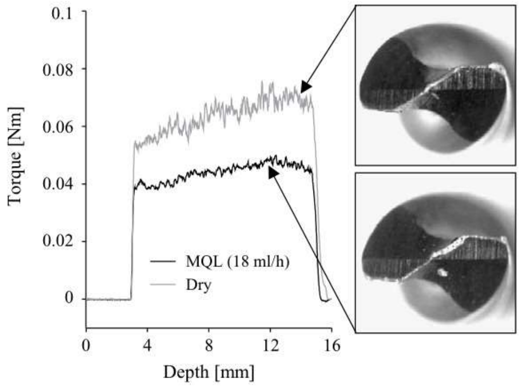

Fig.10 Changes of drilling torque under different cutting environments

The setting of process parameters in drilling is the key to affecting the wear of drilling tools and the quality of hole processing. Scholars at home and abroad have also focused on the relationship between process parameters, deep drilling wear and processing quality. Imran[57] used aluminum titanium nitride (TiAlN) ultrafine tungsten carbide twist drill to drill small holes in nickel-based alloy materials. The influence of process parameters on tool wear was studied. From the wear of the main cutting edge, the secondary cutting edge and the chisel edge, the reasons for the wear of the drilling tool were analyzed. Li Daobo[58] used deform software to establish a quasi-dry BTA drilling model, and analyzed the model from cutting force, tool wear, cutting temperature and chip breaking. There are few studies on the wear of deep drills from the internal structure and size of deep drills. However, Biermann[59] studied the influence of drill geometry on the wear of drills with nickel-based alloy gun drills as the research object, which laid a foundation for the study of the relationship between drill structure and wear.

2.3.2 Research on Wear Resistance of Advanced Drilling Technology

At present, the advanced drilling technology to improve the wear resistance of deep hole drilling tools is mainly carried out from the perspectives of matrix material, coating material, cold and hot treatment, etc., among which the research on deep hole drilling tool coating is the focus of scholars at home and abroad.

The research on the matrix material of deep hole drilling tool is mainly based on the research of tool matrix material. The turning experiments of cemented carbide (YBG102, YBG202) with cobalt (Co) content of 6 % and 10 % were compared by Jin Kuanghao[60] of Central South University, and the idea that cemented carbide with low Co content is more suitable for cutting nickel-based alloy was verified. Jiang Zenghui[61] conducted experiments on turning Ti6Al4V materials with YG8, YT15 and YW2 cemented carbides, and summarized the wear forms and applicable occasions of different cemented carbides, which provided guidance for optimizing the material of deep hole drilling tools. Zhu[62] carried out the research on the performance of YW1, YG8, YD15, YT798 and YT726 five kinds of BTA cemented carbide inserts for drilling titanium alloys, and concluded that YT726 is the best cemented carbide for drilling titanium alloys. Wu Xiaodan[63] of Zhongbei University selected the BTA drill guide block of YA6 cemented carbide for drilling experiments. By analyzing the experimental data, it is concluded that YA6 is not suitable as the material of the guide block, which provides experience for the selection of the guide block material.

DLC (diamond-like carbon) is a diamond-like coating composed of different bonding modes of carbon atoms. Many scholars have carried out detailed research on its characteristics and applicable

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occasions. Bhowmick[64] studied the hydrogenated DLC (H-DLC) and non-hydrogenated DLC (NH-DLC) coated twist drills. Through dry drilling experiments, it was observed that the hydrogenated DLC coating can effectively reduce the transfer and accumulation of metal debris, which verified that the hydrogenated DLC coating has lower friction coefficient characteristics. Folea[65] summarized the coating materials of existing deep hole drilling tools, and carried out a comparative experiment of DLC coating and uncoated drilling tools. It is concluded that the DLC coating drilling tool has the advantages of small friction coefficient, high surface processing quality, good wear resistance and dry processing, but it has the disadvantages of deposition and poor adhesion. Heinemann[66] carried out comparative experiments of twist drills without coating, DLC coating, cobalt high-speed steel, titanium nitride (TiN) coating and molybdenum disulfide (MoS2) coating, and verified that the diamond-like coating has good chip removal ability, but the degree of wear is large, and it is concluded that it is not suitable as a blade coating alone. Biermann[67] used amorphous tetrahedral (ta-C) bonding coating on the guide block of BTA drill by taking advantage of the characteristics of DLC. The morphology of the guide block after drilling with aluminum titanium nitride (TiAlN) coating was compared, and the conclusion that DLC coating was suitable for the coating material of the guide block was summarized.

