МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
КАФЕДРА КОНСТРУКЦІЇ ЛІТАЛЬНИХ АПАРАТІВ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри д.т.н, професор
_________ Сергій ІГНАТОВИЧ
«__» _____________ 2022 р.

КВАЛІФІКАЦІЙНА РОБОТА
ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ МАГІСТРА
ЗІ СПЕЦІАЛЬНОСТІ
«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Вдосконалення ріжучого інструменту для оптимізації процесу виготовлення авіаційних компонентів »

Виконавець: ________ **Цзикан ФАНЬ**

Керівник: к.т.н., доцент _________ **Вадим ЗАКІЄВ**

Охорона праці: к.т.н., доцент _________ **Катерина КАЖАН**

Охорона навколишнього середовища:
к.т.н., доцент _________ **Леся ПАВЛЮХ**

Нормоконтролер: к.т.н., доцент _________ **Володимир КРАСНОПОЛЬСЬКИЙ**

Київ 2022

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
DEPARTMENT OF AIRCRAFT DESIGN

PERMISSION TO DEFEND
The head of the department
Dr. of .Sc., professor
______Serhiy IGNATOVICH
«___ »__________ 2022

MASTER DEGREE THESIS
ON SPECIALITY
"AVIATION AND AEROSPACE TECHNOLOGIES "

Topic: "Cutting tools improvement for optimization of aviation components manufacturing process"

Fulfilled by: ___________ **Zikang FAN**
Supervisor:
PhD, associate professor ___________ **Vadim ZAKIEV**

Labor protection advisor:
PhD, associate professor ___________ **Katerina KAZHAN**

Environmental protection adviser:
PhD, professor ____________ **Lesya PAVLYUKH**

Standards inspector:
PhD, associate professor ____________ **Volodymyr KRASNOPOLSKYI**

Kyiv 2022

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аерокосмічний
Кафедра конструкції літальних апаратів
Освітній ступінь «Магістр»
Спеціальність 134 «Авіаційна та ракетно-космічна техніка»
Освітньо-професійна програма «Обладнання повітряних суден»

ЗАТВЕРДЖУЮ
Завідувач кафедри д.т.н., професор
_________ Сергій ІГНАТОВИЧ
«___» ___________ 2022 р.

ЗАВДАННЯ

на виконання кваліфікаційної роботи пошукача

ФАНЬ Цзикан

1. Тема роботи «Вдосконалення ріжучого інструменту для оптимізації процесу виготовлення авіаційних компонентів», затверджена наказом ректора від 05 жовтня 2022 року №1861/ст.

2. Термін виконання проекту: з 06 жовтня 2022р. по 30 Листопад 2022 р.

3. Вихідні дані до проекту: Твердосплавний ріжучий інструмент

4. Зміст пояснювальної записки: аналіз методів оптимізації різальних пластин для покращення процесу виробництва аерокосмічної техніки, аналіз механічні властивості матеріалів ріжучих інструментів та методів їх покращення, технологія зміцнення ріжучих інструментів імпульсним магнітним полем, експериментальні результати випробувань механічних властивостей ріжучого інструменту після обробки імпульсним магнітним полем, охорона праці та навколишнього середовища.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: презентація Power Point, малюнки та схеми.

6. Календарний план-графік

№ пор.	Завдання	Термін виконання	Відмітка про виконання
1	Огляд літератури з питань роботи. Аналіз передумов застосування ріжучих інструментів в авіаційній промисловості.	06.10.2022-18.10.2022	
2	Аналіз методів оптимізації різальних пластин для покращення процесу виробництва	19.10.2022-29.10.2022	
3	Аналіз механічні властивості матеріалів ріжучих інструментів	30.10.2022-07.11.2022	
4	Технологія зміцнення ріжучих інструментів імпульсним магнітним полем.	06.10.2022-31.10.2022	
5	Проведення випробувань механічних властивостей.	01.11.2022-04.11.2022	
6	Оформлення кваліфікаційної роботи	05.11.2022-10.11.2022	

7. Консультанти з окремих розділів

Розділ	Консультанти	Дата, підпис	
		Завдання видав	Завдання прийняв
Охорона праці	к.т.н., доцент Катерина КАЖАН		
Охорона навколишнього середовища	к.т.н., професор Леся ПАВЛЮХ		

8. Дата видачі завдання: 5 жовтня 2022 р.

Керівник кваліфікаційної роботи: ____________ Вадим ЗАКІЄВ

Завдання прийняв до виконання: ____________ ФАНЬ Цзикан

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty
Department of Aircraft Design
Educational Degree "Master"
Specialty 134 "Aviation and Aerospace Technologies"
Educational Professional Program "Aircraft equipment"

APPROVED BY
Head of Department,
Dr. of Sc., professor
________ Sergiy IGNATOVYCH
"___" _________________ 2022

TASK

For the master degree thesis

Zikang FAN

1. Topic: "Cutting tools improvement for optimization of aviation components manufacturing process", approved by the Rector's order № 1861 "05" October 2022 year.
2. Period of work execution: from 05 October 2022 year to 30 November 2022 year.
3. Initial data: Carbide cutting tools.
4. Content: Analysis of cutting inserts optimization methods to improve aerospace equipment manufacturing process, analysis of mechanical properties of cutting tool materials and methods of their improvement, pulsed magnetic field processing of cutting inserts, experimental results of mechanical properties testing of cutting tools after pulse magnetic field treatment, labor and environmental.
5. Required Power Point Presentation, drawings and diagrams.
6. Thesis schedule:

№	Task	Time limits	Done
1	Analysis of cutting inserts optimization methods to improve aerospace equipment manufacturing process	06.10.2022–18.10.2022	

2	analysis of mechanical properties of cutting tool materials and methods of their improvement	19.10.2022-29.10.2022	
3	Analysis of cutting tools mechanical properties.	30.10.2022-07.11.2022	
4	Pulsed magnetic field processing of cutting inserts	06.10.2022-31.10.2022	
5	Cutting inserts mechanical properties testing.	01.11.2022-04.11.2022	
6	Edit and correct the draft, modify the format.	05.11.2022-10.11.2022	

7. Special chapter advisers

Chapter	Adviser	Date, signature	
		Task issued	Task received
Labor protection	PhD, associate professor Katerina KAZHAN		
Environmental protection	PhD, professor Lesya PAVLYUKH		

8. Date: 8 September 2022.

Supervisor: ____________ Vadim ZAKIEV

Student: ____________ Zikang FAN

РЕФЕРАТ

Пояснювальна записка кваліфікаційної роботи магістра «Вдосконалення ріжучого інструменту для оптимізації процесу виготовлення авіаційних компонентів»

73 с., 21 рис., 4 табл., 42 джерел

Об'єктом дослідження - твердосплавний ріжучий інструмент.

Предметом дослідження - механічні властивості матеріалів ріжучого інструменту.

Метою магістерської роботи - покращення механічні властивостей ріжучих пластин для підвищення продуктивності різання.

Методи дослідження та розробки методи загартування, які забезпечують оптимальне вдосконалення ріжучих пластин. Експериментальні дослідження базуються на визначення механічних характеристик методами консольного згинання та при дії зосередженого навантаження на зразок, що лежить на двох опорах.

Практична цінність Підтверджено, що технологія обробки з використанням імпульсного магнітного поля має високу ефективністю, є зручною у використанні. Запропонований метод зміцнення підвищить терміну служби інструменту та продуктивність різання, що значно знизити вартість та ефективність.

Авіаційне виробництво, ріжучий інструмент, магнітний індуктор, імпульсне магнітне поле, механічні властивості

ABSTRACT

Master degree thesis "Cutting tools improvement for optimization of aviation components manufacturing process"

73 pages, 21 figures, 4 table, 42 references

Object of study – Carbide cutting tool

Subject of study mechanical properties of cutting tool materials.

Aim of master degree thesis is improvement of mechanical properties of cutting insert to increase cutting performance.

Research and development methods are hardening methods that ensure optimal improvement of the cutting inserts, experimental studies are based on the determination of mechanical characteristics by methods of cantilever bending and when a concentrated load is applied to a sample resting on two supports**.**

Practical value of the work it has been confirmed that the processing technology using a pulsed magnetic field has high efficiency and is convenient to use. The proposed strengthening method will increase tool life and cutting performance, which will significantly reduce cost and efficiency manufacturers can use high-hardness and high-strength advanced materials with confidence to achieve a comprehensive improvement in the performance of aviation aircraft.

Aviation manufacturing, cutting inserts, magnetic inductor, pulse magnetic field, mechanical properties

CONTENT

INTRODUCTION

In the 21st century, with the vigorous development of aviation industry in various countries, a large number of orders have been signed for aircraft mainly large passenger aircraft. The vigorous development of aviation manufacturing has driven the processing industry to continuously improve processing technology to meet a large number of processing needs. Because the shape and structure of parts and components of aviation products are complex, the materials are various, and the processing accuracy is strict. In order to meet the design performance and use requirements of aviation products, the manufacture of parts needs to use a variety of technological means, such as cutting, electrical physical machining, electrochemical machining, beam machining, precision casting and precision forging, etc. Among them, machining is still the most widely used and widely used machining method in the aerospace manufacturing field. In the main load-bearing structure of modern aircraft and engines, the proportion of integral structural parts is increasing rapidly. Such parts are usually machined with a solid blank. The weight of the finished part is only 10% to 20% of the blank, and the remaining 80% to 90% of the material is turned into chips. The beams, frames, ribs, and wall panels of the aircraft body, as well as the compressor fans and integral blisks of the engine are all key parts of modern aircraft and aero-engines. Due to special application requirements such as light weight and high strength, the materials used involve high-strength aluminum alloys, titanium alloys, superalloys, composite materials and other difficult-to-cut materials. In addition, the processing purpose of aviation materials is mainly based on the overall structure forming, with complex structure, large material removal, high precision and surface quality requirements, and long processing cycle. All of these factors cause the cutting tool to wear at an excessive rate, leading to failure. According to statistics, tool failure accounts for 20% of the downtime of the machining center, which greatly increases the processing cost. Therefore, tool technology needs to be developed and optimized.

The first part will analyze the current situation of the aviation manufacturing industry in detail, and discuss the necessity of the development of cutting tool technology from many aspects. By citing typical cases, the requirements for cutting technology of aerospace parts at this stage are clarified, and feasible optimization schemes are selected to improve the cutting performance of the tool.

In the second part, the optimization method will be studied in detail. The feasibility, applicability and advancement of this method are studied from the performance characteristics of the tool material itself, the strengthening mechanism, and the effect after strengthening. Combined with the practical optimization measures widely used at this stage, we understand the contradictions and problems faced by the development of tool technology, and give solutions.

The third part designs experiments to verify the actual effect of the optimization method by testing the mechanical properties of the tool material. And keep the test data for effective industrial application in the future.

The fourth part can be expressed as the protection of occupational safety and health of engineers. Engineers need a suitable laboratory or workplace to conduct research and experiments. According to national supervision regulations, the potential risks that may lead to ill health, injury or even death need to be fully considered. And develop protective measures.

The last part is environmental protection, which is committed to eliminating the negative impact of research objects on the environment and society, and providing timely solutions.

PART 1
APPLICATION OF CUTTING PROCESS IN AVIATION MANUFACTURING

The aviation manufacturing field is a high-end equipment industry with a high degree of integration of advanced technologies. Due to the special requirements of high stability, high speed, high safety and subsequent repeated use of the aircraft during the entire take-off and landing process, its related design, manufacturing, processing, and assembly need to meet extremely high process requirements and quality standards. The entire aviation equipment industry chain is mainly divided into three parts: upstream design and supply of various aviation raw materials, midstream aviation equipment manufacturing, downstream aviation application and maintenance services. Among them, in the middle reaches of the industrial chain, the aircraft parts manufacturing industry is the mainstay, which is the basic industry of the aviation manufacturing industry.

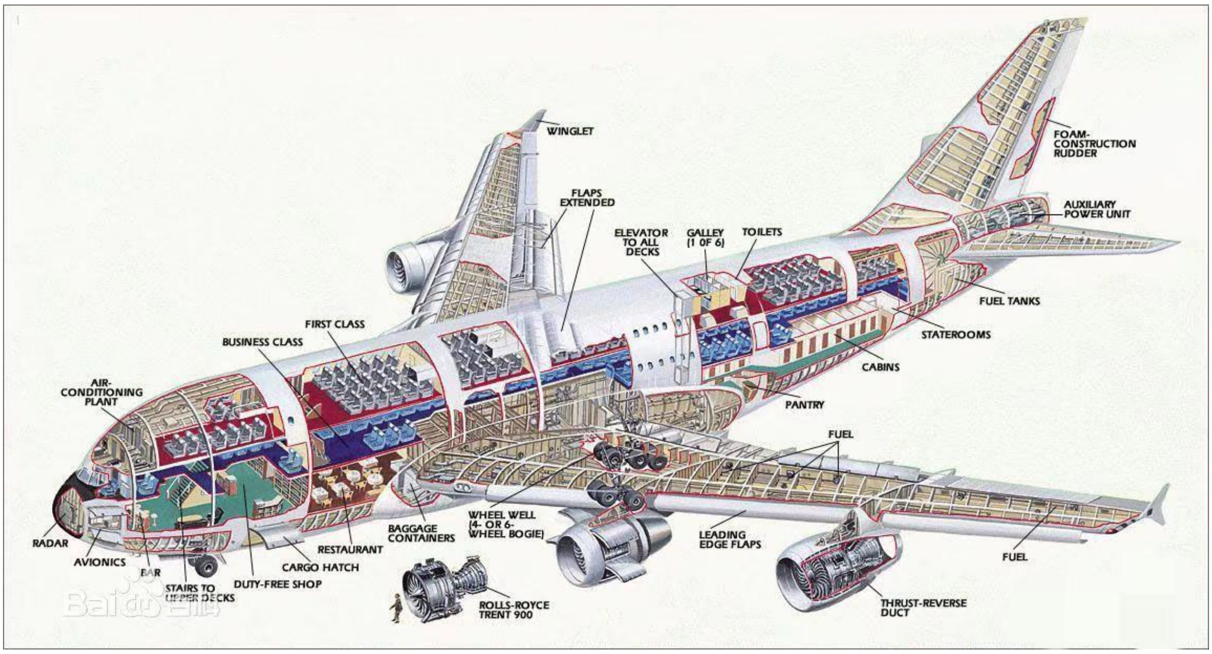


Figure 1.1 – Overall structure of aviation aircraft

Typically, a complete large aircraft needs to be constructed from as many as millions of parts（Figure 1.1）. Depending on the structure, demand, use, performance and other requirements of each subsystem, the number of parts is not only huge, but the types of parts are as many as 20,000 to 40,000 on average. But even though the construction of aircraft requires a large number of parts, aviation parts manufacturing still only accounts for a small share of the overall manufacturing market. The reason is that each type of aircraft often has many special parts. These special parts require different tooling and processes, and have obvious characteristics, which cannot be standardized and batched on a large scale.In addition, aviation materials mainly include high-strength aluminum alloys, titanium alloys, high-temperature alloys, stainless steel and composite materials. For these difficult-to-machine materials, it is required to process them into product parts with complex theoretical shapes or complex structures, and at the same time, the standards are more stringent, which greatly increases the processing difficulty（Figure 1.2）.

On the other hand, large monolithic structural parts are currently widely used in modern aircraft, and such parts are usually machined in one piece from the blank.Such as wing integral panels, spars, engine casings, etc., they have complex shapes and large machining volumes. Another example is the windshield frame of the cockpit, the hatch, the integral blisk of the engine, etc. These three-dimensional large frames require multi-axis machining.

Based on the characteristics of aerospace product parts with high material strength, high product precision, complex structure and processing technology, etc., there is an urgent need to achieve more efficient and accurate cutting in the industry.

