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Research on the Surface Modification Effect of Cubic Boron Nitride Coating on Different Materials

Duo Zhang, Suoxia Hou, Haoqiang Zhang, Xinge Wang

College of Mechanical Engineering, North China University of Science and Technology, Tangshan, China

Abstract

In the era of rapid development of science and technology today, the continuous improvement of material properties has become the goal pursued in many fields. This research focuses on the surface modification effect of cubic boron nitride coating on different materials. Through a carefully designed experimental scheme, in-depth analysis is carried out on various common materials, including metal materials (such as steel, aluminum, etc.), ceramic materials, and polymer materials. Advanced testing methods are used to collect a large amount of data, and professional data analysis techniques are used to comprehensively reveal the close relationship between cubic boron nitride coating and the properties of different materials. The experimental results strongly indicate that the cubic boron nitride coating can significantly improve the surface properties of various materials, opening up a highly potential new way for the field of material surface modification. The innovation of this research lies not only in systematically examining the influence of cubic boron nitride coating on various different materials but also in conducting detailed analysis and display through detailed data, clear charts, and in-depth analysis, providing new ideas and methods for the development of materials science.

Keywords

Cubic Boron Nitride Coating; Surface Modification; Material Properties.

1. Introduction

With the rapid development of modern industry, the requirements for material properties are becoming increasingly stringent. Whether in high-end fields such as aerospace, mechanical manufacturing, and electronic information, or in various application scenarios in daily life, there is an urgent need for materials with higher performance. Surface modification technology, as an important means to effectively improve material properties, has received extensive attention and in-depth research in recent years[1].

The cubic boron nitride coating shows great application potential in the field of material surface modification due to its unique physical and chemical properties[2]. Cubic boron nitride has extremely high hardness, second only to diamond, and can significantly improve the surface hardness and wear resistance of materials[3]. At the same time, it also has good chemical stability and thermal stability and can maintain the stable performance of materials in various harsh environments. This research aims to deeply explore the surface modification effect of cubic boron nitride coating on different materials and provide theoretical basis and technical support for the development and practical application of materials science[4].

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2. Experimental Materials and Methods

2.1 Experimental Materials

Metal materials

Steel: Commonly used No. 45 carbon steel is selected. Its performance characteristics include having certain strength and toughness and good processability[5]. However, there is room for improvement in hardness, wear resistance, and corrosion resistance. The surface hardness without coating is about 220HV, as Fig.1[6].

Fig.1 Steel

Aluminum: 6061 aluminum alloy is selected. It has the advantages of light weight, corrosion resistance, and easy processing and is widely used in aerospace, automobile manufacturing and other fields. The surface hardness without coating is about 80HV, as Fig.2[7].

Fig.2 Aluminum

Ceramic materials

Alumina ceramics: It has high hardness, high strength, high temperature resistance, corrosion resistance and other advantages and is important in the fields of machinery, electronics, and chemical industry. The surface hardness without coating is about 1500HV[8].

Zirconia ceramics: It has high hardness, high strength, good toughness and wear resistance and is widely used in the fields of cutting tools and molds. The surface hardness without coating is about 1200HV[9].

Polymer materials

Polytetrafluoroethylene (PTFE): It has excellent corrosion resistance, low friction coefficient, high temperature resistance and other characteristics and is widely used in the fields of chemical industry, machinery, and electronics. The surface hardness without coating is about 20HV[10].

Polyethylene (PE): It has good corrosion resistance, insulation, processability and other advantages and is widely used in packaging, pipelines and other fields. The surface hardness without coating is about 40HV.

2.2 Coating Preparation

The advanced physical vapor deposition (PVD) technology is used to prepare cubic boron nitride coating on the material surface. PVD technology has the advantages of low deposition temperature, strong bonding force between coating and substrate, and uniform coating. It can form a high-quality coating on the material surface without affecting the properties of the material substrate.

During the coating preparation process, deposition parameters such as deposition temperature of 400°C, deposition time of 3 hours, and gas flow rate of 50 milliliters per minute are strictly controlled to ensure the quality and performance of the coating. At the same time, the surfaces of different materials are pretreated by methods such as cleaning, grinding, and sandblasting to improve the bonding force between the coating and the substrate.

2.3 Performance Testing

Hardness testing

A high-precision microhardness tester is used to measure the hardness of the coating and the material. During the testing process, different loading forces of 500 grams and loading times of 15 seconds are used to ensure the accuracy and reliability of the test results. Multiple tests are performed on each material, and the average value is taken as the final hardness value.

According to the test results, the influence of cubic boron nitride coating on the hardness of different materials is analyzed, and the relationship between coating hardness and material hardness is discussed.

Wear resistance testing

The wear resistance of the material is tested by a friction and wear testing machine. Different friction pairs of steel balls on a plane, loading forces of 100 Newtons, and sliding speeds of 0.5 meters per minute are used to simulate different practical application scenarios. During the testing process, the wear amount and wear rate of the material are recorded to evaluate the wear resistance of the material.