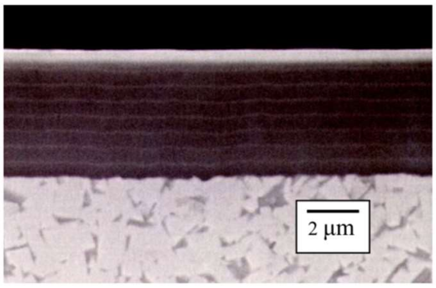

Fig.11 Composite coating profile

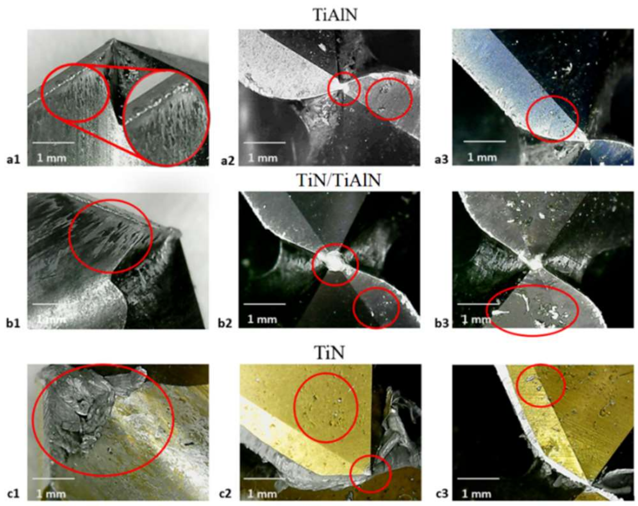

Fig. 12 (a1, b1, c1) The edge of the deposit and the spreading adhesion of the aluminum material ; (a2, b2, c2) tool tip surface pitting and aluminum deposition ; (a3, b3, c3) aluminum filled surface pitting

Compound coating is the most conventional means to improve wear resistance of deep hole drilling tools. In 1981, Buhl[68] deposited titanium nitride (TiN) by CVD method and coated high speed steel. The feasibility of TiN coating was verified from the aspects of microstructure, hardness and adhesion effect. Li Xubo[69] from Xi 'an University of Technology conducted drilling experiments on TiAlN coated and uncoated BTA drills, observed the wear of the wrong tooth blade and the guide block, and analyzed the wear stage of the tool from the perspective of element distribution. The drilling performance, drilling torque, and hole processing quality were comprehensively evaluated to verify the superiority of the AlN-Ti coating. Wang Xinyong[70] compared the performance of chromium aluminum nitride (AlCrN) coating and aluminum titanium nitride (TiAlN) coating in turning GH4169 material. It was observed that the chromium aluminum nitride coating had stronger wear resistance, which provided a direction for the research of new coating of deep hole drilling tools. In 2020, polycrystalline cubic boron nitride (PCBN) was coated on the surface of Neo[71] gun drill for the drilling of lnconel 718 alloy, and good drilling results were also achieved.

At present, the use of composite coatings to improve the wear resistance of deep hole drilling tools is a new research hotspot. Murakami[72] used a composite coating of aluminum-titanium nitride (TiAlN) / polycrystalline diamond (DLC) (Fig.11).It was observed in drilling experiments that the composite coating can reduce the breakage of the coating due to high temperature oxidation and reduce the coating deposition due to compressive stress. Tameemi[73] focused on the effects of titanium nitride (TiN), titanium aluminum nitride (TiAlN), titanium carbide / titanium aluminum nitride (TiN / TiAlN) coatings on the shape, size, surface roughness and other parameters of the hole, which provided experience for the actual drilling of different coatings (Figure 12). According to the research of domestic and foreign scholars on the coating of deep hole drilling tools, the performance of the coating used is summarized (Table 1).