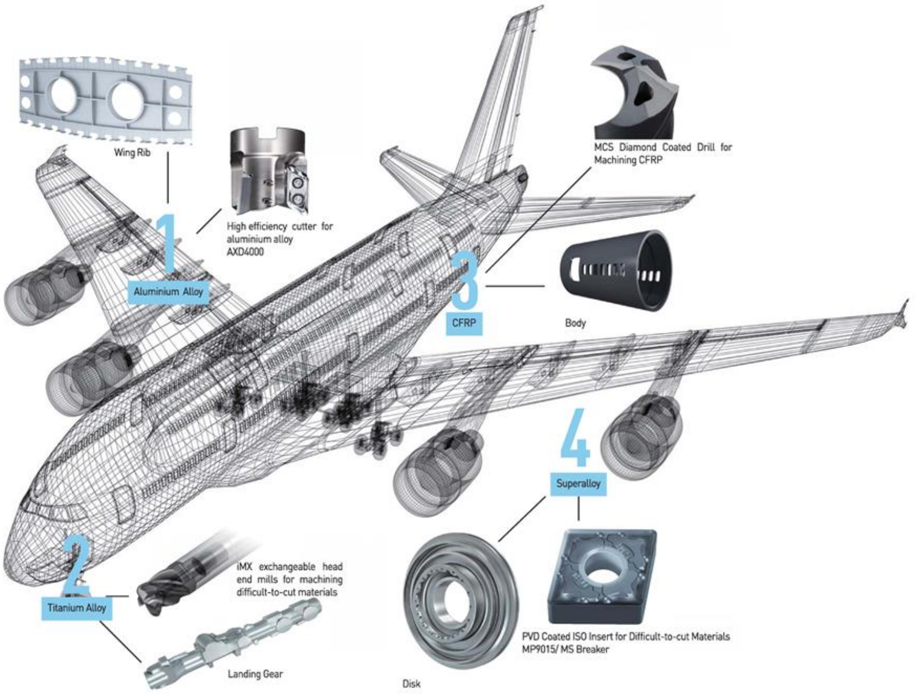


Figure 1.2 – Difficult-to-cut parts of aircraft

1.1 The development and significance of cutting tool

Machining has always been one of the basic means of parts processing technology.Although with the advancement of science and technology, new processing methods are constantly being created and applied. However, cutting is still the most widely used processing method in the manufacturing industry. For parts that require high dimensional and shape matching accuracy, more need to be formed by cutting.

In the late 18th century, with the invention of the steam engine and modern machine tools, the entire era of machining production began to get on track.By the 1870s, with the invention and improvement of new smelting technology, internal combustion engine technology, and electrical technology, the machinery manufacturing industry began to enter the era of mass production.Research on the principles of metal cutting began in the 1850s, and research on the principles of grinding began in the 1880s.By the 21st century, the wide application of CNC machine tools has made high-speed cutting technology a reality (Figure 1.3). As one of the most advanced manufacturing technologies in the new stage, its metal removal rate per unit power is increased by 30%-40% compared with traditional cutting, the tool cutting life is increased by 70%, and the residual cutting heat in the workpiece is greatly reduced. And the low-order cutting vibration almost disappears, which realizes the essential leap of cutting technology.In order to realize the cutting blank, the cutting tool is the indispensable main tool in the cutting technology. Advanced and efficient tools are one of the basic prerequisites for making expensive CNC machine tools fully utilize their efficient machining capabilities.

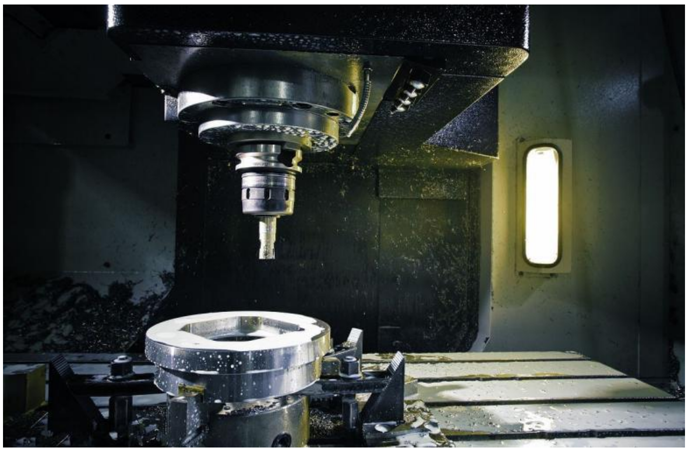


Figure 1.3 – CNC machine tool high-speed cutting process

Cutting tools have been constantly changing, starting with the introduction of high-speed steel tools in the late 19th century.Compared with the original carbon tool steel and alloy tool steel tools, the carbide tools that appeared in 1923 have increased the allowable cutting speed of the tools by more than several times.The cermets and superhard materials such as synthetic diamond and cubic boron nitride that appeared after the 1930s further improved the cutting speed and machining accuracy.At the same time, with the development of material science, the processed aerospace materials are not limited to metal alloys and non-metallic materials, but also include new system "composite materials",composed of two or more substances with different properties.Composite materials are an important direction of the modern material revolution. Because of its anisotropy and non-uniformity, high-performance composite materials are easy to form machining defects during processing, so tool cutting is still the mainstream technology in various new cutting technologies.It can be seen that the tool cutting process is a key factor to support and promote the progress of the aviation manufacturing industry.

1.2 Machinability analysis of difficult-to-machine materials for aviation

Aircraft structure can be mainly divided into five parts: fuselage, wing, tail, landing gear and engine. As the "heart" of an aircraft, an aero-engine is a highly complex and sophisticated thermo-mechanical device.Aircraft performance and reliability depend on engine performance.Aero-engines include numerous subsystems including compressor, combustion chamber, exhaust system, transmission system, fuel system, and control system. The design and manufacture of each subsystem has extremely high technical requirements in the face of long-term high temperature and high pressure environment.

Therefore, this section selects aero-engine as a typical object to analyze the machinability of the difficult-to-machine materials used in the engine. By exploring the physical and chemical properties of various materials and determining the processing characteristics, the optimization direction of the tool performance can be determined, and the appropriate improvement method can be effectively selected.

Modern aero-engines mostly use gas turbine engines, whose working temperature can reach 1700 degrees Celsius. Therefore, most of the aero-engine materials use high-hardness and high-thermal-strength materials such as titanium alloys and high-temperature alloys. While the material brings excellent performance to the engine, the processing difficulty also increases.

Titanium is a new type of rare metal, and the properties of titanium are related to the impurities such as carbon, hydrogen, and oxygen contained in it. Using the different lattice structures of titanium to gradually change the phase transition temperature and phase content, titanium alloys with different structures and properties can be obtained [1].At room temperature, titanium alloys have three collective structures, which are divided into α-phase titanium alloys, β-phase titanium alloys and α+β-phase titanium alloys. In China, it is represented by TA, TB and TC respectively [2].Titanium alloys have been widely used in the manufacture of integral blisks, casings, shafts of high thrust ratio and high efficiency aero-engines and other components. The main characteristics of titanium alloys are as follows:

(1) High strength. The density of titanium alloy is generally around 4.5g/cm3, which is only 60% of that of steel. Its specific strength (strength/density) and specific stiffness (stiffness/density) are much larger than other general metals, which can ensure the unit strength while achieving the purpose of light weight, which is very suitable for the manufacture of aircraft engine components.

(2) High thermal strength. The thermal stability of titanium alloy is good, and the workpiece can maintain the required strength under moderate temperature (500℃) for a long time. Compared with aluminum alloy, the specific strength of aluminum alloy decreases significantly at 150 °C.

(3) Good corrosion resistance. Titanium alloys are particularly resistant to pitting corrosion, acid corrosion, and profit corrosion, and the workpiece can work in wet, acidic, and alkaline environments. Under normal temperature conditions, except for hydrofluoric acid, hot concentrated hydrochloric acid and concentrated sulfuric acid, titanium alloys are basically not corroded by dilute alkaline and dilute acidic solutions such as alkali, chloride, nitric acid, and sulfuric acid [3].

(4) Small elastic modulus and thermal conductivity.The thermal conductivity of titanium is λ=15.24W/(m•°C), which is about 1/4 of nickel, 1/5 of iron, and one of 1/14 of

aluminum. While The thermal conductivity of titanium alloys is lower, about 50% lower than that of titanium. In addition, the elastic modulus is relatively small, the rigidity is poor, and it is easy to deform.

(5) High chemical activity. Under high temperature conditions, titanium will undergo violent chemical reactions with elements such as hydrogen, oxygen, and nitrogen in the atmosphere. When the temperature is above 600°C, titanium will also absorb oxygen and form a hardened layer of 0.1~0.15mm on the surface [4]. In addition, an embrittlement layer is also formed as the hydrogen content increases.

When the hardness of titanium alloy is greater than HB350, it will be particularly difficult to cut, but high hardness is only one aspect of difficult cutting. The above characteristic analysis can obtain the cutting characteristics of titanium alloy:

(1) High cutting temperature. During the chip cutting process, the basic length of the chip and the rake face of the tool is extremely short, and the heat during chip cutting is not easy to be transmitted. The low thermal conductivity of titanium alloys further results in increased temperatures in the cutting zone and near the cutting edge. The high temperature will reduce the durability of the tool and also affect the machining accuracy.

(2) Small chip deformation coefficient .This is a remarkable feature of titanium alloy machining, and the ratio of cutting layer to actual cutting length is less than or close to 1. This results in a long path of sliding friction for the chips on the rake face, increasing tool wear.

(3) High cutting force per unit area. Due to the small contact area between the chip and the rake face, excessive cutting pressure often causes chipping. At the same time, due to the relatively small modulus of elasticity of titanium alloys, it is easy to deform during clamping and processing. And the machined surface will have a large rebound phenomenon, resulting in severe friction and vibration between the machined surface and the tool flank, resulting in tool wear.

(4) Serious chilling phenomenon. In the actual cutting process, due to the strong chemical activity of titanium, it is easy to form a hard and brittle skin layer and it is not uniform; on the other hand, the large cutting force required by titanium alloys will cause plastic deformation and surface hardening. Not only does this lead to tool wear, but it can

also lead to a dramatic drop in the performance of the part. In addition, titanium also has good chemical affinity, and it is easy to appear adhesion phenomenon during processing [4].

Superalloys refer to a class of metal alloys based on Fe, Ni, and Co that can withstand certain complex stresses and perform permanent work in a high temperature environment above 600 °C.Usually according to the collective elements, a variety of superalloys can be divided into four categories: iron-based, iron-nickel-based, nickel-based and cobalt-based [5].The single collective structure (austenite) of the superalloy makes it have good structure stability and reliability at various temperatures. It has high high temperature strength, good oxidation and hot corrosion resistance, and good fatigue properties, fracture toughness and plasticity.

In modern aircraft engines, the amount of superalloys accounts for 40% to 60% of the total engine. Mainly used for four hot end components: guide, turbine blade, turbine disk and combustion chamber.

Its cutting characteristics are as follows:

(1) Large cutting force. Usually, the strength of the material decreases as the temperature increases during the cutting process, which facilitates cutting. However, the high hardness and high strength maintained by superalloys require a large unit cutting force.

(2) High cutting temperature. The reason is similar to that of titanium alloy processing. The small thermal conductivity cannot effectively transfer heat to the outside world, which will cause great damage to the cutting tool and at the same time cause thermal deformation of the workpiece, which will seriously reduce the machining accuracy.

(3) Severe work hardening tendency. Because of its high plasticity and strengthening coefficient, the combined effect of cutting force and cutting high temperature will cause large plastic deformation, which will cause cold work hardening of the machined surface. At the same time, the strengthening phase decomposed from the solid solution will be dispersed and distributed under the action of high cutting temperature and stress, resulting in an increase in the degree of material hardening and processing difficulties [6].

1.3 Analysis of difficulty machinability of aerospace parts structure

This section will analyze the structural machining of typical aerospace parts. The aero-engine is still selected as the research object, and the typical parts of the aero-engine, which are mainly represented by the aero-engine integral blisk, disk shaft, and casing, are considered.

The development of each different part is accompanied by changes in function, structure, and material, and at the same time, cutting tools are required to have different cutting performance when machining different structural features, which is also a supplement and optimization to the cutting process.At present, most of the disc parts in typical aviation parts tend to be thin-walled and require high process accuracy; various types of shafts require coaxiality with high coincidence of the inside and outside, and are thin-walled; the structure of the casing is complex, and the amount of material to be removed is large. These difficult-to-machine parts require continuous improvement in cutting technology.

1.3.1 Analysis of process characteristics of integral blisk

As a typical new type of integral structure, the integral blisk of the engine has extremely high standards for the dimensional accuracy, positional accuracy and surface roughness of the workpiece surface while integrating the blade and the impeller. Its structure is complex, the number of channels is large, deep and narrow, and the blades are thin and twisted. In addition, difficult-to-machine materials are used, resulting in poor machinability (Figure 1.3). The comprehensive processing technology of the blisk has become the embodiment of the world's high-level manufacturing technology.

Figure 1.3– Blisks

The structural characteristics of the blisk are as follows: the size and diameter of the blisk are relatively large and the rigidity is weak;the thickness of the blades on the overall blisk of the fan is thin, with a wide chord, a large twist angle, and a long blade cantilever; the airflow channel of the blisk is nonlinear and narrow; the blisk web is thinner and the web area is larger [7].

The machining process used for the blisk is usually divided into rough milling, semi-finishing, finishing and root cleaning.The purpose of rough machining is to remove large allowances between the blades and to homogenize the allowances for subsequent machining.The rough milling insert generally leaves a margin of 1.5~2mm for the semi-finishing blade. The uniformity of the allowance can make the surface stress of the blade processing uniform, and it is convenient to meet the standard of blade accuracy in the subsequent processing. The channels on the blisk are narrower and require a smaller diameter machining tool.Rough milling cutters should try to use tools with shorter lengths and larger diameters.Fine milling of the blade shape is the most important part of the blisk processing process, which directly determines the final processing quality of the blisk, and requires the position accuracy, surface quality, blade thickness, etc.

Since the blade is prone to looseness and chatter during fine milling, it will cause machining deformation.Therefore, it is the key to solve the problem of loosening and flutter during blade processing, reduce and eliminate processing deformation, and improve processing efficiency.The fine milling of the blisk runner is different from the fine milling of the blade body. Its characteristics are that the tool extends into the runner for the longest part, the contact area between the tool and the part is large, and the machining integrity of the runner surface is high. The blisk, the smooth transition area at the junction of the blade and the disc, is the area with the most serious interference.It needs to be processed separately with a small diameter spherical taper shank rod milling cutter, and pay attention to leave a little margin to avoid scratching the leaf surface. In specific machining, a tool smaller than the root R must be used for multi-tool machining.

In general, for cutting tools, the machining of blisks needs to optimize the way of advancing and retreating and improve the cutting performance of the tool.

1.3.2 Analysis of the process characteristics of the disc shaft

The disc shaft is another typical core component of an aero-engine. This part also has the characteristics of difficult material cutting and complex structure.The disc shaft is usually made of high-temperature heat-resistant alloy containing more than 50% Ni. One of its structural processing difficulties is the deep processing of the inner cavity. The deep cavity of the inner hole of the disc shaft is thin-walled, which is easy to vibrate, which not only affects the processing efficiency, but also causes the parts to deform, out of tolerance or even scrapped.On the other hand, when deep-cavity machining is performed, the length-to-width ratio of the tool can reach up to 8.5 times, and the vibration of grooving and profiling will be large, which will lead to limited chip evacuation and the risk of tool scrapping. To process the blade root groove on the disc shaft, it is necessary to select the matching insert according to the contour shape of the blade root groove.

With the improvement of the engine performance requirements of the aviation industry, the increase of the overall rigidity of the parts has become a design trend.The integral disc shaft integrates the originally separated disc and journal to form a new integral structure, which is an important bearing component of the engine rotor.The integrated structure of the disc and the shaft makes the disc shaft part form a special semi-closed inner cavity, which has poor openness and more stringent requirements for cutting technology.

During machining, due to the large machining allowance, in order to ensure the smooth and efficient removal of materials in the whole process, it is necessary to select alloy tools with better rigidity and stability, as well as non-standard tools with larger chip parameters.On the other hand, in order to avoid risks and improve processing accuracy, most of the workpiece processing should be completed at one time as much as possible. This not only needs to maximize the concentration of turning, milling, drilling, boring and other processes, but also needs to ensure that the durability of the tool is improved.

1.3.3 Analysis of the technological characteristics of the casing

The casing is the main load-bearing component of the aero-engine, and its structural forms are diversified according to the different engine models and different acting positions. Usually, it is a cylindrical or conical thin-walled part.According to the material, there are many materials used in the casing. Among them, the main material of the fan casing is titanium alloy, and the turbine casing is mostly made of nickel-based superalloy materials and high-strength steel materials.

