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Discussion on Non-destructive Testing Technology and Application of Material Surface

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Abstract: The non-destructive testing technology is discussed, focusing on the mainstream non-destructive testing technology of various material surfaces, and the characteristics, principles and applications of non-destructive surface characterization technology are discussed and analyzed. It focuses on the future development direction of scanning electron microscopy detection method, atomic force microscope detection method and X-ray diffraction detection method. The application of a new hyperspectral detection technology in material detection is described, and finally an important development trend is discussed with the development of deep learning, the combination of hyperspectral technology and deep learning in the future is an important development trend.

1. Introduction

Non-destructive testing technology is a non-destructive testing method, which uses the reaction changes of the material structure to light, heat, magnetism, etc., to evaluate the internal or surface defects, structural characteristics and properties of the material without causing damage or damage to the material. It is based on the interaction between the material and the detector to obtain information about the state of the material [1]. Non-destructive testing of material surfaces plays an important role in today's science and engineering. NDT technology offers many advantages over traditional destructive testing methods, such as saving time and money, maintaining material integrity, and improving production efficiency and product quality. These characteristics make NDT technology have a wide range of application prospects in material selection, manufacturing and maintenance processes. This paper will focus on non-destructive testing of material surfaces and their application fields, with a special focus on the various methods and advantages of non-destructive testing techniques in material surface characterization, each of which will explore its principles, advantages and applications in detail.

2. Application and prospect of surface non-destructive testing technology in composite material testing

In this study, we discuss a variety of non-destructive surface characterization techniques, including light microscopy, surface contact angle, penetration detection, magnetic particle magnetic detection, scanning electron microscopy (SEM), atomic force microscopy (AFM), X-ray diffraction (XRD), hyperspectral detection, etc. The application of these technologies in composite materials and other neighborhoods is discussed, through which we can obtain the surface morphology, microstructure and defect information of composite materials, and quantitatively analyze and evaluate them. Non-destructive surface characterization technology provides high-resolution, non-contact surface observation capabilities, effectively revealing the characteristics and defects of composite surfaces. These technologies are fast, accurate, and non-destructive, providing important support for the manufacturing, quality control and performance evaluation of composite materials. Therefore, non-destructive testing technology is widely used in engineering. However, non-destructive surface characterization techniques also face some challenges, such as limitations in the analysis of complex surface topography and microstructure. Future research can further explore and improve non-destructive surface characterization techniques to improve their resolution, sensitivity, and scope of application to meet the needs of composite surface characterization.

2.1 Scanning electron microscopy detection

Scanning electron microscopy (SEM) is the most commonly used material surface analysis method at the nanoscale to observe and analyze the surface morphology, structure and composition of samples [2]. Compared to traditional light microscopes, SEM offers higher magnification and higher resolution, enabling the observation of smaller details. The basic principle of scanning electron microscopy is to use the phenomenon of electron beams interacting with samples for imaging [3].

During the work of scanning electron microscopy, samples often need to undergo pre-treatment, such as fixation, drying, metal sputtering, etc., to enhance the conductivity and surface details of the sample. The sample is placed on a sample stage and scanned along the sample surface by controlling the scanning and movement of the electron beam. The electronic signal generated by the interaction between the sample and the electron beam is received by the detector and converted into an image, and through the processing and display of the signal, the surface morphology, texture, structure and composition of the sample can be observed.

Wang Yuting [12] used scanning electron microscopy to analyze the rock morphology characteristics and identification characteristics from siliceous matter, carbonate cementation and clay minerals, and concluded that the scanning electron microscope map of cement can be found that compared with single polarized light and orthogonal light, the scanning electron microscope map is more intuitive and three-dimensional, and can directly observe the rough surface and fracture morphology of the sample. Its resolution is also very high, and the morphological composition of the ultrastructure can be seen. Wang Yuexia [3] used scanning electron microscope to observe the microstructure and histochemical analysis of Chinese herbal medicine, which provided certain technical support for the identification of traditional Chinese medicine and its active ingredients, and effectively helped to extract nanoparticles from traditional Chinese medicine, and the iron nanoparticles found and synthesized by this technology showed excellent antioxidant properties and large bacteriostatic rate, which were effective in inhibiting Helicobacter and ulcers. AE Tontowi[4] studied the degree of densification of composite crystalline polymers by observing them with scanning electron microscopy, making an important contribution to how glass particles are densified.

