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Advances in Preparation Technology of Tool Coatings

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Abstract: With the continuous development of modern industry and the difficult-to-machine materials gradually increases, the machining requirements of cutting tools continue to improve and the cutting environment is increasingly harsh. As the coating applies, the efficiency and precision of machining have been effectively improved. Coating on the tool surface can not only extend the service life of the cutting tool, greatly reduce the processing cost, but also reduce the environmental pollution in the process of processing. Excellent coating preparation technology is an important factor for its effective performance. According to different processing requirements, processing costs and processing environment, researchers have been working hard on the road of coating preparation technology. In this work, it summarizes the principle of physical vapor deposition, chemical vapor deposition and the corresponding advantages and disadvantages, and briefly introduces the pulsed DC magnetron sputtering, high power pulsed magnetron sputtering, arc ion plating and a variety of composite magnetron sputtering technologies.

Keywords: Tool coating, Physical vapor deposition, Chemical vapor deposition, Magnetron sputtering.

1. Introduction

In the metal processing manufacturing industry, the number of materials that are difficult to process is increasing, and the requirements for cutting toughness, hardness, environmental protection and life of cutting tools are getting higher and higher [1-3]. The use of coated tool improves the cutting performance of the tool, reduces the cutting wear of the tool, and prolongs the service life of the tool [4,5]. Tool coating plays a role of buffer and protection in the cutting process. The existence of coating can avoid the direct contact between tool matrix and cutting material, reduce the cutting heat transfer, reduce the possibility of chemical reaction in tool matrix, thus improving the cutting accuracy of coating and increasing the service life of tool [6].

In order to maximize the performance of the coating, the coating preparation technology is continuously developed and optimized. At present, the preparation technologies of tool coatings mainly include chemical heat treatment technology, plasma spraying technology, thermal spraying technology, sol-gel technology and gas deposition technology, etc. [7]. Vapor deposition technology is a technology that converts the required materials into gaseous atoms or molecules in a vacuum chamber and then deposits them on the substrate surface to form solid films. It is mainly divided into physical vapor deposition (PVD), chemical vapor deposition (CVD) and plasma vapor deposition (PCVD). This coating preparation method is mainly carried out in vacuum chamber, which can reduce the pollution to the outside world to a certain extent, and is widely used by modern coating researchers.

2. Vacuum Vapor Deposition

2.1. Chemical vapor deposition technique

Chemical vapor deposition technology is the earliest vapor deposition technology and the most common coating preparation technology. Its main principle is to decompose volatile compounds or make them undergo chemical reactions, and then deposit the generated substances in the form of molecules, ions and even atoms onto the required matrix to form solid films. Compared with other coating preparation technologies, CVD is a simple and mature surface coating manufacturing technology. Even on complex shapes, uniform nanocrystalline films with good step coverage can be deposited. At the same time, films prepared using the CVD method usually show better adhesion and higher internal stress [8]. In addition, at low deposition temperature and within a short time, CVD technology can well control the size and structure of the coating -- single layer coating, multi-layer coating, composite coating, nanostructure and functional gradient coating [9]. CVD is a flexible technology that can complement other technologies such as laser, plasma, vacuum and thermal spraying [10-14]. However, the high ambient temperature required by CVD technology limits its application in tool coating. In the process of coating deposition by CVD technology in common cemented carbide cutting tools, the internal structure of matrix will be changed and different phases will appear when the temperature is too high. At the same time, problems such as low deposition rate, rough surface and environmental pollution of CVD technology need to be further improved [15,16].

2.2. Physical vapor deposition technique

As one of the widely used surface modification technologies, physical vapor deposition technology has the advantages of high density of coating structure, good adhesion, low deposition temperature and environmental protection [17]. PVD coating has a very wide range of applications, as large as automotive aircraft parts protection, small tool surface. The basic principle of PVD is to convert solid materials into vapor atoms in the form of evaporation or ionization in a vacuum environment, and then transfer these atoms to the substrate surface to form a solid film. The coating prepared by PVD has high hardness, heat resistance, wear resistance and corrosion resistance. PVD preparation technology is mainly used for coating preparation in vacuum environment, which has relatively lower pollution to the environment compared with CVD. In addition, the coating deposited by PVD technology is very thin and has a high density, so different coatings can be deposited on the same substrate according to requirements to improve the surface performance of the substrate. However, the PVD technology requires a greater energy consumption, accounting for 33.5% of the consumption in the CVD process and 77.7% in the PVD process during the same deposition step [18].

With the continuous improvement of social demand, physical vapor deposition technology has been developed and optimized, and some branches have been produced according to different principles. The commonly used methods include vacuum evaporation plating, ion plating, sputtering coating, etc.[19].