Figure 1.4–Aircraft engine casing

The difficult-to-machine structure of the casing basically includes thin walls(Figure 1.4); both ends have mounting edges; the outer surface of the casing has annular reinforcing ribs, bosses, and annular bands; the inner surface has annular grooves, cylindrical annular bands, and spiral grooves; the oblique holes of the circumferentially arranged shell are distributed on the cylindrical ring belt; the shell wall is provided with radial holes, special-shaped holes and special-shaped grooves.The overall structure of the casing seems simple, but there are many technical difficulties in the actual processing process.

In general, the processing technical difficulties mainly include:

(1) The material is difficult to process and the removal rate is large. It can be seen from the above analysis that the material blanks used in the housing, such as high-temperature alloys, titanium alloys, etc., have the characteristics of high hardness, high strength, corrosion resistance, and high temperature resistance. These often lead to severe tool wear, severe work hardening, and difficult cutting.

(2) Complex shapes and structures. In order to reduce the weight of the aero-engine and improve the performance, the casing mostly adopts an integrated structure. Structures such as mounting seats and bosses are no longer connected to the surface of the shell by welding, and the wall thickness is getting smaller and smaller. The rigidity of the parts is weak, and the machining process is prone to vibration. It causes the deformation of the machined casing, making the machining result unclear.

(3) High machining accuracy. As the base of the entire engine, the casing is numerous and of various shapes. Based on the small tolerance requirements of the multi-system on the mutual positions of the main surfaces of the parts, the machining accuracy of the cutting process must be improved.

1.4 Research overview of tool optimization methods

Focusing on the development of tools, the optimization of tool technology mainly focuses on three aspects: material, surface strengthening treatment, structure and geometric parameters.Among them, the surface strengthening treatment of cutting tools is a field that has been fully studied by scholars, and it is also one of the most effective measures to directly improve the cutting performance of cutting tools.There are many ways of strengthening treatment, the main methods include heat treatment, cryogenic treatment, chemical heat treatment, coating strengthening, and external field application technology.Among them, coating strengthening technology is currently the most widely used and most effective strengthening method in the field of technical processing. Better cutting performance is obtained by combining the tool with a high-hardness and high-wear-resistant coating material by vapor deposition. This thesis will explore the most widely used tool coating strengthening technology, and find a more effective and beneficial processing technology based on the green manufacturing concept and a series of factors such as production efficiency and energy cost.

The treatment of external pulsed magnetic field is a technology that has been widely studied at present, and has certain theoretical basis and application cases.As an external field technology, magnetization can accelerate the reaction rate, refine the crystal structure, and affect the phase transition process through a non-contact energy transfer form [8]. Furthermore, the material technology is improved, and it has the advantages of convenient operation, low cost and no pollution. This thesis will focus on the treatment of pulsed magnetic field strengthening, and design related experiments.

1.4.1 Tool coating technology

With the continuous emergence of advanced materials and advanced technologies in the field of machining and manufacturing, the working environment of tools is becoming more and more severe.Tool cutting needs to withstand high temperature (300~1200 ℃), high pressure (100~10000N/mm^2), high speed (1~30 m/s) and large strain rate (103~107 s^{-1}). Its hardness and wear resistance properties are constantly challenged, while at the same time having high strength and toughness.The toughness and hardness of materials are usually contradictory, and the use of coating technology provides a solution to this contradiction.

Figure 1.5 – Coated cutting tools

Tool coating is to use vapor deposition method to coat a layer of refractory compound with high wear resistance on the surface of cemented carbide or high-speed steel tool (Figure 1.5). It can also be coated with superhard materials such as ceramics, diamond and cubic boron nitride.

This technology is applied to hard paper alloy, which can better solve the contradiction between the wear resistance and toughness of hard alloy, and further greatly improve the performance and service life of the tool.M. Nouari and A. Ginting studied the wear mechanism and cutting performance of multi-layer CVD-coated cemented carbide tools when cutting titanium alloys under the condition of dry cutting Ti-6242S[9]. Fox-Rabinovichet al. used a variety of nano-multilayer composite-coated carbide tools to machine the nickel-based superalloy Inconel 718 , and found that the TiAlCrN/NbN nano-composite coating tool had a longer service life [10]. Abhay Bhat et al. used WC-Co uncoated, TiCN/Al2O3/TiN coated and TiAl coated carbide tools to cut nickel-based superalloy Inconel 718, and analyzed the tool wear mechanism[11]. The research shows that the main failure modes of cemented carbide cutting tools are corrosion and adhesive wear, and the wear resistance of TiCN/Al2O3/TiN coated cemented carbide cutting tools is the best.

In addition, some manufacturers have greatly improved the performance of coated tools by improving coating materials and ratios.

1.4.2 Pulse Magnetic Field Strengthening Process

The magnetization treatment technology uses the magnetic field to act on the magnetic material, and the material changes some characteristics due to the energy received from the magnetic field, so as to achieve the effect of improving the performance of the material.Magnetic fields can be divided into two categories: continuous magnetic fields and pulsed magnetic fields. The continuous magnetic field can be divided into a steady magnetic field and a time-varying magnetic field, and the steady and constant magnetic field can be divided into a uniform magnetic field and a gradient magnetic field.According to the current form that generates the magnetic field, the magnetic field can be divided into DC magnetic field, AC magnetic field, and pulsed magnetic field.

Scholars from all over the world are particularly eager to explore the field of magnetic fields. After the 1990s, with the development of low temperature and superconducting technology, magnetic field technology began to apply high-energy fields such as strong magnetic fields and pulsed magnetic fields.Although the equipment for generating the pulsed magnetic field is complicated to manufacture, compared with the DC and AC magnetic fields, the pulsed magnetic field is a high-intensity magnetic field, and its current amplitude, pulse frequency, duty cycle, etc. can be adjusted, so it is more suitable for processing. From the above analysis, for the magnetic field strengthening process, this paper recommends the use of off-machine magnetization, and the magnetic field selects the pulsed magnetic field.

Bataineh found that pulsed magnetic treatment can improve the wear performance and service life of twist drill bits[12]. The results show that the durability of the high-speed steel bit is increased by 35.5% after pulsed magnetization treatment.The former Soviet Union expert Nikiforv Y P used a pulsed magnetic field to strengthen the drill bit, and tested its wear resistance through experiments. The results found that the wear resistance of the drill bit increased by 1.5-2 times after the magnetic field strengthening [13].In addition, foreign scholars have studied the wear characteristics of high-speed steel and cemented carbide with magnetic cutting. Bagchi P K, Ghosh A, etc. thought through experiments that because cemented carbide is difficult to magnetize, the magnetization effect is not as significant as that of high-speed steel tools [14]. However, some scholars believe that , due to the existence of strong magnetic Co in cemented carbide, carbide cutting tools are sensitive to various types of magnetic treatment[15].But no matter what, it proves that magnetic field strengthening can be applied to two types of tool materials such as cemented carbide and steel high-speed steel.

Conclusion to be the Part1

In order to reflect the importance of tool cutting technology in the field of aviation manufacturing, this part specifically expounds the difficulty and high requirements of different typical parts on aviation aircraft. Combined with their structural and technological characteristics, the optimization direction of the tool is fully considered, and surface strengthening treatment is selected to improve the cutting performance of the tool. Then it briefly discusses the most widely used coating technology. Further, under the background of the era of low energy and environmental protection in the manufacturing industry, combined with the feasibility theory and practical cases, the advanced tool optimization technology of pulse magnetization was found. The two processing techniques will be studied in more detail in the next section.

PART 2
STRENGTHENING OF CUTTING INSERTS

This topic selects the pulsed magnetic field treatment technology from many optimization tool methods for specific discussion, and analyzes the coating materials and tool materials used for cutting tools at the same time.The difficulty of tool optimization is that the toughness and hardness of materials are usually contradictory, and the use of coating technology is one of the feasible solutions to solve this contradiction. Since the technical problem of low bonding strength between coating and base material has been solved, tool coating technology has developed rapidly.Countries continue to strengthen the research on tool coating materials and their preparation technology. Coated tools are widely used in cutting, and the research on tool coating has a solid theoretical foundation and rich practical cases.Compared with many surface strengthening treatment methods, the laws and mechanisms of magnetic treatment are still not fully grasped. However, as a non-contact energy transfer process, magnetic field treatment can significantly and rapidly affect the structure and properties of materials, and will surely become a new material treatment method with simpler operation, more obvious effect, low cost and high efficiency.The purpose of this work is to explore the strengthening principle of the two technical means, compare their advantages, disadvantages and practicability, to effectively achieve further optimization of cutting tools.

2.1 Materials used in cutting inserts

The tool material is the key to determining the performance of the tool, and it is also related to the application effect of the tool surface strengthening treatment technology.The base material of the tool has general performance indicators, and needs to meet the requirements of sufficient surface hardness, less wear during operation, stability at high temperature, easy processing and suitable economic cost [16].At present, the most commonly used tool materials are high-speed steel, cemented carbide, tool steel, ceramics and superhard materials.Among them, high-speed steel and cemented carbide are the most widely used materials. Tool steel has good sharpening properties and is generally used for the production of manual knives, such as files, saw blades, scrapers, etc. Ceramic materials and superhard materials (such as polycrystalline diamond PCD and polycrystalline cubic boron nitride PCBN) have similar properties. Although they are extremely hard and ideal for semi-finishing and finishing superalloys, chilled cast irons, hardened steels, etc., they are also brittle and are currently limited in scope.Based on the research on pulse magnetic field strengthening treatment and coating strengthening technology in this paper, high-speed steel and cemented carbide are mainly selected as the analysis and experimental objects.

2.1.1 Magnetic properties of metal cutting tool materials

Ferromagnetism refers to the magnetic state of a material with spontaneous magnetization.This phenomenon refers to the magnetic moments of adjacent atoms or ions in matter, aligned roughly in the same direction in certain regions due to their interactions. When the applied magnetic field strength increases, the alignment degree of the combined magnetic moment of these regions increases to a certain limit value.The magnetic moments of adjacent atoms or ions in a substance are aligned roughly in the same direction in certain regions due to their interactions. When the strength of the applied magnetic field increases, the alignment degree of the combined magnetic moment of these regions will increase to a certain limit value, which will cause the phenomenon of magnetization.

French physicist P.E. Weiss, the founder of ferromagnetic theory, put forward the phenomenological theory of ferromagnetic phenomenon in 1907. He postulated that there is a strong "molecular field" inside the ferromagnet, which can spontaneously magnetize the interior even in the absence of an external magnetic field.The small area of spontaneous magnetization is called magnetic domain, the magnetic moment between adjacent electron spins is about 10-4m, and the magnetization of each magnetic domain reaches magnetic saturation.The ferromagnet is divided into several small regions after spontaneous magnetization. Since the magnetization directions of each region (magnetic domain) are different, the magnetic properties of the regions cancel each other, so the ferromagnetic material as a whole does not exhibit magnetic properties to the outside world. At this time, as long as an external magnetic field is added, the magnetism will be dominant, resulting in an obvious magnetization effect.

The strength of magnetism in the macroscopic view is represented by the magnetization M. M refers to the vector sum of magnetic moments possessed by a magnetic dipole per unit volume, the formula is as follows:

$$M = (\sum_{i=1}^{n} \mu_{m_i})/\Delta V) \quad (2.1)$$

Where : μ_{m_i} represents the number of magnetic moment i .

For a magnet in an external magnetic field, the magnetic field strength H and the magnetization M have the following relationship:

$$M = \chi H \quad (2.2)$$

Where : χ is the magnetic susceptibility of the magnet, which is the characterization of the magnetic strength.

The magnetization of ferromagnetic materials has a nonlinear relationship with the external magnetic field. This relationship is a closed curve called a hysteresis loop (in Figure 2.1).

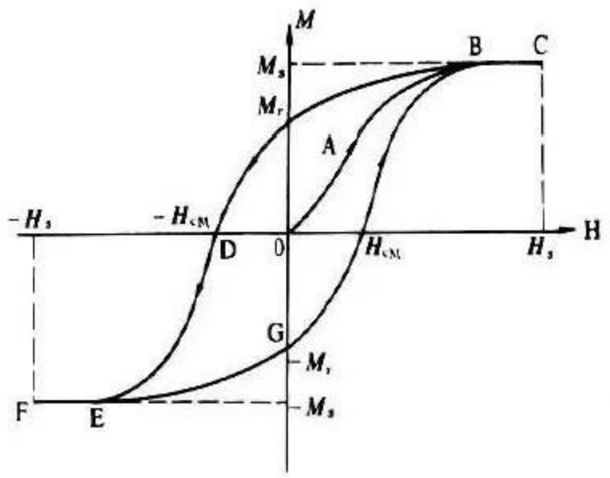


Figure 2.1 – Magnetic hysteresis loops of magnetic materials

In general, the magnetization M and magnetic induction B of a ferromagnet depend on the history of the magnetic states it has experienced.Taking H=M=B=0 as the initial state, the magnetizing magnetic field changes periodically through magnetization, demagnetization, reverse magnetization, and demagnetization.When H decreases to zero, M is not zero. In order to make M zero, a reverse magnetic field needs to be added, which is the magnetic coercive field H_C.

If we examine the mechanical response of a ferromagnetic material to an applied magnetic field, we find that the length or volume of the material changes slightly in the direction of the applied magnetic field. This property is called magnetostriction.

Its essence is that the coupling energy of the spin and orbit of the ion or atom and the elastic energy of the material need to reach a balance.From the energy point of view, the magnetostrictive effect of magnetic materials conforms to the point of view that the free energy is extremely small. That is, when the magnetization state of the magnetic material changes, the total energy of the system is minimized by changing the shape and volume [17].

When magnetizing a magnetic single crystal, it was found that the shape of the magnetization curve (M-H) is related to the direction of the magnetic field applied to the crystal.As shown in Figure 2.2,

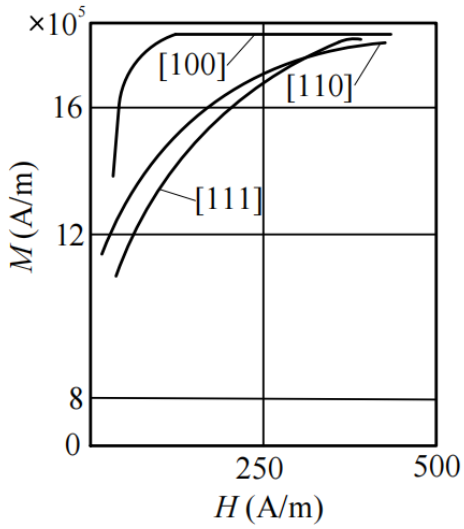


Figure 2.2 – Single crystal magnetocrystalline anisotropy map of Fe

This shows that there are differences in the behavior of the magnetization curve when a magnetic field is applied along different crystal axes. This phenomenon is called magnetocrystalline anisotropy [18]. Due to magnetic anisotropy, the same crystal is easy to reach saturation in some directions to be magnetized, but difficult in others. This most easily magnetized direction is defined as the easy axis. Similarly, the direction that is least magnetized is defined as the hard axis.

Thus, magnetocrystalline anisotropy describes the spatial (angular) energy distribution of magnetization in a magnetic material, as well as the stability of the magnetization distribution at different spatial angles.

Using the concept of energy, the magnetization work that needs to be paid for the magnetization of the ferromagnet from the demagnetization state to the saturation is:

$$\int_0^M \mu_0 H \; dM = \int_0^M dE = E(M) - E(0) \tag{2.3}$$

Where: the left end is the magnetization work, which is determined by the area enclosed by the magnetization curve and the M axis; the right end is the increased free energy.

Therefore, along the easy axis direction, the area enclosed by the magnetization curve and the M axis (longitudinal axis) is the smallest, and the increase in free energy is the smallest; along the hard axis direction, the increase is the largest.

The relationship between the magnetization energy and the angle caused by the magnetocrystalline anisotropy can be expressed as:

$$E_k = K_0 + K_{u1}\sin^2\theta + K_{u2}\sin^4\theta + K_{u3}\sin^6\theta + K_{u4}\sin^6\theta\cos^6\varphi + \cdots \tag{2.4}$$

$\square_{\square}$ represents the free energy density that is only related to the direction of the saturation magnetization in the crystal, which is called the crystal magnetic anisotropy energy;

$\square_0$ ~$\square_{\square 4}$ are all magnetic anisotropy constants. In fact, due to the relatively low energy coefficient of the higher-order terms, it is generally accurate enough to obtain the second-order term;

$\square$- pole angle of magnetization, $\square$- direction angle.