Scanning electron microscope (SEM) is an important characterization tool with a wide range of applications in materials science, nanotechnology, biology and other fields. In the future, the development of scanning electron microscopy will continue to drive improvements in its performance and functionality to meet changing scientific and engineering needs, and future scanning electron microscopy development will focus on improving resolution, enabling multimodal imaging, in situ and dynamic observation capabilities, three-dimensional imaging, and methods for data processing and analysis [5]. These advances will further advance the application of scanning electron microscopy in materials science, nanotechnology, and other fields, and provide researchers with more powerful characterization and analysis tools [6].

2.2 Atomic force microscopy detection

Atomic Force Microscopy (AFM) is a high-resolution microscopy technique used to observe high-resolution three-dimensional images and information on the surface of sample materials and to distinguish atomic-level surface changes [8]. It works by scanning the sample surface at the nanoscale using a non-contact probe, and obtaining information about surface topography and physical properties by measuring the interaction force between the probe and the sample surface. The working principle of AFM is based on the interaction force between the scanning probe and the sample surface. The probe consists of an inelastically curved tip that probes the height and mechanical properties of the sample surface through the interaction force between the probe and the sample. During scanning, the probe is precisely moved to obtain topological information about the sample surface. AFM can provide high-resolution images of surface topology that reveal microstructure and topography features of materials at the nanoscale and below [7].

Meng Jingyu [8] et al. have made significant contributions to the study of the microstructure, interfacial structure, charge change and charge distribution of electrical materials in the nanoregion of electrical materials by using atomic force microscopy. Cao Shuai [9] used atomic force microscopy to observe the chromosomes of the meiotic phase of wild tobacco, and found that the relevant changes in chromosome width and height may be caused by meiosis-related proteins, and the results showed that the results were very similar to the previous results. Yang Yingge [10] used atomic force microscopy to observe the ZAO film samples prepared by different magnetron sputtering powers, and analyzed the two-dimensional and three-dimensional and profile drawings of the samples, and the results showed that with the increase of sputtering power, the film samples were more uniform and dense, the grain growth was fuller, the crystallization quality was higher, and the roughness and adhesion increased. The experimental results provide an experimental basis for further study of the tribological properties of zinc oxide films.

As the most commonly used material characterization method in today's material testing, atomic force microscopy has great potential for future development, and future atomic force microscopy will focus on the functional measurement of materials. For example, by manipulating the force, current or magnetic field of the probe, the integration and automation of atomic force microscopy will be the focus of future development. In terms of automation, by introducing automated control and data processing methods, more efficient and accurate sample scanning and data analysis can be achieved, and the reproducibility and accuracy of experiments can be improved.

2.3 X-ray diffraction

X-ray Diffraction (XRD) is a technique used to analyze crystal structure. It uses the interaction of X-rays with atoms in the crystal to cause diffraction phenomena, and infers the structural information of the crystal by measuring the intensity and angle of the diffracted light. The working principle of XRD is based on Bragg's law, which states that when an incident X-ray beam diffracts with a crystal facet, the diffracted beam is received by the detector at an angle. According to the formula of Bragg's law, the relationship between the diffraction angle and the crystal plane spacing can be calculated. By measuring the intensity and angle of diffracted light at different angles, an X-ray diffraction pattern can be obtained, usually with the diffraction angle as the horizontal axis and the diffracted light intensity as the vertical axis. Through the analysis of X-ray diffraction patterns, many information about the crystal structure can be obtained, including lattice constants, unit cell parameters, crystal form and crystal plane orientation. XRD can be used to determine the crystal structure of materials, the composition of crystal phases, the orientation of crystals, and defects in crystals [11].

Li Xu [12] used the X-ray method to measure the diaphragm of a condenser microphone with different tension magnitudes, and the surface X-ray method was a method that could directly quantitatively measure the structural tension of the diaphragm. Cao Xi [13] used the X-ray method for the first time to determine the content of ferric oxide phase in ammonia synthesis catalyst, through the actual analysis of the application surface, the X-ray diffraction analysis data of ferric oxide phase content in ammonia synthesis catalyst can fully meet the technical requirements of industrial production, scientific research and import and export commodity inspection for its quality control analysis, and can be popularized and applied in the field of petrochemicals; Xu Guang [14] et al. measured the residual stress of the superalloy bellows (which is a key component in the rocket pipeline system) before forming, the bellows after forming and the bellows annealing treatment by X-ray method, and the results showed that the X-ray method can clearly measure the stress changes in various periods, which plays a very important role in analyzing the service life of the tube fittings of the rocket pipeline system. Wang Leilei [15] X-ray measurement of roasted alumina sample, and the results showed that the alumina sample had a α crystal structure.