Table 1. Coating performance of deep hole drilling tool

enamel	abrasion resistance	coefficient of friction	adhesive ability	Coating damage resistance
DLC	+	+	-	-
TiN	-	-	+	-
TiAlN	+/-	-	+	+/-
AlCrN	+	-	+	+
PCBN	+	-	+	+
TiAlN/DLC	+/-	+/-	+/-	+
TiN/TiAlN	+	-	+/-	+/-
Note : ' + ' is better ; ' + / - ' means general ; ' - ' denotes poor				

Micro-texture is a new technology of tool surface treatment in recent years, and it has a new application in deep hole drilling tools. Liu Yang[74] designed the micro-texture forms of stripe type, corrugated type and comb type, and compared the optimal cutting micro-texture shape through the simulation model. On the basis of this, Yu Yang[75] textured the front and rear surfaces of the BTA drill cutter teeth, and established experimental groups with different texture widths and texture spacings. Through drilling experiments, it was verified that reasonable surface texture can effectively reduce the contact between the cutter surface and the chip, store the cutting fluid, and reduce the wear of the blade.

In terms of deep hole drilling tool processing technology, Firouzdor[76] carried out research on the wear resistance of high-speed steel drills by cryogenic treatment. After deep drilling experiments, the durability of drills treated by low-temperature tempering has been greatly improved. It is concluded that fine carbide precipitation in cryogenic treatment is the key to improving the wear resistance of drilling tools. Ion implantation technology is also a method to improve the wear resistance of deep hole drilling tools. Morozow[77] performed three different nitrogen flux ion implantation techniques on the BTA drill guide block. Scanning electron microscopy, energy dispersive spectroscopy, X-ray photoelectron spectroscopy, and secondary ion mass spectrometry were used to observe and analyze the guide block. From drilling and hardness experiments, it was verified that high nitrogen flux ion implantation can effectively improve the durability and surface hardness of the guide block.

2.3.3 Research on Tool Wear Monitoring and Prediction of Deep Hole Drilling

Monitoring and predicting tool wear state from a mechanical point of view has always been the mainstream direction of research. In 1991, Yang[78] used optical fiber micro-bend sensor to detect the axial force of deep hole drilling, and indirectly realized the monitoring of drilling tool wear. Heinemann[79] proposed a monitoring method based on thrust and torque. By collecting the signals in the cutting process, the relationship between thrust, torque, AE-RMS signal and tool life is established (Figure 13). The real-time signal acquisition of the tool is realized, and the tool wear state is indirectly observed. Patra[80] analyzed the wear stage of the drilling tool through the micro-drill experiment. Based on the thrust and cutting conditions in the micro-drill drilling, the on-line monitoring of the drilling tool was realized by using the artificial neural network. Hong[81] proposed a data-driven tool condition detection method, which is characterized by cutting force, torque and vibration signals. The smoothing method is used to optimize the experimental data of gun drill, and the accuracy of tool wear estimation is improved. Jimenez[82] proposed an experimental method to predict tool wear from the time domain and frequency domain of drilling tool thrust, which provides a direction for drilling tool wear prediction.