Magnetic anisotropy can change the microstructure of materials by magnetic field strengthening treatment. The difference in magnetic susceptibility causes additional magnetic driving force, which is manifested by the difference in the magnetization energy received by the crystal in different crystallographic axes. This energy difference causes the crystal to rotate until it reaches the lowest energy position, while a process that is accompanied by changes in the material's microstructure.

The internal magnetic domains of non-ferromagnetic materials have low saturation magnetization and inactive alignment. Further research is needed on their magnetic field strengthening effects.

2.1.2 Mechanical properties of high speed steel

High-speed steel is a kind of high-alloy tool steel. At that time, it was called high-speed steel because its appearance greatly improved the cutting speed. Due to the addition of more alloying elements such as W, Al, Cr, and V during production, it has good comprehensive performance and high strength and toughness. And because of its good manufacturability and forgeability, it is usually used to make complex tools such as taps, broaches, gear hobs, etc. When the cutting temperature of the high-speed steel tool is higher than about 600 °C, the hardness does not decrease significantly, and it can still maintain good cutting performance. Its carbon content is 0.7% to 1.65%, and the total amount of alloying elements such as W, Mo, Cr, V, and Co in the steel exceeds 10%.

Ferromagnetic materials are generally Fe, Co, Ni elements and their alloys. According to the classification of magnetic materials, high-speed steel is a strong magnetic material and can be magnetized. The former Soviet Union scholar Талей applied magnetic energy to the tool to test, and the results showed that the service life of various high-speed steel tools was significantly prolonged after being magnetized [19]. Scholars Neema MI, Pandey PC, etc. magnetized high-speed steel tools through a steady and constant magnetic field, and found that the durability of the treated high-speed steel tools was increased by 2 to 4 times. And they also pointed out that when the magnetic field strength increases, the tool durability also increases; the magnetization effect is affected by the amount of cutting, and the magnetization effect is more significant under the conditions of lower cutting speed and smaller feed rate [20][21].

American Innovex company uses the self-developed FIuxaTron U102 tool magnetization device to magnetize high-speed steel tools and carbon tool steel tools. It was found that the average service life of the cutting tool after magnetization was prolonged by 20-50% [22].

Scholars regard the magnetization process as a contactless energy transfer process. For high-speed steel materials, the magnetization process is accompanied by two changes of magnetic domain wall displacement and magnetic domain rotation, which must change the material properties to a certain extent, such as the increase in hardness. Foreign studies have proved that magnetostriction can change the lattice parameters of martensite, mainly in the reduction of the average atomic spacing [23].

2.1.3 Mechanical properties of cemented carbide

Cemented carbide has become the most widely used tool material due to its many properties and advantages. Cemented carbide is a shaped powder metallurgy product obtained by sintering refractory hard metal carbide (WC/TiC, etc.) and metal binder (Co, Ni, etc.) at high temperature. In 1923, German scientist Schrotter added a certain amount of cobalt to WC powder, and obtained a new alloy combining tungsten carbide and cobalt for the first time, and the hardness value was only slightly lower than that of diamond [24]. Because of its high strength, high hardness and high wear resistance, cemented carbide is used to manufacture cutting tools, measuring tools, molds, etc. In particular, the tools made by it can also be cut at 800~1000℃.However, because of its brittleness, it is not easy to process complicatedly. Thus, in the field of machining, cemented carbide is mostly used to make simple inserts such as turning tools, milling cutters, drills, and boring tools.

Carbide tools are generally divided into three categories. Its characteristics and processing characteristics are shown in Table 2.1 below.

Table 2.1 – Carbide tool types and their characteristics

Category	Common grades	Characteristic	Application
YT （ class of P ）	YT5YT14、 YT15、YT30	-high hardness and wear resistance, good heat resistance, slightly lower bending strength than YG type, often processing long chip	- suitable for processing carbon and alloy steels, including steel forgings, stampings and castings with uneven surfaces

		ferrous metals	
YG （class of K ）	YG3X、 YG6、YG8、	- good toughness, high strength and thermal conductivity, commonly used for processing short-chip ferrous metals, non-ferrous metals, etc.	- suitable for cast iron, alloy steel, non-ferrous metals, etc., including rough and finish machining during continuous cutting, rough and fine enlargement of holes
YW （class of M ）	YW1、YW2	- good oxidation resistance and wear resistance, bending strength, fatigue strength and toughness are higher than YT type, often processing long and short chips ferrous metals, non-ferrous metals	- suitable for finishing of difficult-to-machine steels such as high manganese steel, heat-resistant steel, stainless steel, etc., or semi-finishing of general steel and non-ferrous metals

In recent years, researchers at home and abroad have done a lot of research on the treatment and strengthening of carbide cutting tools. Coating technology is used on the vast majority of carbide tools. The cutting performance is improved by coating the substrate with a thin layer of high wear resistance on the surface.The higher process requirements of the coating treatment make the tool cost also increase.

In terms of magnetism, the base tungsten carbide and titanium carbide of cemented carbide are non-magnetic, but the added binder metal is generally a ferromagnetic material. Like Co, Co crystal is a hexagonal crystal with significant magnetic anisotropy [17].

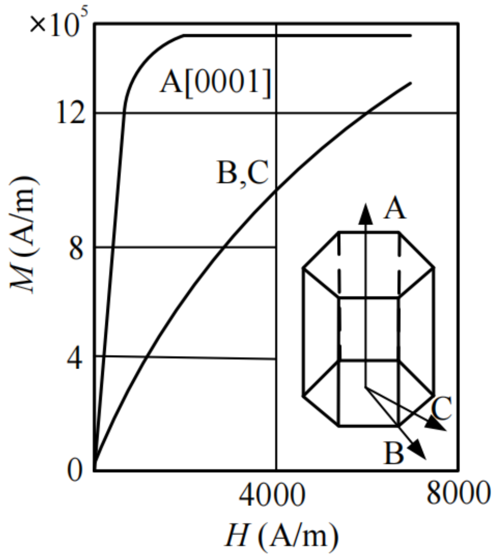


Figure 2.3 – Magnetization curve of magnetically anisotropic crystal Co

It can be seen from the M-H diagram (Figure 2.3) that the energy difference required for Co crystals to achieve saturation magnetization in different directions of the easy axis and the hard axis is quite different. Generally speaking, the greater the difference between the two-axis magnetization curves, the greater the magnetic anisotropy coefficient of the crystal, and the greater the magnetic anisotropy of the magnetocrystalline. Therefore, the chemical treatment will also cause changes in the mechanical properties of the cemented carbide.

2.2 Current status of coated tool technology

Tool coating is to coat a layer of refractory metal or non-metallic compound with good wear resistance on the surface of cemented carbide or high-speed steel tool with good strength and toughness by vapor deposition method.It can also be coated with superhard materials such as ceramics, diamond and cubic boron nitride.The coating acts as a physical barrier, providing limited thermal insulation and avoiding direct contact between the tool and the workpiece. It reduces the interdiffusion between the tool and the workpiece, thereby improving the tool's resistance to oxidation, adhesion and abrasive wear. To achieve the purpose of improving tool life, cutting efficiency and workpiece surface quality.

With the development and wide application of advanced processing technologies such as difficult-to-machine materials and green dry cutting, the cutting environment of tools is becoming more and more severe, and the coating materials of tools are constantly updated. Coating materials have gradually developed from the initial binary coating to ternary and multi-component coatings, and the structure has gradually changed from single layer to multi-layer, gradient and composite structure.

2.2.1 Coating process

The foundation of the coating process development is the vacuum vapor deposition technology. By injecting metal or metal compound in atomic or molecular form on the surface of the workpiece to be processed in a vacuum environment, a solid film is obtained after deposition. The oxygen content of the active gas under vacuum is low, and the gas intermolecular collision is less, and the prepared film can be produced with low porosity and impurity content; the degree of vacuum also changes the growth mechanism of the coating, which can refine the grains and affect the structure and distribution of the coating, thereby obtaining a coating with high hardness and high purity [25][26].

At the beginning of the development of this technology, there are two vapor deposition methods, namely CVD (Chemical Vapor Deposition) chemical vapor deposition technology and PVD (Physical Vapor Deposition) physical vapor deposition technology.

1) CVD technology [27-31]

CVD is a very flexible and widely used chemical vapor deposition method for preparing coatings.

CVD is the chemical reaction of plasma at a certain temperature and gaseous state through excitation, heating and other methods. Then, gas-solid reactions such as heat sealing are completed to form a solid-state deposition layer on the surface of the substrate.

The advantage is that CVD can deposit coatings at low vacuum conditions. The preparation of various nitride, carbide, oxide, boride, silicide coatings can be carried out at deposition temperatures below their melting or decomposition temperatures.

In addition, different chemical reactions can be used for the preparation of the same membrane, and the flexibility is relatively large. That is, the composition of the reaction raw materials can not only be adjusted and changed, but also the characteristics and composition of the coating can be controlled.

The disadvantage is that CVD is not as convenient as PVD technology when coating a localized surface. Moreover, the higher process temperature is not very friendly to the stability of the tool material properties.During the original CVD coating process, due to the aggressiveness of chlorine and the brittle deformation of hydrogen, the coating surface will be cracked to a certain extent, and decarburization may occur from time to time. It was not until the emergence of medium and low temperature CVD methods that the situation was improved. At the same time, measures need to be taken to solve the problem of environmental pollution.

2) PVD coating method[32-34]

PVD is a physical coating method using sputtering or evaporation in a vacuum environment. In this process, arc discharge (low voltage, high current) is used to force the target to evaporate, and then a new solid-state layer is produced after physical reactions such as ionization with the incoming gas.This deposition method, in which the ionized material is impacted on the tool substrate by the electric field, can obtain a dense and uniform high-hardness film.

Compared with CVD, coatings deposited at low temperature and with compressive stress state inside the film are more suitable for high-precision carbide complex tools.And generally have the advantages of high strength and high hardness, good thermal stability, good wear resistance, stable chemical properties, low friction coefficient, environmental protection and no pollution.

The disadvantage is that PVD requires a high degree of cleanliness of the substrate. Moreover, due to the poor wrapping property, the ability to cover parts such as steps is poor. The process repeatability is not good and the processing cost is high.

2.2.2 Coating structure

With the rapid development of material science, there are more and more practical application cases of polymer composite materials, which greatly promotes the development of coating technology. In order to better meet the requirements of various cutting processes, the coating composition has gradually developed from single to diversified. The earliest simple binary coating was gradually developed into a ternary or multi-component coating; the coating structure was also gradually complicated, and gradually changed from a single layer to a multi-layer, gradient, and nano-composite structure.

1) Multi-layer composite coating

The types and characteristics of common coating materials are shown in Table 2.2.

Table 2.2 – Characteristics and applications of common coating materials

Coating material	Matrix material	Main features	Application field
TiN、TiC、Al_2O_3、TiCN、TiAlCN	carbide, high speed steel	- high hardness and wear resistance	- suitable for carbon steel, stainless steel, high strength steel processing
Al、W、Ti、Ta、Mo、Al_2O_3、Si_3N_4、Ni-Cr、BN	stainless steel, corrosion resistant alloy Steel, Mo alloy etc.	- high temperature and oxidation resistance	- serospace parts, turbine blades, nozzles, exhaust pipes, certain industrial heat-resistant components
TiN, TiC, Al_2O_3, Cr_7C_3, Ni-Cr, Fe Ni-Cr-P-B amorphous, etc.	non-ferrous metals, steel, stainless steel, etc.	- preservative	- surface protection of chemical pipelines, automobiles, airplanes, ships and other components

			and fasteners

It is generally known that TiN, TiCN, TiAl, etc. are hard coating materials that have been industrialized and widely used.Nowadays, only one of the materials is used to coat a layer of coating to meet the increasingly high process requirements, so the industry uses a multi-layer composite coating to further improve the performance of the coating. Multi-layer coatings are formed by combining two or more different materials alternately and superimposedly, which retains the excellent properties of each material. At the same time, by rationally designing the multi-layer structure, the internal stress of the coating can be effectively reduced, and the crack resistance of the coating and the bonding strength of the film/substrate can be improved.

Li et al. [35] prepared AlTiSiN coatings with low hardness and high hardness (Coating A and Coating B) by adjusting the substrate bias, and combined the two into two-layer, four-layer, and eight-layer TiAlSiN coatings. The study found that the use of multi-layer structure helps to improve the toughness of the coating and prolong the service life of the tool.

In terms of production applications, Oerlikon Balzas Coatings has applied the AlCrO/AlCrN multi-layer composite coating to the surface of gear hob, and has an absolute advantage in the tool coating industry. Figure 2.4 is a photo of the cross-sectional morphology of the produced multilayer film.

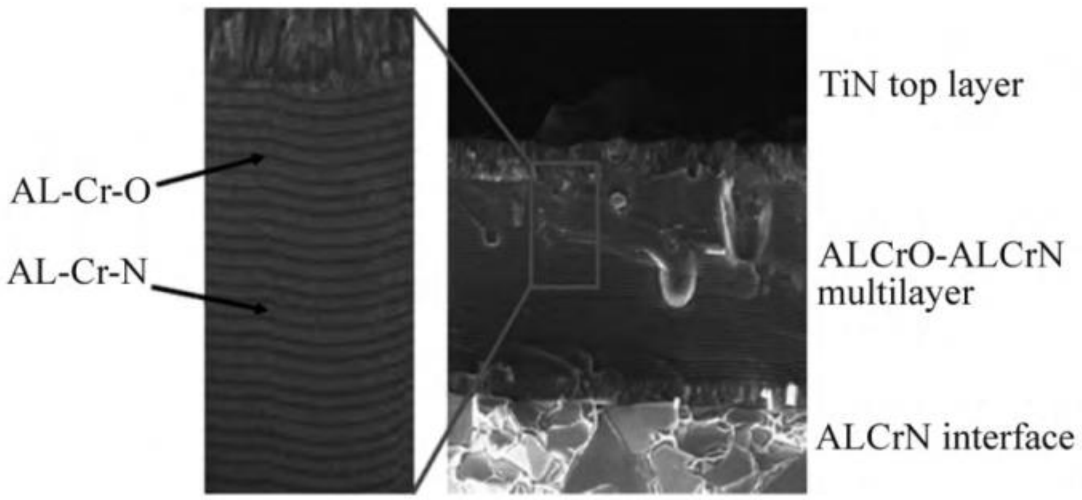
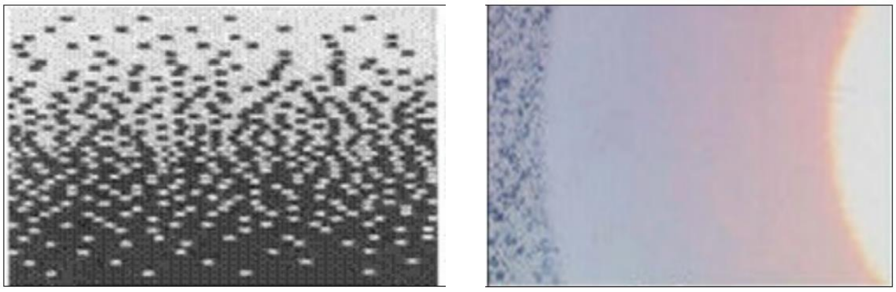


Figure 2.4 – SEM Cross-sectional images of the AlCrO/AlCrN multilayered coating

When the thickness of each layer of the multi-layer coating is on the order of nanometers, it is called nano-multi-layer coating, also known as superlattice coating.If the modulation period and modulation ratio are well controlled, the coherent relationship between the nanolayers can be maintained, and this relationship can exert excellent synergistic effects, such as supermodulus and superhardness effects.

2) Gradient coating



(a) Ideal structure for gradient coatings (b) TiAlCN gradient films

Figure 2.4 –Gradient coating image

The chemical composition of the gradient coating exhibits a gradient along the longitudinal growth direction of the film. As shown in Figure 1-3(a).

This change may be caused by the change in the ratio of each element between compounds, such as the change in the content of Ti and Al in TiAlCN.It may also be a gradual transition from one compound to another [36], a Cr/Cr2N/CrN coating with a N gradient.Deposition of graded coating with graded composition on cemented carbide or high-speed steel tools can effectively eliminate the stress concentration between the coating and the substrate and the interface inside the coating. And significantly enhance the bonding strength of the film base and prolong the service life of the tool.