Vacuum evaporation coating is a film forming method in which solid materials are vaporized in a vacuum environment to transform them into gaseous state, and then the gaseous atoms are deposited on the surface of the coated product. The vacuum degree of vacuum coating can reach the level of 10-5~10-3. In this environment, gaseous particles obtained can reach the surface of the coated product smoothly. Meanwhile, the oxygen content in the air is less, which reduces the possibility of the coating structure being destroyed by oxidation. Vacuum evaporation technology has the advantages of a wide range of substrate materials, fine film structure and high purity. Vacuum evaporation technology is the deposition and coating of materials in the way of atoms, relying on the heat energy of evaporation to drive the movement of molecules in the vacuum chamber, so the melting point of the evaporation source is required to be high enough. At the same time, there is no bias between the substrate and the emission source, the kinetic energy of particles is low, and the binding force between the coating and the substrate is poor.

Ion plating technology is a kind of evaporation coating technology on the basis of applying an electric field evaporation of atoms into high-energy ion deposition to the solid state thin film is formed on the substrate material of coating technology. This deposition technique can effectively improve the adhesion between coating and substrate. With the continuous improvement and optimization of technology, ion plating technology has gradually evolved from the original glow discharge ion plating technology to arc ion plating technology, which includes hollow cathode ion plating technology, hot wire arc ion plating technology, cathode arc ion plating technology, etc. Arc discharge ion plating technology is characterized by high plasma density, high metal ionization rate, high ion activity in the film layer, and easy to react into compound coatings. In the process of coating deposition, high-energy ions can clean the surface of the sample, remove impurities on the surface of the sample, and improve the binding strength of the coating. However, at the same time, the surface of the coating deposited by high-energy ions is rough, which reduces the overall performance of the coating.

The main principle of magnetron sputtering technology is to establish a magnetic field perpendicular to the electric field on the basis of ion plating. At the same time, ions generated by the protective gas in the glow discharge process are used to bombard the cathode target, and the film-forming particles produced by sputtering are used to crystallize and solidify on the substrate [20]. Compared with vacuum evaporation, the substrate temperature rises of magnetron sputtering technology is lower and the coating bonding strength is stronger. Compared with ion plating technology, the films deposited by magnetron sputtering technology are denser and smoother in surface, and are widely used in the preparation of various tool coatings.

2.3. Magnetron sputtering technology

According to the type of target material, magnetron sputtering technology can be divided into three categories, namely two-stage sputtering coating, planar target magnetron sputtering coating and cylindrical target magnetron sputtering coating, while planar target magnetron sputtering is currently commonly used pulsed DC magnetron sputtering technology, high power pulsed magnetron sputtering technology, high power pulsed magnetron sputtering and pulsed DC magnetron sputtering composite technology. Although pulsed DC magnetron sputtering technology can theoretically reduce or even eliminate the cluster particles produced by arc ion coating technology, the ionization rate of pulsed DC magnetron sputtering is low, making it difficult to control the forming of a large number of ions. The instantaneous power of high-power pulsed magnetron sputtering technology is 3 orders of magnitude higher than the normal value, and the ionization rate is higher, which improves the nucleation rate and mobility of the coating, and greatly promotes the growth of the film [21]. It has been proved by experiments that high-power pulsed magnetron sputtering technology can further densify and smooth the surface of the coating [21-23]. However, metal ions ionized from the surface of the target are sucked back, and the deposition rate of high-power pulsed magnetron sputtering is relatively low, which restricts its development [24].

High power pulsed magnetron sputtering technology and pulsed DC magnetron sputtering technology have their own advantages and disadvantages. Combining the two technologies to form a composite technology can avoid the technical defects of the two technologies, improve the deposition rate of the coating, the ionization rate of the sputtering material and improve the coating performance. Luo et al. [25] used the composite process composed of HIPIMS and DCMS to deposit TiN hard coatings on the hardened steel matrix. The results showed that the deposition rate of the coatings reached 0.049un/min, the compressive residual stress decreased significantly from -6.0 to -3.5 GPa, and the coating hardness increased from 34.8 to 38.0 GPa. The cross section of the coating shows a dense columnar crystal structure, and the coating surface is smooth. A 30-50 nm thick interfacial ion mixing layer was observed on the surface of the ion-etched substrate, and the interfacial ion mixing layer combined with the metal Ti base layer contributed to excellent adhesion properties. Poolcharuansin P et al. [26] studied the discharge behavior of composite magnetron sputtering, and the results showed that when the working pressure changed, the plasma ignition caused by HIPIMS technology would be delayed, while the composite magnetron sputtering technology did not, and the number of ions in the vacuum chamber increased. Compared with HIPIMS technology, DCMS technology can provide stable sputtering power and inhibit the accumulation of charge on the target surface of high-power supply. The effective combination of the two technologies is expected to produce tool coatings with good mechanical properties, tribological properties and microstructure.

3. Conclusion

The preparation technology of tool coating is developing continuously. With the continuous optimization of technology, it is also gradually adapting to the growing demand of processing industry. The new technology not only requires the hardness, binding force and residual stress of the coating, friction coefficient, wear rate and other mechanical and tribological properties as well as the internal microscopic characterization of the coating, but also needs to reduce the energy consumption required for preparation. Through the progress and popularization of tool coating preparation technology, it will add a boost to the development of the processing manufacturing industry and even the industry in the future.

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