With the continuous development of instruments and detection technology, the resolution of X-ray diffraction technology has been further improved. Future developments will focus on developing faster and more efficient data acquisition and analysis methods to improve experimental efficiency and enable real-time data analysis and real-time structural characterization. In addition to traditional crystal structure analysis, X-beam diffraction can also be used for structural characterization in amorphous materials, liquids, and gases. Future development will promote the application of X-ray diffraction technology in new fields, such as real-time monitoring of material synthesis processes, research on material interfaces and interface reactions, etc.

2.4 Hyperspectral detection

Hyperspectral imaging is an analysis method based on hyperspectral imaging technology to obtain spectral information about objects or scenes in a large number of continuous wavelength ranges and correlate them with spatial locations. Hyperspectral imaging combines the advantages of optical imaging and spectral analysis to provide more detailed and comprehensive material characterization and information. While traditional imaging systems can only acquire images of one specific wavelength at a time, hyperspectral imaging systems can acquire continuous spectral images over hundreds or thousands of narrow bands. This means that each pixel contains not only image information about the appearance of the object, but also spectral information about the object in that band. By analyzing this spectral information, key characteristics such as the composition, properties, mass, and condition of the object can be determined [16].

Ma Yutang [17] proposed a hyperspectral operating composite insulator pollution detection technology, which established discriminant models by extracting spectral features with different pollution degrees. The final results show that the accuracy of spectral information feature extraction is greatly improved compared with traditional detection methods. Zheng Suluo [18] uses hyperspectral technology to detect meat tenderness, color, fiber structure, various nutrients or toxic and harmful components, and realizes the analysis and visual expression of meat internal and external quality, which provides an important theoretical basis for the wide application of hyperspectral technology in meat detection. Gao Rui et al. [19] used hyperspectral technology to measure the crude protein content of forage, and the experimental results provided the optimal model and theoretical basis for the hyperspectral detection of pasture crude protein content, and opened up a new technical route for guiding grass production.

With the continuous advancement of optical devices and spectroscopic instrument technology, hyperspectral material detection methods will obtain higher resolution and sensitivity. As a fast and convenient detection method, hyperspectral material detection is expected to be combined with other characterization and analysis methods in the future to form a multimodal comprehensive analysis method to obtain more comprehensive and accurate material information. For example, joint applications with imaging techniques (e.g., scanning electron microscopy) or other spectroscopic techniques (e.g., Raman spectroscopy, mass spectrometry) can provide more comprehensive material characterization and analysis [20]. In addition to the traditional fields of materials science and engineering, hyperspectral material detection also has the potential to be widely used in environmental monitoring, food safety, medical diagnosis and other fields. The emergence of new material characterization needs and application scenarios will promote the development and innovation of hyperspectral material detection methods.

3. Conclusion

In general, non-destructive testing technology on the surface of materials plays an important role in the field of materials science and engineering. Through accurate and reliable detection of the surface of the material, the surface defects, breakage, contamination and other problems of the material can be found and evaluated in time, providing strong support for quality control, material evaluation and product design.

At present, with the continuous progress and innovation of science and technology, more and more non-destructive testing technologies are applied to the detection of material surfaces. However, non-destructive testing technology on the surface of materials still faces some challenges and opportunities. Challenges include the complexity of various materials, the diversity of surface properties, and the selection of testing equipment and methods. In order to further promote the development of this field, it is necessary to strengthen multidisciplinary cooperation and exchanges, combine advanced technologies such as machine learning and artificial intelligence, and continuously improve and innovate surface nondestructive testing technologies to meet the needs of composite manufacturing and application.

In short, the application and development of non-destructive testing technology on the surface of materials is of great significance. By continuously improving and promoting these technologies, we can effectively guarantee the quality and reliability of material products, promote the advancement of materials science and engineering, and provide more sustainable, safe and efficient solutions for applications in various fields

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