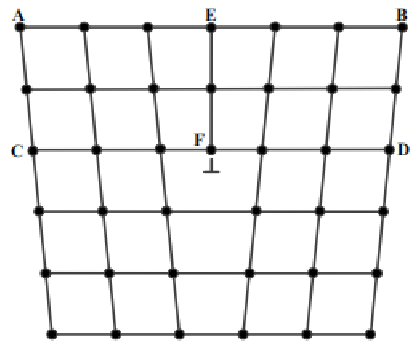
2.3 Analysis of pulsed magnetic field processing applied in metal cutting field

The modification of tool materials is generally carried out by traditional heat treatment and tool coating methods. However, traditional strengthening treatment methods have certain defects in different aspects. Surface coating technology coats a hard film by vapor deposition, but it is difficult to ensure that it can be fully combined with the surface layer of the workpiece substrate, thus affecting the actual performance and life.And usually, there is a pretreatment process before the coating strengthening process, which needs to passivate or blunt the cutting edge, that is, increase the blunt circle radius of the cutting edge. Experiments have shown that even if the process of cutting edge passivation is removed, the cutting edge blunt circle radius will increase due to the coating of the tool. This is extremely detrimental to the micro-tools for micro-cutting, and coating strengthening has become the opposite method. Heat treatment mainly includes carburizing, nitriding, shot peening and other methods. However, the material is easily deformed during high temperature treatment,which will also affect the cutting performance and durability of the tool after processing. And the process will produce a variety of toxic gases. If the generated waste gas and waste residue are not effectively treated, it will pollute the natural environment.

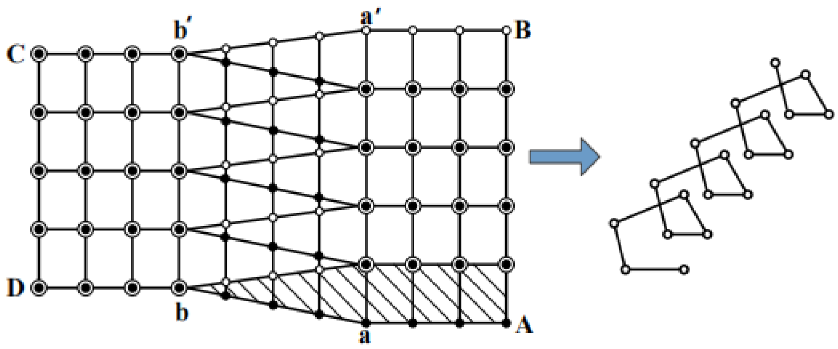
Unlike these techniques, Pulsed Magnetic Field Enhancement is an external field technique for non-contact energy transfer. As for the mechanism of its ability to improve cutting performance, experimental investigations show that the strong magnetic field applied externally affects the motion state of atoms or molecules inside the magnetic material, causing changes in behaviors such as arrangement, matching, and migration. Macroscopically, it means that the physical properties of the material as a whole change.The method effectively improves the wear resistance and service life of the tool through magnetostriction, affecting the movement of dislocations and changing the internal metallographic structure. These phenomena will be fully explored in the following sections.And the researchers confirmed that strong magnetic fields can not only act on ferromagnetic materials like conventional strong static magnetic fields, but also significantly affect the structure and properties of non-ferromagnetic materials. The practicality and application range are further expanded. As an emerging technology in the field of production and processing, magnetization is gradually being applied to the research of tool modification.

2.3.1 Dislocation

From the research of tool materials, it is concluded that ferromagnetic materials are characterized by magnetocrystalline anisotropy, and the magnetization is different on different crystal axes.In addition, the change of the original equilibrium distance between atoms caused by the external magnetic field is also related to the lattice orientation. The variation of the distance between atoms along the easy axis direction is different from the variation of the distance between atoms along the direction of the hard axis, thus resulting in lattice distortion.The dislocation is a linear crystal defect related to the distortion of the atomic arrangement in the crystal, which can be regarded as the boundary between the slipped part and the non-slipped part in the crystal.



(a) Edge dislocation



(b) Screw dislocation

Figure 2.5 – Atomic configuration of edge and screw dislocations

Dislocations are classified into general edge dislocations and screw dislocations. They each have their own characteristics (Figure 2.5). It should be noted that a dislocation formed by an extra half-row atomic plane (which can also be understood as a missing half-row atom) somewhere in the crystal is called an edge dislocation; the dislocations generated by the dislocation of the upper and lower parts of the crystal along the slip plane are called screw dislocations.

The dislocation line of an edge dislocation must be perpendicular to the slip direction and the Burger vector. And the slip plane of edge dislocation is unique, and the dislocation line and slip direction must be on the slip plane. Screw dislocations have no extra atoms missing/added. The dislocation line is parallel to the Burger vector, the motion direction of the dislocation line is perpendicular to the Burger vector, and the slip plane is not unique.

In addition to the above two dislocations, there is also a mixed dislocation. Mixed dislocations are abundant in material crystals. The dislocation lines of mixed dislocations are neither parallel nor perpendicular to the Burger vector.

In order to perform the mathematical calculation of dislocations, a vector representing the magnitude and direction of the atomic movement during crystal slip is artificially specified, called the Burger vector. Many properties of dislocation, such as dislocation energy, force, stress field, dislocation reaction, etc., are related to it.

Dislocations are involved in almost every aspect of plastic deformation of metals. During plastic deformation of polycrystalline, it is hindered by grain boundaries and affected by different grains in the orientation. The plastic deformation of any one grain is not in an independent free deformation state. They require the corresponding deformation of the surrounding grains at the same time to cooperate in order to maintain the bonding between grains and the continuity of the whole object. Because the slip directions of each grain are different, the shear stress on each slip system is large during deformation.

When a grain with the most favorable orientation undergoes plastic deformation, this means that the dislocation source on its slip plane is activated.When the crystal slips, the dislocations also continuously move forward on the slip plane. However, the orientation of the surrounding grains is different, and the slip system is also different. A moving dislocation cannot cross the grain boundary, and the slip system cannot develop into another grain.The dislocations will form plane packing groups at the grain boundaries, which will cause a large stress concentration. Under the action of the applied stress and the stress concentration caused by the dislocation plane packing group in the slipped grains, more and more grains will be plastically deformed.

2.3.2 Influence of pulsed magnetic field treatment on tool life

In foreign countries, the Fluxatron tool processing system developed by Innovex Corporation of the United States [37] can increase the tool life to 175%, and the processing time is only 42 s.Ford uses magnetized drills and carbide inserts for machining. The life of the drill bit has been increased from 500~600 pieces to 700~800 pieces, and the life of the carbide tool has been increased from 60~80 pieces to 100~159 pieces.And it is confirmed that the magnetization treatment is also effective for the coated tool.

Metal cutting is During processing, the cutting layer of the material is squeezed by the tool to generate chips. With the feed of the tool, most of the metal generates chips, and a small part of the metal is extruded through the flank to generate a new machined surface.essentially a complex forming process in which the blade and the blank are extruded. Therefore, the cutting process is inevitably accompanied by tool wear, and residual stress is inevitably generated inside the tool, which is also the premise for fatigue cracks. The propagation of fatigue cracks will eventually lead to structural failure of the material.How to deal with residual stress has a very important influence on the corrosion resistance, fatigue performance and dimensional stability of the tool, which directly affects the service life of the tool.

Researchers at home and abroad have found through experiments that proper magnetization treatment can effectively eliminate or reduce the residual stress of steel materials. Innovex Corporation of the United States believes that the main reason why pulsed magnetization can improve the service life of the tool is to reduce the residual stress generated by the tool during manufacture [37]. Molotskii M et al. [38] believed that the material would have residual stress relaxation under the action of a magnetic field, which was caused by the tiny plastic deformation of the material.Researchers from Tsinghua University have quantitatively studied the effect of magnetic treatment on the residual stress of carbon steel welding.The results confirmed that after magnetic treatment, the residual stress in the direction of the vertical weld and along the weld can be reduced by about 50MPa, and the maximum reduction of the stress can reach 40% of the original stress level. After magnetization, both the peak value of the stress curve and the stress curve itself showed a decreasing trend.The researchers also studied the influence factors of magnetization treatment to eliminate residual stress, and reached some conclusions through experiments. For example, the steady magnetic field treatment has almost no effect on the residual stress distribution in the workpiece; when the frequency of the intermittent wave magnetic field is low, the magnetic treatment effect is better.Regarding the mechanism of magnetization treatment to reduce the residual stress of the material, the research team believes that the dynamic magnetic field is the key. The magneto-induced vibration caused by it interacts with the unevenly distributed stress in the material, which will lead to the micro-regional plastic deformation of the material, and the result of the accumulation of this plastic deformation is the reduction of residual stress.

On the other hand, the study of Youssef Fahmy et al in the United States found that magnetization treatment can significantly improve the fatigue life of carbon steel materials.The Turkish scholar CelikA et al. confirmed that applying a DC magnetic field in the early stage of fatigue cracks in the workpiece can prolong the fatigue life of the workpiece.

The author's analysis,with the gradual increase of the applied magnetic field strength, the magnetostrictive effect inside the steel material will switch from positive to negative. Until the material reaches saturation magnetization, the magnetostriction also reaches the corresponding negative saturation value.Therefore, in a dynamic magnetic field whose magnitude and direction vary with time, magnetostriction will also have alternating positive and negative states. This magnetostriction produces magnetostrictive vibrations. When the magneto-induced vibration interacts with the unevenly distributed residual stress in the material, it will lead to the slip of dislocations in the active zone and the occurrence of plastic strain, thereby reducing the residual stress [39].

In addition, according to the dislocation theory analysis, dislocations are hindered in polycrystalline materials, and dislocation packing and stress concentration occur.Under the continuous cycle of residual stress generated by tool machining, the stress concentration at the grain boundary cannot be relaxed, and the stress peak becomes higher and higher. When the grain boundary strength is exceeded, cracks are generated at the grain boundaries.The reason why the material fatigue life is improved in the magnetic field is that, the magnetic field promotes the diffusion behavior of atoms in the material, which relaxes the peak stress, which slows down crack initiation and increases the material fatigue life.

2.3.3 Effect of pulsed magnetic field processing on metallographic microstructure and mechanical properties of ferromagnetic tool materials

Due to the characteristics of high carbon steel being easily magnetized as a ferromagnetic material, this chapter takes it as a typical object of treatment. The microscopic effect of magnetization treatment on the metallographic structure needs to be studied.

Carbides occupy most of the metallographic composition of high-speed steel, and the mechanical properties of materials are largely determined by the volume, morphology and distribution of carbides.

The 400× in-situ comparison diagram of M42 high-speed steel material before and after pulse magnetization is shown in Figure 2.6.

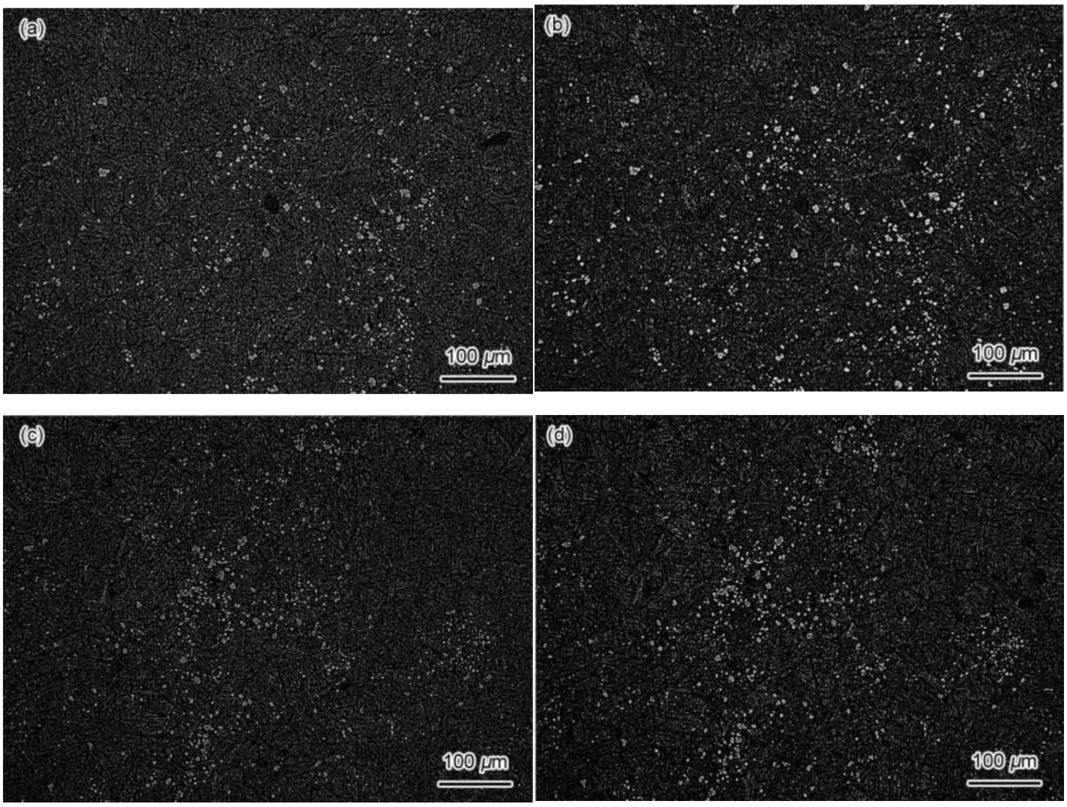


Figure 2.6.– Low magnification morphologies of carbides in M42 high-speed steel before and after pulsed magnetization

(a) , (c) -are the microstructure photos of two optional points of the metallographic sample before magnetization treatment;

(b) , (d) -are the corresponding microstructure photos of two optional points of the metallographic sample after magnetization treatment.

The black in the Figure 2.6 is the matrix structure, and the white lumps and dots are carbides.It can be seen from the in-situ comparison diagram that the number of carbides in the high-speed steel material increases significantly after being strengthened by the pulsed magnetic field, and many fine carbides appear.In addition to the new carbides added, it can be found after further observation at high magnification that some of the original massive carbides have been fragmented and become finer after treatment.These newly precipitated disperse carbides can strengthen the martensitic matrix and enhance the wear resistance of the material, which is one of the reasons why pulsed magnetization can increase tool life.

(1) Material hardness

Mohamed E1 Mansori et al. found that the case hardening rate of machined surfaces increased with increasing magnetic field strength after a magnetized cutting process. It is believed that during the cutting process, the magnetic field activates the movement of the dislocation source, resulting in a sharp increase in the dislocation density in the surface layer, resulting in hardening.At the same time, along with the generation of new dislocations, the domain walls are displaced. This displacement effectively impedes the movement of dislocations, which leads to a further increase in the dislocation density, and thus the hardening rate increases with increasing magnetic field strength.However, some researchers have obtained the conclusion that the hardness decreases through experiments. For example, Guo Song from Jiangxi University of Science and Technology, China, magnetized YG8 cemented carbide samples, but did not see the hardness increase, but decreased to a certain extent [40].However, the reduction is not large, which may be caused by the error of hardness measurement, or it may be the redistribution of dislocations caused by magnetization, which weakens the original effect.There are many types of cemented carbide, and the matrix composition is also different. Therefore, the effect of magnetization on the hardness of other cemented carbides needs a lot of experiments to explore.

It can be seen from the foregoing that the martensite content of the high-speed steel material increases after the pulse magnetization treatment. Martensite is a hard and brittle structure, and the increase of martensite content can increase the hardness of high-speed steel samples. In addition, the microstructure of the sample becomes relatively uniform after magnetization treatment, and the strength of the high-speed steel can also be improved at the same time.

Figure 2.7 shows the microstructure comparison of retained austenite in high-speed steel materials before and after pulse magnetization treatment.