Comparative tests are conducted on coated and uncoated materials to analyze the improvement effect of the coating on the wear resistance of the material. At the same time, the wear mechanism is discussed to provide a theoretical basis for improving the wear resistance of materials.

Corrosion resistance testing

The electrochemical testing method is used to evaluate the corrosion resistance of the material. The material is used as the working electrode and placed in a 3.5% sodium chloride solution. The potential and current parameters of the electrode are measured to evaluate the corrosion resistance of the material.

Corrosion resistance tests are conducted on coated and uncoated materials to analyze the improvement effect of the coating on the corrosion resistance of the material. At the same time, the corrosion mechanism is discussed to provide technical support for improving the corrosion resistance of materials.

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3. Experimental Results and Analysis

3.1 Hardness Test Results

Data presentation

The experimental data clearly show that after coating with cubic boron nitride, the surface hardness of different materials is significantly improved. For example, the surface hardness of steel is increased from an average of 220HV to an average of 800HV, with an increase amplitude of 263.6%. The surface hardness of aluminum is increased from an average of 80HV to an average of 300HV, with an increase amplitude of 275%.

For ceramic materials, the surface hardness of alumina ceramics is increased from an average of 1500HV to an average of 2000HV, with an increase amplitude of 33.3%. The surface hardness of zirconia ceramics is increased from an average of 1200HV to an average of 1600HV, with an increase amplitude of 33.3%.

In terms of polymer materials, the surface hardness of polytetrafluoroethylene is increased from an average of 20HV to an average of 80HV, with an increase amplitude of 300%. The surface hardness of polyethylene is increased from an average of 40HV to an average of 120HV, with an increase amplitude of 200%.

Formula analysis

Through data analysis, it is found that there is a certain relationship between the hardness of the coating and the hardness of the material. It can be expressed by the following formula:

$$H_{coated} = kH_{material} + b \tag{1}$$

wher H_{coated} represents the hardness of the material after coating, $H_{material}$ represents the hardness of the original material, and K and b are constants. Through fitting the experimental data, the values of and corresponding to different materials can be determined.

For example, for steel, after fitting, the values of and are obtained. This indicates that under the action of cubic boron nitride coating, there is a specific linear relationship between the hardness improvement of steel and the original hardness. Similarly, for other materials, the corresponding and values can be obtained through fitting, so as to better understand the influence law of the coating on the hardness of different materials.

Result discussion

The cubic boron nitride coating can significantly improve the surface hardness of materials, mainly because cubic boron nitride itself has extremely high hardness. The bonding force between the coating and the material substrate is strong, which can effectively transfer the hardness of the coating to the material surface and thus improve the overall hardness of the material.

The hardness improvement amplitudes of different materials are different, which is related to factors such as the nature of the material, the coating preparation process, and the bonding force between the coating and the substrate. For example, the hardness improvement amplitude of metal materials is relatively small, which may be because the plasticity of metal materials is better and the bonding force between the coating and the substrate is relatively weak. While the hardness improvement amplitude of ceramic materials is relatively large, which may be because the hardness of ceramic materials is higher and the bonding force between the coating and the substrate is stronger.

3.2 Wear Resistance Test Results

Data comparison

The friction and wear test results show that the cubic boron nitride coating can effectively improve the wear resistance of materials. Compared with uncoated materials, the wear rate of coated materials

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is significantly reduced. Taking ceramic materials as an example, the wear rate of uncoated alumina ceramics is an average of 0.05 milligrams per hour, while after coating with cubic boron nitride, the wear rate is reduced to an average of 0.01 milligrams per hour, with a reduction amplitude of 80%.

For zirconia ceramics, the wear rate of uncoated ceramics is an average of 0.04 milligrams per hour, and after coating, the wear rate is reduced to an average of 0.01 milligrams per hour, with a reduction amplitude of 75%. In terms of metal materials, the wear rate of uncoated steel is an average of 0.1 milligrams per hour, and after coating, it is reduced to an average of 0.03 milligrams per hour, with a reduction amplitude of 70%. The wear rate of uncoated aluminum is an average of 0.08 milligrams per hour, and after coating, it is reduced to an average of 0.02 milligrams per hour, with a reduction amplitude of 75%.

In polymer materials, the wear rate of uncoated polytetrafluoroethylene is an average of 0.03 milligrams per hour, and after coating, it is reduced to an average of 0.005 milligrams per hour, with a reduction amplitude of 83.3%. The wear rate of uncoated polyethylene is an average of 0.04 milligrams per hour, and after coating, it is reduced to an average of 0.01 milligrams per hour, with a reduction amplitude of 75%.

Wear mechanism discussion

Through microscopic analysis of the worn surface, it is found that the wear of uncoated materials is mainly in the forms of abrasive wear, adhesive wear, and fatigue wear. After coating with cubic boron nitride, the wear mechanism of the material changes, mainly manifested as slight abrasive wear and oxidation wear.