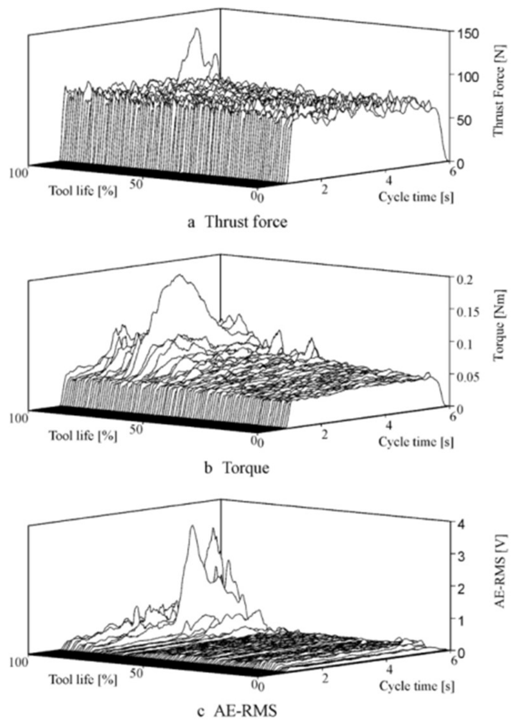

Fig. 13 Thrust, torque, aE-RMS signal And tool life Three-dimensional data map

Due to its process characteristics, deep hole drilling cannot directly observe the wear of drilling tools, but it is a new research method to judge the wear state of drilling tools by using acoustic signals. Li Jia[83] used the improved EMD algorithm to decompose the noise signal in deep hole drilling, and used the Hilbert transform to process the decomposed acoustic signal, and extracted the state characteristics of the acoustic signal when the drilling tool was worn, which provided a basis for acoustic monitoring of drilling tool wear. Hu Hongzhi[84] proposed a tool wear identification method based on the acoustic signal of the twist drill. The EMD-SSA-SVM algorithm is used to decompose the acoustic signal of the drill wear, and the acoustic signal is used to identify the wear of the drill.

As a hot spot of scientific research in recent years, machine vision technology is gradually emerging to monitor and predict deep drilling. In 2017, Kurek[85] established a neural network based on CNN to preprocess the borehole image, so that the neural network can learn in a limited number of image samples, judge the abnormality of the borehole image independently, and provide early warning for the wear of the drilling tool. Wu Xuefeng[86] of Harbin University of Science and Technology photographed the wear image of the rake face of the BTA drill blade, and used grayscale, image denoising, and threshold segmentation to highlight the tool wear area. The minimum circumscribed matrix method is used to measure the wear amount of the blade wear area, which provides a solution for rapid monitoring of the blade wear amount.

In summary, many scholars have conducted in-depth research on the wear of deep hole drilling tools. However, with the rapid development of advanced materials, the development of advanced drilling technology is still relatively backward, and the latest high-performance cemented carbide, coating materials, and processing technology cannot be applied to deep hole drilling tools. At present, more and more difficult-to-machine materials are emerging. The development and research of deep hole drilling tools for difficult-to-machine materials are still confused, and further development and research are urgently needed.

3. Development Trend of High Temperature Alloy Deep Hole Drilling Tools

Scholars at home and abroad have conducted extensive research on deep hole drilling tools, and have made many breakthroughs in tool optimization, tool vibration, tool durability, etc., revealing the vibration principle and wear mechanism of deep hole drilling tools. In the future, deeper research can be carried out to improve tool optimization, vibration reduction, and durability.

(1) In terms of tool optimization, the optimization design of traditional deep hole drilling tools has been relatively mature, but the research in the field of special deep hole drilling tools is still immature. In the future, further optimization can be carried out on deep hole micro drilling and super large deep hole drilling tools, and new structural innovation can be carried out in the field of traditional deep hole drilling tools.

(2) In terms of tool stability, the development of vibration mechanism, vibration suppression method and vibration monitoring has been very mature, but the research in the field of accurate vibration elimination and prediction of vibration is still not perfect. The advantages of machine learning algorithms can be used to solve these research defects.

(3) In terms of tool wear resistance, the research on wear mechanism and wear detection has been more comprehensive, but advanced drilling technology still needs to follow the development of materials science. In the future, new blade materials, coating materials and processing technologies can be applied to deep hole drilling tools, and further durability research can be carried out in combination with existing difficult-to-machine materials.

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