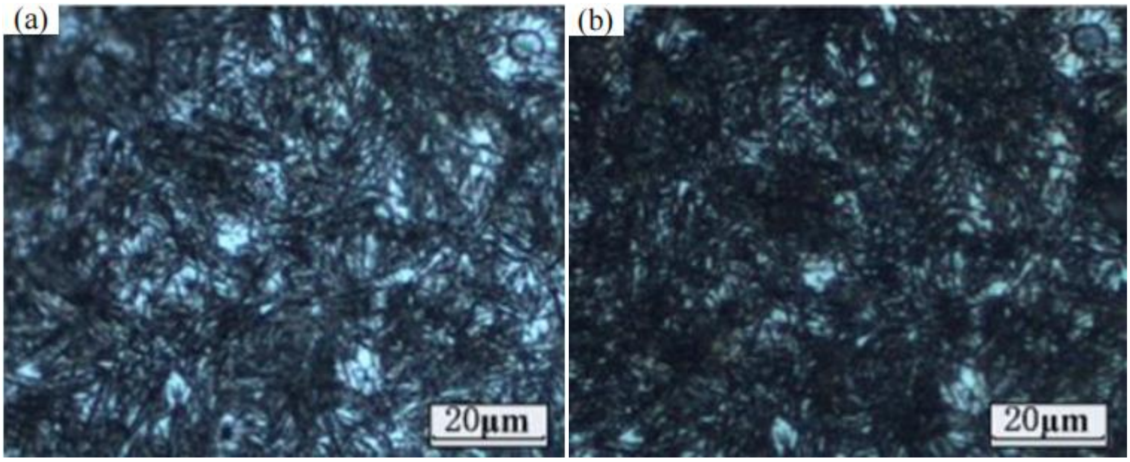


Figure 2.7 – Microstructure of retained austenite in high-speed steel before and after pulse magnetization

Figure 2.7(a) shows the metallographic structure of the sample before magnetization treatment. The bright part is retained austenite surrounded by acicular martensite. Figure 2.7(b) shows the metallographic structure after pulsed magnetization. It can be clearly seen that the retained austenite of the sample decreases after magnetization treatment, the acicular martensite structure becomes dense and finer, and the content of martensite increases.

Some scholars pointed out that the reason for this change is the effect of magnetostriction in the magnetization process of the material [41]. Since magnetostriction can cause small deformation of austenite, the solubility of austenite to carbon is significantly reduced under deformation pressure. Therefore, it appears that a large amount of dispersed carbides are precipitated in the matrix. This is the main reason for the increase in the number of carbides in the matrix of the high-speed steel material after pulsed magnetization.

On the other hand, in general, the transformation from austenite to martensite requires high temperature cooling, that is, a certain degree of undercooling is required.In the process of pulsed magnetization, although the temperature of the matrix can be increased due to the eddy current effect. However, the pulse frequency used is low frequency, and the heat generated cannot provide the tissue with the same degree of supercooling as heat treatment.Some scholars have pointed out that the combined effect of magnetostriction and frictional stress can promote the transformation of retained austenite produced by tempering in high-speed steel into martensite. It has also been pointed out that the martensite of the samples after magnetization becomes thinner and the grains are more uniform .Therefore, after the high-speed steel material is subjected to pulse magnetization, the three changes in the metallographic structure are corresponded one by one in the comparison diagram, namely the change of carbide, the transformation of retained austenite into martensite, and the grain refinement.

(2) Material plasticity

Under the action of a magnetic field, the plastic changes of non-metallic crystals and metal crystals have also been discovered by researchers.

Al'shits et al. found that an external magnetic field can increase the plasticity of NaCl crystals. The analysis deduces that the dislocations in the crystal can be unpinned under the action of an external magnetic field. And slip occurs when there is long-range stress in the material, which increases the plasticity of NaCl crystals.

Subsequently, the researchers found that dislocations also exist in metals when they are unpinned under the action of a magnetic field. For example, the magnetic field can promote the iron creep and tensile deformation process experimental results were found [38].In China, Song Yanli et al. also discovered the phenomenon of magneto-induced microdomain plasticity. For the mechanism of magnetoplasticity, researchers generally believe that it is caused by material dislocations that are more likely to break off and increase their mobility under the action of a magnetic field.During this process, the magnetic field can change the electronic configuration between the pinning and the dislocation. Through the transfer of magnetic field energy, the bonding state between the pinned object and the dislocation realizes the transition from a low-energy stable state to a high-energy unstable state.In addition, the magnetic field accelerates the diffusion of impurity atoms and vacancies in the material, which is conducive to the progress of dislocation climbing, and also leads to the reduction of the plastic deformation resistance of the material.

From the metallographic level of the material, after the material is impacted by a pulsed magnetic field, the martensite structure will become more finer, and the original large grains will be partially divided and refined after magnetization.It can be observed in the experiment that this segmentation is caused by newly precipitated black acicular martensite. This acicular martensite can divide the prior austenite grains and refine the austenite grains.Therefore, after the pulse magnetic field strengthening treatment, the grains of the high-speed steel material will be refined, and the plasticity and toughness of the material will be further enhanced.

Conclusion to be the Part2

In this part, two kinds of cutting tool materials are determined for the current pulse magnetic field strengthening treatment, and combined with the principle of magnetization, the strengthening mechanism of magnetic field on magnetic metal cutting materials is obtained. After intuitive observation of the microstructure level of high-speed steel, three changes in the metallographic structure after pulse magnetization were restored, namely the change of carbide, the transformation of retained austenite to martensite and grain refinement. It is clear that the pulsed magnetic field strengthening treatment technology improves the mechanical properties of materials by changing the microstructure of materials. This method further improves the performance of the tool. At the same time, on the basis of the first part, the tool coating technology is further analyzed. Compared with the pulsed magnetic field technology, the advantages and disadvantages of different optimization approaches are summarized.

PART 3

MECHANICAL PROPERTIES INVESTIGATIONS OF CUTTING INSERTS MODIFIED BY PULSED MAGNETIC FIELD PROCESSING

At present, the pulse magnetic field strengthening treatment process is mainly used in high-speed steel and cemented carbide tools.Since cemented carbide is currently the most widely used tool material on the market, this chapter measures the corresponding mechanical properties of the magnetized cemented carbide tool to explore the strengthening effect of the pulsed magnetic field.

Brittle fractures often occur under the action of mechanical and thermal shock during carbide cutting. Breakage, like wear, is one of the main causes of tool failure.Breakage can be considered an abnormal wear and tear. When used under certain cutting conditions, if the tool cannot withstand strong stress, sudden damage may occur, causing the tool to lose its cutting ability in advance, which is called tool breakage.Wear is a relatively slow and progressive surface damage process.The form of tool damage can also be divided into brittle damage and plastic damage. Brittle materials, such as cemented carbide, tend to have brittle fractures as a cutting tool. Brittle materials exhibit only small elastic deformation but no plastic deformation until fracture.It means that when the external force reaches a certain limit, the material will be suddenly destroyed without warning, and it will fail in an instant.In this regard, the brittle damage of the tool is more serious.

The previous paper confirmed that the magnetization treatment technology can effectively improve the hardness and plasticity of high-speed steel. An the main modification direction of the mechanical properties of cemented carbide by magnetization treatment is to make up for the weakness of its brittleness.Therefore, this chapter will conduct bending strength experiments. The statistical strength theoretical system was established for the cemented carbide before and after magnetization treatment to verify its improvement effect.

3.1 Theoretical analysis of statistical strength of brittle materials

Two important characteristics that distinguish brittle materials from ductile materials are the discreteness of strength and the volume effect of strength. This is the inevitable result of the random evolution of small defects such as a large number of scattered holes and cracks in brittle materials. It can only be dealt with by means of probability and statistics.As early as 1939, W. Weibull applied the weakest ring principle to make pioneering work on the statistical theory of strength [42], and proposed the famous Weibull distribution.In many subsequent works, the experimental results effectively proved the feasibility of applying the statistical strength theory of brittle materials under different stress states. Now it has become one of the main methods to link the microscopic and macroscopic mechanical properties.

Classical statistical strength theory is based on the weakest ring principle. It assumes that the material breaks at the most dangerous defect (i.e. the weakest link), which in turn will cause the entire chain to break.

Then under the applied stress δ at this moment, the probability of fracture is:

$$P_f(\delta) = 1 - exp[-NF(\delta)] \tag{3.1}$$

P_f is the fracture probability of a body containing N cracks at stress δ.

Weibull theory assumes that materials are isotropic and homogeneous. And it was determined that the destabilizing propagation of the most dangerous cracks would lead to the failure of the entire component. Its probability density function $f(\delta)$ is:

$$f(\delta) = \frac{m}{\delta_0}\left(\frac{\delta-\delta_n}{\delta_0}\right)^{m-1}\exp\left[-\frac{\delta-\delta_n}{\delta_0}\right]^{m},\quad \delta \geq \delta_n \tag{3.2}$$

Where δ_n is the threshold value of stress, which can generally be taken as zero for brittle material samples;

δ_0 - a parameter;

m-Weibull modulus, which indicates how uniformly the defects are distributed in the volume.

The fracture probability caused by a crack is:

$$F(\delta) = \int_{\delta_n}^{\delta} f(\delta)d\delta = 1 - \exp\left[\left(\frac{\delta-\delta_n}{\delta_0}\right)^{m}\right] \tag{3.3}$$

Considering that N is very large, for the general case, it can be deduced as:

$$P\ \ (\delta) = \left\{1 - \exp\left[- \int \left(\frac{\delta - \delta_n}{\delta_0}\right)^m dV\right]\right\} \quad when\ \delta \geq \delta_n \tag{3.4}$$

V-workpiece volume.

The distribution of cracks varies widely depending on the surface conditions and heat treatment conditions.

When $V = 1$ and $\delta - \delta_n = \delta 0$, $P(\delta) = 0.632$.

Therefore, δ_0 is the stress per unit volume giving a probability of failure $P(\delta) = 0.632$. And it can be seen that δ depends on the working volume.

After transforming equation (3.4), we get:

$$\lg ln \frac{1}{1 - P(\delta)} = \ln n(\delta^{/}) + \lg V. \tag{3.5}$$

It can be deduced that in a rectangular coordinate system with $\ln \mathrm{n}(\delta^{/})$ and $\lg ln \frac{1}{1-P(\delta)}$ as axes, the change of the sample volume will only cause the image translation.

If a distribution function is given:

$$n\ \ (\delta^{/}) = \left(\frac{\delta - \delta_n}{\delta_0}\right)^m \tag{3.6}$$

The abscissa axis is $\lg\ (\delta - \delta 0)$, then in this formula, the distribution function will be linear:

$$\lg ln \frac{1}{1 - P(\delta)} = m \cdot \lg\ \ (\delta - \delta_n) - m \cdot \lg \delta_n + \lg V \tag{3.7}$$

Through the analysis of formula (3.7), it can be concluded that the uniformity index m will not change under the manufacturing conditions, but the working volume will.

Therefore, two batches of samples with the same volume from the same factory can be selected, and the strength values before and after strengthening can be tested by different workloads.

the value of m can be determined from the equation:

$$\frac{\overline{\delta_1}}{\overline{\delta_2}} = \left(\frac{V_2}{V_1}\right)^m \tag{3.8}$$

where $\overline{\delta_1}$, V_1 – average strength and working volume of one series of samples;

$\overline{\delta_2}$, V_2 – the average strength and working volume of another series of samples.

Transforming equation (3.8) we will obtain:

$$m = \frac{\lg V_2 - \lg V_1}{\lg \delta_1 - \lg \delta_2} \quad (3.9)$$

It can be seen that in this experiment, m is very important, and it can be found that it directly reflects the brittleness of the material through derivation. The experimental design will revolve around obtaining the m value.

In the general case, it is more convenient to determine the value of the indicator m by the formula derived when decomposing the j-function into a static series, under the assumption that the fractional value of the second term of equation (3.6) is negligible:

$$m = \frac{127.5}{K_\delta} - 0.5, \quad (3.10)$$

where, $K_\delta = \frac{S}{\delta_{av}}$ -Intensity variation coefficient;

$S = \sqrt{\frac{\sum \boldsymbol{\varepsilon}^2}{\boldsymbol{n}}}$, $\varepsilon = \delta_1 - \bar{\delta}$ - standard deviation;

δ_{av} - arithmetic mean of intensities.

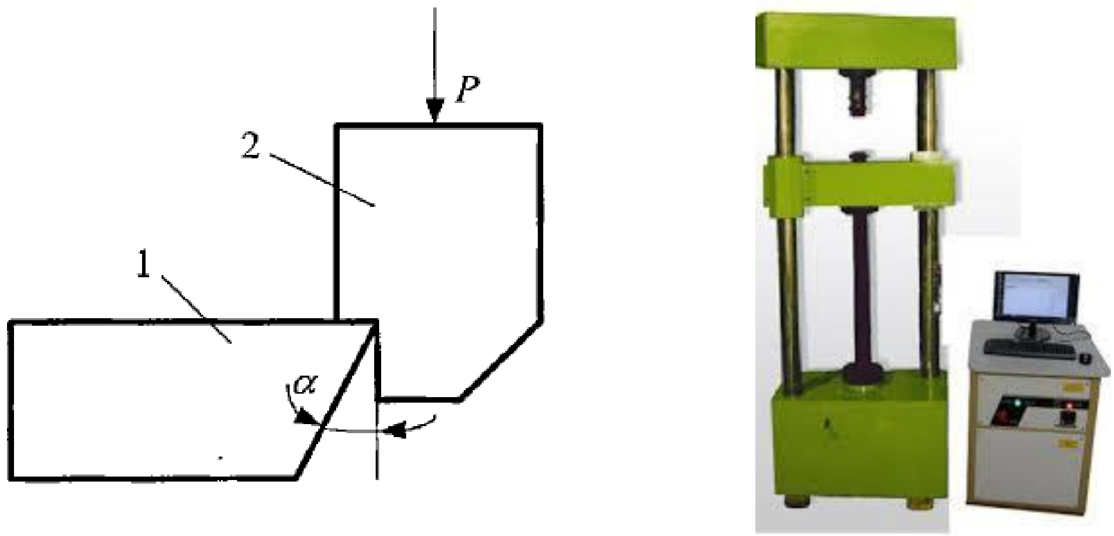
When the *m* value is in the range of 3-20, the formula (3.10) is more satisfactory than the formula (3.9). When n < 30, we need to use the estimated value S:

$$S = \sqrt{\frac{\sum \varepsilon^2}{n-1}} \quad (3.11)$$

Therefore, the index m, which represents the uniformity of the tool material, can be estimated by the coefficient of variation calculated by mathematical processing of a sufficient number of test results.

3.2 Cantilever beam bending strength test

In order to test the modification effect of magnetization treatment on cemented carbide, the research group designed and built a cantilever beam bending strength test platform. In this measurement, a bending test machine is selected to apply an additional load to the test object. And according to the variable control, the samples with different components and different strengthening conditions were compared, and the effect of pulsed magnetic field treatment was tested in many aspects. The physical map of the equipment and the loading scheme are shown in Figure 3.1.



а)   б)

a - the scheme of loading of a sample at cantilever bending:

1 - sample; 2 - punch;

b – experimental setup for testing samples during cantilever bending

Figure 3.1 - Tests of samples during cantilever bending

The testing machine loads the cutting force P on the cutting position of the sample in the direction shown in the figure.The limit value of the failure load P_P was recorded in time during the experiment.

The purpose of the experiment is to simulate the stress state of the tool when brittle failure occurs during the machining process. Based on the strength of the sample, the influence of the structural factor m is determined. The ultimate stress value δ is the ratio of the failure load P_P to the contact area F under a constant impact load (velocities up to 0.01 m/min). The strength is reflected by the magnitude of the stress.

The experimental result data record Table 1 is as follows.

Table 3.1 – Impact of PMFP on the cemented carbide strength in cantilever bending conditions

Cemented carbide grades	Strengthening	Critical Stress, MPa (stress of fracture)	Stress ratio coefficient $\frac{\delta_{PMFP}}{\delta_{initial}}$	Strength variation coefficient K_δ	Показник однорідності Equality characteristic m

TiC5Co10	without strengthening		515	--	0,68	1,375
	PMFP		618	1,2	0,52	1,95
TiC15Co6	without strengthening		495	-	0,72	1,27
	PMFP		604,5	1,22	0,6	1,625
WC/Co8	without strengthening		558,4	-	0,68	1,375
	PMFP		625,3	1,14	0,56	1,78
WC/Co6	without strengthening		522,25	-	0,71	1,3
	PMFP inductor №2)	B 1	501,3	0,96	0,87	0,97
		B 2	624	1,2	0,58	1,7
		B 3	548	1,05	0,6	1,625
		B 4	491,1	0,92	0,87	0,97
	PMFP (inductor №1)	B 2	588	1,12	0,66	1,43

By comparing the magnitude of the stress at brittle fracture, the test results show (Fig. 3.2, Table 3.1, confidence interval: Δ_{σ_bend}=±4.056MPa) that pulsed magnetic field treatment can increase the strength properties of cemented carbide. As can be seen from Table 3.1, the strength of the material generally increased by about 1.12 times after PMFP.