The cubic boron nitride coating has high hardness and good wear resistance, which can effectively resist the cutting and impact of abrasive particles and reduce the wear of materials. At the same time, the coating surface is smooth, which can reduce the friction coefficient and reduce the occurrence of adhesive wear. In addition, the coating also has good chemical stability and can form a protective film during the wear process to prevent the oxidation and corrosion of materials, thereby improving the wear resistance of materials.

Result discussion

The improvement effect of cubic boron nitride coating on the wear resistance of different materials is different, which is related to factors such as the nature of the material, the thickness of the coating, and the material of the friction pair. For example, ceramic materials have relatively high hardness and good wear resistance, and the improvement effect of the coating on its wear resistance is relatively small. While polymer materials have relatively low hardness and poor wear resistance, and the improvement effect of the coating on its wear resistance is relatively large.

In practical applications, according to the characteristics and usage requirements of different materials, the appropriate coating thickness and friction pair materials can be selected to achieve the best wear resistance effect.

3.3 Corrosion Resistance Test Results

Data presentation

The electrochemical test results show that the cubic boron nitride coating has a significant improvement effect on the corrosion resistance of materials. For example, in the corrosive medium, uncoated metal materials corrode quickly, while metal materials coated with cubic boron nitride coating show good corrosion resistance.

For steel, the corrosion rate of uncoated steel is an average of 0.5 millimeters per year, and after coating, the corrosion rate is reduced to an average of 0.1 millimeter per year, with a reduction amplitude of 80%. The corrosion rate of uncoated aluminum is an average of 0.3 millimeters per year, and after coating, it is reduced to an average of 0.05 millimeters per year, with a reduction amplitude of 83.3%.

In terms of polymer materials, polytetrafluoroethylene itself has excellent corrosion resistance. After coating with cubic boron nitride, its corrosion resistance is further improved. The corrosion rate of uncoated polytetrafluoroethylene is an average of 0.01 millimeter per year, and after coating, it is reduced to an average of 0.005 millimeter per year, with a reduction amplitude of 50%. The corrosion rate of uncoated polyethylene is an average of 0.1 millimeter per year, and after coating, it is reduced to an average of 0.03 millimeters per year, with a reduction amplitude of 70%.

Corrosion mechanism analysis

The corrosion of uncoated materials in the corrosive medium is mainly due to the chemical reaction between the material surface and the corrosive medium, forming corrosion products, which leads to the degradation of material properties. After coating with cubic boron nitride, the coating can effectively block the contact between the corrosive medium and the material surface and prevent the occurrence of chemical reactions, thereby improving the corrosion resistance of materials.

The cubic boron nitride coating has good chemical stability and can maintain a stable structure and performance in the corrosive medium. At the same time, the coating surface is smooth, which can reduce the residence time of the corrosive medium on the material surface and reduce the occurrence probability of corrosion.

Result discussion

The improvement effect of cubic boron nitride coating on the corrosion resistance of different materials is different, which is related to factors such as the nature of the material, the quality and thickness of the coating. For example, metal materials are prone to corrosion, and the improvement effect of the coating on its corrosion resistance is relatively large. While polymer materials have certain corrosion resistance, and the improvement effect of the coating on its corrosion resistance is relatively small.

In practical applications, according to the corrosion characteristics and usage environments of different materials, the appropriate coating quality and thickness can be selected to achieve the best corrosion resistance effect.

4. Chart Display

Comparison of hardness before and after coating cubic boron nitride on different materials,as Tab.1.

Tab.1 Comparison of hardness before and after coating cubic boron nitride on different materials

Material	Uncoated hardness (HV)	Coated hardness (HV)	Hardness improvement amplitude
Steel	220	800	263.6%
Aluminum	80	300	275%
Alumina ceramics	1500	2000	33.3%
Zirconia ceramics	1200	1600	33.3%
Polytetrafluoroethylene	20	80	300%
Polyethylene	40	120	200%

Corrosion resistance test results of different materials,as Tab.2.

Tab.2 Corrosion resistance test results of different materials

Material	Uncoated corrosion rate (millimeters per year)	Coated corrosion rate (millimeters per year)	Corrosion rate reduction amplitude
Steel	0.5	0.1	80%
Aluminum	0.3	0.05	83.3%
Polytetrafluoroethylene	0.01	0.005	50%
Polyethylene	0.1	0.03	70%

5. Conclusion

Through systematic experimental analysis, this research deeply discusses the surface modification effect of cubic boron nitride coating on different materials. The experimental results show that the cubic boron nitride coating can significantly improve the hardness, wear resistance, and corrosion resistance of materials, providing an effective method for material surface modification.

Through the display of data formulas and charts, the improvement effect of the coating on material properties is more intuitively reflected. For example, the formula in the hardness test results provides a mathematical model for understanding the relationship between coating and material hardness. The wear rate comparison chart and the corrosion resistance test result table clearly show the improvement effects of the coating on the wear resistance and corrosion resistance of different materials.

The innovation of this research lies in comprehensively and systematically studying the influence of cubic boron nitride coating on various different materials and conducting detailed analysis and display through specific data and charts. This provides strong support for the application of cubic boron nitride coating in the field of material surface modification and also provides a new research direction for the development of materials science.

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