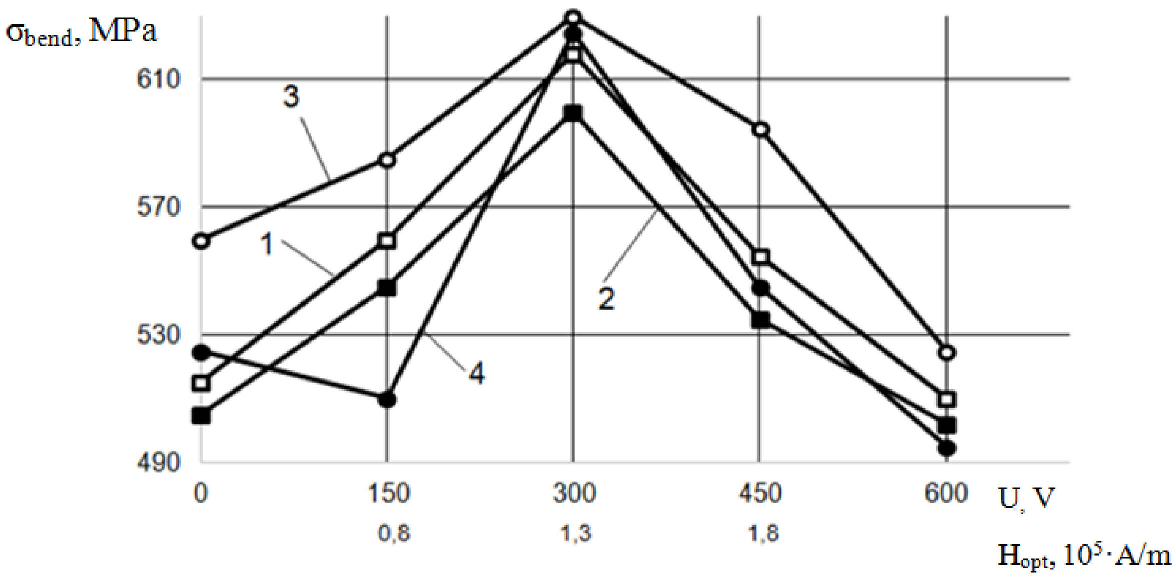


Figure 3.2 - Dependence of strength on cantilever bending after PMFP on the inductor №2: 1 – TiC5/Co10; 2 – TiC15/Co6; 3 – WC/Co8; 4 – WC/Co6

According to the relationship between stress δ and Weibull modulus, magnetic pulse treatment helps to improve the uniform distribution of defects. The effect is best when the b2 mode is used in the probation process. The coefficient of intensity variation is reduced by a factor of 1.2, and the uniformity is increased by a factor of 1.3. And the experiment also confirmed the correctness of the formula, with 95.4% reliability of the number of tests.

3.3 Change in the strength investigations of cemented carbide under concentrated loads for samples located on two support points

A study of the change in the strength of cemented carbide under concentrated loads for samples located on two support points.

Unlike experiment 1, the concentrated load test supported the sample through two support points.Put the sample on the test machine P-10 for testing. (Figure 3.3)

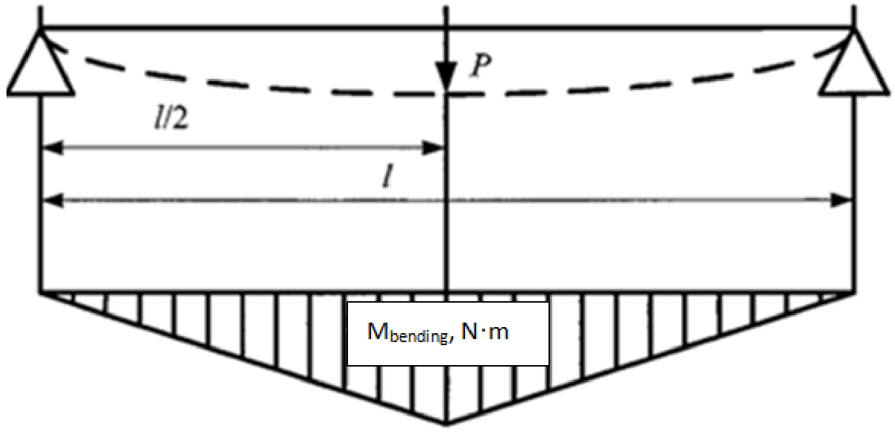


Figure 3.3 - Scheme of bending test specimens concentrated load

The experiments were designed with the central load applied by the roller bearings. The purpose is to avoid sliding friction in the additional load part and reduce the influencing factors in the process of bending deformation as much as possible.

It can be seen that this measurement simulates the actual cutting process of the tool in order to represent the total effect of P*z* (cutting force) and P*y* (thrust force).

The flexural strength is calculated according to the following formula:

$$\delta_{bend} = \frac{M}{W} , \qquad (3.12)$$

where M - bending moment;

W - section modulus.

Under concentrated force loading:

$$M = \frac{P \cdot l}{4} \ , \tag{3.13}$$

where l- the length of the span between the supports.

Where P -the load applied by the testing machine at that time.

Treat the workpiece as a rectangle:

$$W = \frac{b \cdot h^2}{6}, \tag{3.14}$$

where b – the height of the sample;

h – the width of the sample.

Therefore, the elastic stress calculation formula can be derived

$$\delta_{bend} = \frac{3 \cdot P \cdot I}{2 \cdot b \cdot h} \ , \tag{3.15}$$

The estimation of δ_{bend} can be applied to indexable inserts.

Table 3.2 - The effect of PMFP on the strength of the hard alloy under concentrated load

Cemented carbide grades	Strengthening	Bending stress, MPa	Stress ratio coefficient $\frac{\delta_{PMFP}}{\delta_{init}}$	Strength variation coefficient K_δ	$\frac{K_{\delta_{init}}}{K_{\delta_{PMFP}}}$
TiC5Co10	without strengthening	101,3		0,2	
	PMFP	124	1,22	0,1	2
TiC15Ko6	without strengthening	98,7		0,16	
	PMFP	118	1,2	0,17	2,3
WC/Co8	without strengthening	107		0,22	
	PMFP	131	1,22	0,12	1,9

WC/Co6	without strengthening		99,6		0,18	
	PMFP	B 1	95,4	0,96	0,15	1,2
		B 2	121	1,21	0,1	1,8
		B 3	102,7	1,03	0,1	1,8
		B 4	89,8	0,9	0,15	1,2

Table 3.2 and Figure 3.4 show the test results. The experimental results also show that the pulsed magnetic field strengthening helps to improve the uniformity of defects and improve the strength characteristics of the material during brittle fracture. The relationship between the numerical values reflected in the experimental results of Experiment 2 is very similar to that of Experiment 1. As can be seen from Table 3.2 and Figure 3.4, the strength of the material is increased by a factor of 1.2-1.22.

The results of the two identical experiments demonstrate that changes in material strength can be measured in a variety of ways. And when this experiment is carried out, it tends to choose the second experiment, which can greatly save the measurement times and time, and reduce the experiment cost.

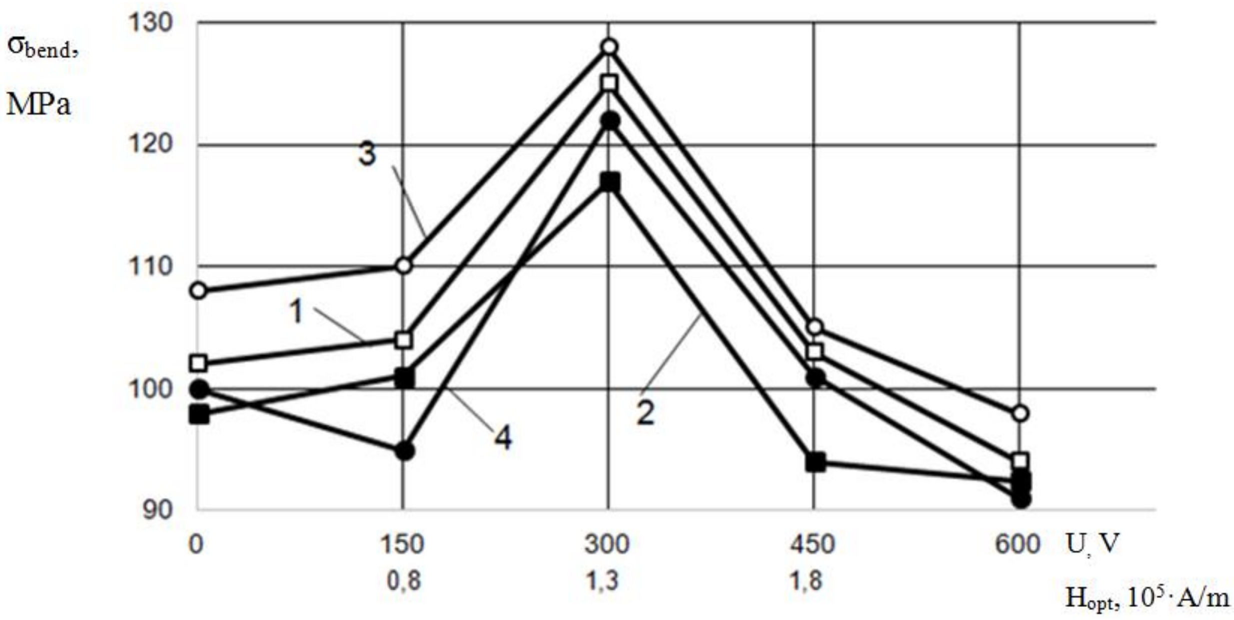


Figure 3.4 - Dependence of bending strength under the action of concentrated load: 1 – TiC5Co10; 2 – TiC15Co6; 3 – WC/Co8; 4 – WC/Co6

Conclusion to be the Part3

Strength, as the main measure of mechanical properties of brittle materials, has different characterization methods, such as common tensile strength, compression resistance, bending resistance and shear strength. The flexural strength test is often simpler and easier to obtain than other tests. In this part, two sets of bending strength measurement schemes are designed for testing the mechanical properties of cemented carbide, and the results truly reflect the strength of the tested material. Consistent results were obtained, which confirmed that the toughness and strength of cemented carbide after pulsed magnetic field strengthening treatment were significantly improved. In addition, the two test schemes are compared, and for comprehensive consideration, the concentrated load test is more applicable.

PART 4

LABOR PROTECTION

In order to obtain the cutting tool strengthened by the pulsed magnetic field and test its mechanical properties, it is necessary to build a pulsed magnetic treatment platform() and allowed some mechanical property testing experiments.The magnetic field generator usually needs to use a high-voltage pulse power supply, and it is important to pay attention to the safety of electricity.The magnetic induction intensity of conventional magnetic fields is mostly between 0.01 T and 0.1 T, and magnetic fields above 1.0 T can be called strong magnetic fields.The maximum magnetic field strength that the magnetic field generator can provide is as high as 1.5T, but you can rest assured that the pulse frequency used for strengthening is low frequency and will not produce ionizing radiation research.

Figure 4.1 - Pulse magnetic field enhancement processing platform

Another risk factor is that when testing the mechanical properties, it is necessary to consider the dangerous situation of the tool cracking and sputtering on the human body.The subject of this work is an engineer working with these devices. This chapter will consider the working conditions of an empty pulsed magnetic field laboratory and some precautions for its researchers.

4.1 Harmful and hazardous working factors

In order to protect the health of workers in the process of labor and production, avoid the hazards of toxic and harmful substances, and prevent occupational poisoning and casualties. The formulation of laboratory standards requires comprehensive consideration of the working environment and process based on quantitative characteristics. Analysis of some harmful factors in the working environment that may cause accidents after accumulation.

According to GOST 12.0.003-2015, the harmful factors and hidden dangers of pulse magnetic field strengthening treatment and mechanical testing work are:

-increased the temperature of surfaces of equipment;

-increase the noise;

- increased levels of electromagnetic radiation in the atmosphere;

- increased static levels;

-increases voltage in the circuit , and the current flows through the human body to form a loop

- cutting tool edge face, sharp edge

The first point is the danger of electric shock:

- Short circuit may cause explosion and fire.
- Arcs or sparks can ignite ignitable items or ignite explosive materials.
- Recklessly opening or operating the equipment may damage the equipment and cause bodily injury.
- Overloading electrical appliances can cause them to damage, short circuit or burn
- Electric shock can cause fatal damage to the human body. When the human body is exposed to electric current, people with minor injuries will immediately experience symptoms such as panic, sluggishness, pale complexion, muscle contractions at the contact site, and dizziness, tachycardia, and general malaise.Severely injured suffer from coma, persistent convulsions, ventricular fibrillation, and cardiac and respiratory arrest.Some patients with severe shocks may not have severe symptoms at the time, but may suddenly worsen after an hour. Burns of soft tissue in the current path can be more severe.After a large piece of limb soft tissue is electro-burned, ischemia and necrosis often occur in the distal tissue. Increased plasma myosin and red cell membrane damage can cause acute tubular necrotizing nephropathy.

The second point, for electromagnetic radiation. Under the continuous action of low-intensity electromagnetic waves, the human nervous system, cardiovascular system, and endocrine experience are affected. Some people may experience symptoms such as headaches and low immunity.

The third point, for cutting tools. Injuries that workers may receive while testing knives mainly include burns, stab wounds and cuts.

4.2 development of protective measures

1）Electrical Safety. Protection against contact potential is in accordance with DSTU 7237.2011. The following methods and methods must be used to prevent accidental electric shock:

-The circuit of laboratory electrical equipment should be equipped with leakage protector. Regularly check the wires, sockets and plugs, and repair and replace them in time if any damage or aging is found.

-In the laboratory, it is forbidden to pull or connect the wires randomly, and do not connect too many electrical appliances through the adapter on one power socket. The unused wires should be removed in time, and the lines with unknown directions should be treated as live lines and handled with care.

-Do not use high-power electrical appliances without authorization. If you have special needs, you must contact the department supervisor and use a special electrical circuit.

-Before the experiment, it is necessary to know the configuration of the power supply used in the experiment. Its voltage and frequency should be consistent with the power supply voltage and frequency required by the experimental equipment. The required power current should be less than the current allowed by the power control switch, power socket, and power terminal board.

- During the experiment, the line should be connected first, and then the power supply should be plugged in. At the end of the experiment, the power must be cut off before the wiring is removed.

-Be familiar with the operating procedures of the instrument and equipment before starting up the equipment, and then turn on the power after confirming that the state is in good condition.

-During the strong electric experiment, there must be more than 2 experimenters.

-Electrical appliances should be kept clean, dry and in good condition. When hands, feet, or body are wet or standing on a wet floor, do not turn on the power switch or touch the electrical appliances.

-During the use of electric heating equipment, the user shall not leave.

-After a sudden power failure in the laboratory, stop all reactions and cut off the main switch of the laboratory to avoid danger when a sudden power call occurs.

-Sparking or static electricity should be avoided.

2）When a magnetic field occurs, operators in the vicinity of the magnetic field should remove metal objects from their bodies. Do not expose to magnetic fields for long periods of time.

3）Do not touch the magnetized tool directly to avoid being burned. Goggles are required to be worn during the mechanical performance test. In order to prevent the knife from breaking suddenly during the pressurization, the fragments fly into the eyes. Also, be careful to avoid being cut by sharp knives.

4.3 Fire Safety Rules at the workspace

Consider and develop measures according to the fire protection requirements of DBN A.3.2-2-2009 and the explosion protection requirements of DSTU 7113:2009. The specific laboratory fire safety regulations are as follows:

1. It is not allowed to pull wires privately in the laboratory. If the work requires, please report to the person in charge for replacement, and no one is allowed to change it at will.

2. All flammable and explosive items stored in the laboratory should be kept at a certain distance from fire sources and power sources, and should not be stacked at will.

3. Smoking is strictly prohibited, let alone smoking or using open flames in the laboratory.

4. A certain amount of fire-fighting equipment needs to be stored in the laboratory, and the fire-fighting equipment should be placed in an obvious location that is easy to access.

5. The laboratory exits, aisles, and corridors cannot stack packing boxes and other sundries; keep the laboratory environment clean and hygienic, and the corridors are unobstructed; the equipment and equipment are neatly arranged and arranged in an orderly manner, and the fire escape indication signs are obvious.

6. Laboratory managers need to understand fire prevention measures, and be able to use fire-fighting equipment; they must understand the basic methods of fire-fighting, and be able to put out initial fire hazards and self-rescue.

7. When the staff leaves the laboratory, you must turn off the power of the instruments and equipment; after the experiment and work, you must cut off the main power supply, turn off the gas and water sources, and lock the doors and windows when leaving the laboratory.

8. In the event of a fire or fire alarm, an effective rescue should be organized immediately, and the relevant leaders of the center should be reported in time. All rescue personnel must obey the leaders and obey the instructions.

Conclusions to the Part 4

This part of the thesis considers the personal safety of workers, and fully specifies rules in accordance with labor protection supervision and management standards to ensure workers' right to know risks.The potential safety hazards during the experiment are fully considered, including factors such as electricity, electromagnetic radiation, and damage to the workpiece. Advised engineers on safe operation and ensured the normal operation of the work area.

PART 5

ENVIRONMENTAL PROTECTION

Machinery manufacturing has always been the main pillar industry in the field of science and technology, and has played a great role in promoting the economic development of countries around the world. Now Green Manufacturing, as known as Environmentally Conscious Manufacturing, covers the entire life cycle of products and it is a modern manufacturing model that comprehensively considers environmental impact and resource benefits. We need to achieve the optimal combination of environmental protection and social benefits.

In cutting processing, cutting fluid is the main source of pollution. Cutting fluid has long been regarded as an important process factor to improve tool life and production efficiency and ensure processing quality due to its good cooling, lubrication, cleaning and chip removal, and rust prevention.However, with the large-scale application of advanced equipment such as CNC machine tools and machining centers in production, the cutting speed is getting higher and higher, and the amount of cutting fluid is also increasing (Figure 5.1). The negative effects are becoming more and more obvious, and it is difficult to meet the requirements of environmental protection.

Cutting fluid wastewater usually contains various components such as mineral oil, surfactants, and additives. Therefore, the cutting fluid must be treated and then discharged.Oil-based cutting fluid can be treated by combustion treatment or waste oil regeneration, while water-based cutting fluid is more troublesome to deal with (Figure 5.2). Generally, most harmful substances need to be removed by methods such as evaporation, demulsification or microbial adsorption to make them meet the wastewater discharge standards.

Figure 5.1 - Cutting fluid

Figure 5.2 - Cutting fluid wastewater treatment

If not treated effectively, its components can cause serious pollution to water resources and soil.Among them, mineral oil is one of the main components of cutting fluid wastewater. It has poor biodegradability and can stay in water and soil for a long time. It can pollute groundwater for decades and affect the growth of crops.The use of oily wastewater to irrigate farmland will affect the absorption of nutrients by crops, resulting in reduced yield or death of crops.Moreover, most of the drinking water in many countries comes from groundwater, and the discharge of cutting fluid waste can directly affect the quality of groundwater.The additives in the cutting fluid also pollute the environment very seriously. Short-chain chlorinated paraffins such as extreme pressure agents contained in cutting fluids are harmful to the aquatic environment. This thing is especially harmful to microorganisms, shells and fish in the water, so these products have been classified as serious marine pollutants.

According to the survey, in high-productivity production enterprises, the supply, maintenance and recycling costs of cutting fluid together account for 13%-17% of the workpiece manufacturing cost, while the tool cost only accounts for 2%-5%. About 22% of the total cost related to cutting fluid is the processing cost of cutting fluid.

Under the double standard of environmental protection and manufacturing cost, dry cutting has become the development direction of new cutting technology. Dry cutting means cutting without cutting fluid.Since the 1990s, it has been applied to actual production internationally and has achieved certain social benefits.However, dry cutting is not simply to stop using cutting fluid, but to ensure high efficiency, high quality, high tool durability and reliability of the cutting process while stopping the use of cutting fluid. This requires the use of dry cutting tools and processing methods with excellent performance to replace the role of cutting fluid.

According to incomplete statistics, the world economy loses hundreds of billions of dollars every year due to machining wear and tear of cutting tools (Figure 5.3). The resulting scrap materials and wasted production resources are even more incalculable.Therefore, finding optimization measures to improve the cutting performance of the tool is of great significance for resource saving and further environmental protection.

Figure 5.3 - Tungsten carbide scrap

A variety of effective tool strengthening methods have been explored in the machining industry. For example, material properties can be improved by heat treatment, cryogenic treatment, surface coating strengthening, etc.However, the heat treatment process will not only produce barium salt and nitrate waste water, but also produce barium chloride waste residue and harmful gases such as nitrogen oxides and sulfur dioxide particles. The high-temperature CVD process used in the coating technology will emit exhaust gas and waste liquid. If the related waste water, waste gas and waste residue are not properly disposed of and discharged into the outside world, it will cause serious environmental pollution.The pulsed magnetic field strengthening treatment studied in this paper ensures that the whole process is environmentally friendly and energy-saving. It is an advanced manufacturing technology (AMT) with high efficiency, low consumption, clean and pollution-free.

The pulsed magnetic field treatment technology makes the target substance undergo physical or chemical changes through the action of the magnetic field.

From the perspective of magnetic field generation, the pulsed magnetic field is a low-frequency strong magnetic field. During the magnetization process, the highest magnetic field strength can reach 1500mT, the frequency is about 10Hz, and the magnetization time is short.

Research has shown that high-energy electromagnetic waves that penetrate matter and cause it to ionize carry ionizing radiation.

The formula for radiant energy is as follows,

$$\mathrm{E} = \frac{\mathrm{hc}}{\lambda}$$

Where,h - Planck's constant;

c - speed of light;

λ - wavelength.

Frequency $f = \frac{1}{\lambda}$. Therefore, it can be obtained from the formula that the higher the frequency of electromagnetic waves, the greater the radiation. The pulsed magnetic field in the test will not cause harm to the human body and the environment.

From the strengthening effect, the magnetization treatment can effectively improve the cutting performance and service life of the tool, and the machining process is simple and fast, reducing the consumption of resources and energy. And the magnetic field can reduce the cutting vibration after the magnetic field is added to the cutting area. The working stability of the components is improved, and the noise pollution caused by vibration is reduced.

GENERAL CONCLUSION

Nowadays, with the continuous improvement of the aerospace industry's requirements for the performance of aviation aircraft, the materials, design structures and manufacturing standards used in aviation aircraft are constantly promoting the optimization of cutting technology. Under the background of the rapid development of manufacturing technology, this thesis focuses on the optimization route of modifying cutting tool materials.

First of all, the important position of cutting technology in the aviation manufacturing industry is clarified. And it clarifies that the development of aerospace materials and tool materials is spiraling upward, and the two are mutually restrictive and interdependent.There are so many aircraft parts, it is not realistic to study the whole directly. Therefore, under extreme working conditions, the processing technology of the three typical parts of the aero-engine blisk, the casing and the shaft is studied.The machining optimization strategy is deduced from the machining requirements. And from many surface strengthening methods, a promising optimization method is selected, and at the same time, it is compared with the most widely used coating technology.

Aiming at the difficulties in tool optimization, this thesis proposes to actively use PMFP (Pulsed Magnetic Field Process) to treat tools.High-speed steel and cemented carbide, two of the most widely used tool materials, demonstrate the suitability of PMFP by analyzing their respective physical characteristics.By analyzing the principle and development of coating technology, the advanced nature of magnetization treatment is sought.Through the method of metallographic in-situ observation, combined with many research cases. The distribution and variation of matrix carbides, martensitic microstructure and retained austenite of high-speed steel materials before and after pulse magnetization treatment were analyzed.It was found that after magnetization treatment, the number of carbides in the matrix of high-speed steel increased significantly, and the carbides showed three changes of precipitation, fragmentation and deformation;the microstructure of the material becomes finer and denser, the acicular martensite increases, and the grains are refined;the retained austenite content is reduced.In this way, the main mechanism of pulsed magnetic field strengthening treatment is summarized. PMFP can affect the change of material structure in the form of non-injury and non-contact, and achieve the purpose of tool modification from the microscopic level.

Then,fully consider the magnetic state of the cemented carbide, and the cemented carbide relies on the bonding metal Co, etc. to obtain the magnetic properties.In order to verify the strengthening effect of magnetization treatment on cemented carbide, two measurement schemes are designed and adopted.Finally, the bending strength of cemented carbide before and after magnetic field strengthening was successfully measured, and obtained ideal results. Bending strength can be used as an index of mechanical properties of brittle materials. Through the strength comparison, the brittleness and toughness changes of the material can be effectively evaluated. Experiments show that the pulse magnetic field treatment improves the strength of cemented carbide, and the degree of material performance improvement varies with the application of the magnetic field. It is confirmed that PMFP can effectively make up for the shortcomings of the material and improve its strengths.

Finally, because both intensive treatment and measurement tests should be performed in the laboratory, the working environment must meet established standards.In the labor protection section, after reviewing normative supervision documents, a series of workplace precautions and general harmful factors that engineers may be exposed to in performing work tasks are regulated.In the part of environmental protection, considering the use of waste cutting fluid to pollute the environment and the waste of resources caused by scrapped tools, it is imperative to develop environmentally friendly and low-consumption optimization methods. In addition, the influence of the environment during the magnetization process is also explained.

REFERENCES

1 Liu Qixian, Liu Yang, Gao Kai, et al. Research progress and application of titanium alloys[J]. Aerospace Manufacturing Technology, 2011, (04): 45~55.

2 Du Min, Jiang Zenghui, Feng Jilu. Machining characteristics of titanium alloys and selection of tool materials [J]. Aviation Manufacturing Technology, 2011, (14): 55~57.

3 C. Leyens, M. Peters. Titanium and Titanium Alloys. Weinheim Wiley-VCH, 2003.

4 Zhu Zhishou. Research status and development of titanium alloy technology for aviation in my country [J]. Journal of Aeronautical Materials, 2014, 34(4): 44~50.

5 Liu Haibin. Research on high-speed turning of nickel-based superalloys[D]. Nanjing: Nanjing University of Aeronautics and Astronautics, 2007.

6 Lu Aihua. Study on high speed milling temperature of superalloy[D]. Nanjing: Nanjing University of Aeronautics and Astronautics, 2008.

7 Wang Zengqi. Processing technology of aero-engine integral blisks [J]. Aviation Manufacturing Technology, 2013, (09): 40~43.

8 Jian L, Can W, Gang Y, et al. A Novel Combined Electromagnetic Treatment on Cemented Carbides for Improved Milling and Mechanical Performances[J]. Metallurgical and Materials Transactions, 2018,49(10).

9 M. Nouari, A. Ginting. Wear characteristics and performance of multi-layer CVD-coated alloyed carbide tool in dry end milling of titanium alloy [J].

Surface and Coatings Technology, 2006, 200(18-19): 5663~5676.

10 G.S. Fox-Rabinovich, K. Yamamoto, A.I. Kovalev, et al. Wear behavior of adaptive nano-multilayered TiAlCrN/NbN coatings under dry high performance machining conditions [J]. Surface and Coatings Technology, 2008, 202(10): 2015~2022.

11 A. Bhatt, H. Attia, R. Vargas R, et al. Wear mechanisms of WC coated and uncoated tools in finish turning of Inconel 718 [J]. Tribology International, 2010, 43(5): 1113~1121.

12 Bataineh O, Klamecki B, Koepke B G. Effect of pulsed magnetic treatment on drill wear[J]. Journal of Materials Processing Tech., 2002,134(2)

13 Nikiforv Y P, Krasichkov A , Lobachkov E A. Unit for magnetic hardening of cutting and forming tools [J]. Soviet Engineering Research, 1989, 9: 116-117

14 Bagchi P K,Ghosh A. Effect of Magnetic Field on Wear of Characteristics of Cutting Tools[J].J.Inst.Eng. India. 1970,50:141-145

15 Robert F Hochman.Surface modification[J]. Advanced Materials and Processes,1995, 147(1): 29-30

16 Song Zhifang. Development Status and Future Prospects of Tool Materials[J]. Industry and Technology Forum, 2013,12(12):129-130.

17 Zhong Wending. Ferromagnetism (Volume 2) [M]. Beijing: Science Press, 1987.

18 Yuan Defu, Ma Xinglong. Magnetic Physics [M]. Chengdu: University of Electronic Science and Technology of China Press, 1994.

19 Tang Xinru.Magnetic strengthening of drill bits[J].Mechanical Design and

Manufacture.1986,(2):56-58

20 Neema M L，Pandey P C. The effect of magnetization on the wear of high speed steel tools[J]. Wear, 1980, 59: 355-362

21 Shivaswami H G,Neema M L,Pandey P C.Improving tool life by magnetization [C]. Product Conference on Production Engineering, 1977, 9, 6-11

22 Shi Bei. U-105 type pulse magnetization tool system [J]. Tool Technology, 1993, 01: 12.

23 Postnikov. Electrophysical and electrochemical phenomena in friction and cutting and lubrication [M]. Beijing: National Defense Industry Press. 1983:151-236

24 Zhou Xusheng. Preparation process and mechanism of WC-Co composite powder [D]. Nanchang University, 2015

25 Qiu S，Ｒen S Q，Huang L Q，et al． Influence of Different Vacuum Conditions on the Distribution of Insoluble Inclusions in a Multi-Crystalline Silicon Ingot ［J］． Vacuum，2016，128: 66 － 72

26 Ustinov A I，Melnichenko T V，Liapina K V，et al． Structure and Properties of Porous Nickel and Copper Fllms Produced by Vacuum Deposition from the Vapour Phase［J］． Vacuum，2017，141: 272 － 280

27 Guozheng, Chen Qiang, Wang Zhengduo, et al. Research progress of chemical vapor deposition/atomic layer deposition copper precursors［J］． Journal of Vacuum Science and Technology, 2015, 35(10): 1282-1290

28 Xie Wenfeng, Liu Jiajia, Hernondez Karla, et al. Research progress of

chemical vapor deposition of molybdenum disulfide thin films［J］. Journal of Wuhan University of Technology, 2016, 38(4): 31-37

29 Liu Zhihong, Zhang Shuying, Liu Zhiyong, etc. Principle and research progress of chemical vapor deposition for preparing powder materials［J］. Powder Metallurgy Materials Science and Engineering, 2009, 14(6): 359-364

30 Aydin O I, Hallam T, Thomassin J L, et al. Interface and Strain Effects on the Fabrication of Suspended CVD Gra phene Devices［J］. Solid-State Electronics, 2015, 108:75-83

31 Wei Q P, Yu Z M, Ashfold M N R, et al. Effects of Thickness and Cycle Parameters on Fretting Wear Be havior of CVD Diamond Coatings on Steel Substrates［J］. Surface & Coatings Technology, 2010, 205 (1): 158-167

32 Wu Di. Research progress and application of physical vapor deposition technology[J]. Mechanical Engineering and Automation, 2011, (4): 214-216

33 Bouzakis K D，Michailidis N，Skordarisa G，et al．Cuttingwith Coated Tools: Coating Technologies，Characterization Methods and Performance Optimization［J］. CIRP Annals-Manufacturing Technology，2012，61(2) : 703 — 723

34 Strnad G，Buhagiar J. Lastest developments in PVD Coatings for Tooling［J］. Scientific Bulletin of the “Petru Major” University of Targu Mures，2010，7 (XXIV) (1) : 32 — 37

35 LI Guo-dong, SUN Jian-fei, XU Ye, et al. Microstructure, Mechanical Properties, and Cutting Performance of TiAlSiN Multilayer Coatings

Prepared by HiPIMS[J]. Surface and Coatings Technology, 2018, 353: 274-281.

36 Zhao Haibo, Zhou Tong, Liang Hongying, Li Bo. Classification and Application Tool Technology of Tool Coating 2008,39(12):14-17.

37 Hu Desen. Magnetization of cutting tools and wear-resistant surfaces[J]. Tool Technology. 1992(3): 45-46.

38 Molotskii M I, Kris R E, Fleurov V V. Internal friction of dislocations in a magnetic field[J]. Phys Rev B Condens Matter. 1995, 51(18): 12531-12536.

39 Lin Jian, Zhao Haiyan, Cai Zhipeng, et al. Research status and prospect of magnetic treatment to reduce residual stress in steel materials[J]. Materials Engineering. 2005(03): 55-59

40 Guo Chao.Research on strengthening technique of metal cutting tools by magnetization.Jiangxi University of Science and Technology.Master Thesis.2014.

41 Lei Tingquan, Yao Zhongkai, Yang Dezhuang. Deformation heat treatment of steel[M]. Beijing: Machinery Industry Press, 1979.

42 Weibul W. Proc Roy Swedish Inst Eng Res , 1939 , 151 : 153