RESEARCH ARTICLE

Current Research and Development Trend of Functionally Gradient Materials

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Abstract: The paper summarizes the research status of international functionally gradient materials (FGM), introduces the optimization design principles, preparation processes and characteristics evaluation of functionally gradient materials, and focuses on the basic principles and process methods of the preparation process of functionally gradient materials, such as powder metallurgy. , Vapor deposition method, self-propagating high temperature synthesis method, thermal spray method, electrodeposition method, laser cladding method, etc., and look forward to the development prospects and directions of functionally gradient materials.
Keywords: functionally gradient materials; optimized design; preparation process

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1 Introduction

Functionally Gradient Matefials (FGM) is a new type of functional material developed based on a new material design concept. Because the material constituent elements (composition, organizational structure, etc.) change continuously in geometric space. As a result, a heterogeneous material whose properties are continuously changing in geometrical space is obtained. Therefore, when used in a complex environment, it has a greater advantage than a material with uniform properties.

The emergence of FGM stems from the demand for ultra-high temperature materials for high-performance aerospace vehicles. The concept was first proposed by Japanese scholars, and it has attracted people's attention due to its broad application prospects. The United States, Russia, Germany, China and many other countries have successively carried out research work on FGM, and Japan regards the development of FGM as one of the ten new major battles of cutting-edge science, and has done more systematic research work.

Japan's research goal is to develop materials with a surface heat resistance of 2000K and a temperature drop of 1000K. 1987-1989 was the first stage, developing small test pieces (thickness 1-10mm, diameter 30mm), and 1990-1991 was the second stage, developing applicable square plates (thickness 1-10rmm, length and width 300mm). On October 8-9, 1990, the first FGM International Symposium was held in Japan. More than 400 experts and scholars from more than 10 countries attended the conference and published a collection of papers. After that, a seminar will be held every two years. In China, FGM has also received widespread attention and has been included in the corresponding development plan.

2 Research Status of FGM

2.1 International Research Trends of FGM

Although FGM did not last long, it quickly attracted great attention from countries all over the world. Japan, the United States, Germany, Britain, Switzerland, South Korea and other countries have successively carried out FGM research. Since the first FGM International Symposium was held in Sendai, Japan in 1990, 4 FGM International Symposiums have been held so far. The Secret Technology Agency of Japan has also established a consortium consisting of industry, government, and universities, dedicated to FGM research. In addition to Japan, some countries in the United States and Europe are also actively carrying out research in this area. The National Institute of Standards and Technology (NIST) has launched a large-scale research project with the goal of "Developing FGM for Ultra-High Temperature Oxidation-Resistant Protective Layers". The European Union consisting of Switzerland, Ukraine, Finland and the United Kingdom is also conducting FGM research. With Professor Rodel of Darmstadt University of Technology as the core, Germany has carried out research work on 45 topics in universities and national research institutes across the country.

In recent years, China's Central South University, Harbin Institute of Technology, Wuhan University of Technology, Beijing University of Science and Technology and other institutions of higher learning and scientific and technological institutions have been actively carrying out work in this area, and the government has included the research and development of FGM in the national high-tech The "863" plan has been heavily funded. It can be seen that FGM has become a frontier subject of materials science today.

2.2 FGM Research and Development Process

The FGM research and development department consists of three parts: material design, material synthesis and performance evaluation. The research objectives are formulated according to the use conditions of the material, including the heat-resistant temperature, heat-resistant temperature difference, thermal conductivity, and mechanical strength that the material should reach. The material design department collects various performance data of materials, establishes a database, selects a material system according to factors such as functional goals and manufacturing costs, and then calculates the use conditions and material data on behalf of others to obtain the best composition distribution that minimizes thermal stress.

The material synthesis department develops the material synthesis process according to the material system and composition distribution, and prepares samples or test pieces that meet the best composition distribution. The performance evaluation department conducts various performance tests on samples or test pieces, such as mechanical performance test, thermal shock test, and thermal drop test. The measured value is fed back to the clam material design department, the database is improved, and the composition distribution is adjusted to achieve the required performance. Instruct the materials synthesis department to prepare samples or test pieces.

2.3 Optimal Design of FGM

Whether the performance of FGM can change continuously and steadily depends mainly on the continuous change of the composition, so the optimal design of the composition is extremely important. Generally speaking, FGM design mainly includes two aspects, one is the design of the material system that constitutes the FGM, and the other is the design of the thermal stress relaxation structure.

The material system design mainly considers that the selected properties should be compatible with the target environment (temperature, atmosphere, strength, etc.); in addition, full attention should be paid to the physical and chemical compatibility between the selected materials, including the thermal expansion rate. , The two phases have better wetting characteristics and material preparation conditions as much as possible (sintering characteristics of the two phases, densification conditions, etc.).

The thermal stress relaxation structure design is to make the thermal stress of FGM the most suitable under the premise of selecting the material system. This optimal condition must consider the residual stress of the material during the preparation process, and also consider the response thermal stress of the material under the conditions of use (such as temperature gradient, thermal shock performance, etc.). Only when environmental requirements and thermal stress are met at the same time The most suitable design for stress is the complete design. We can use Figure 3 to show the program flow of material design, which is introduced in the literature. The use of supersap finite element analysis method and numerical analysis method can theoretically determine the thermal stress inside the material to achieve the most suitable composition distribution form.

3 Classification of Functionally Graded Materials

3.1 Heat-resistant Functionally Graded Materials

This category is the main application field of functionally graded materials. It is based on ceramic-metal combination, and is mainly used in aerospace industry, nuclear energy and other fields. As the space shuttle enters and exits the atmosphere, the tip of the nose and the front of the wing can reach a high temperature of 1600K. At the same time, as the super heat-resistant material of the space shuttle body, it must have high strength. Effective use of the features of functionally graded materials + can well meet the requirements of the aerospace industry. In addition, the combustor of the space shuttle propulsion system has a great thermal load, and must have high reliability, durability, and long life. However, the current engine is affected by the high thermal load and the resulting thermal stress, and its service life is greatly limited. Functional gradient materials are ideal materials for future aerospace engines.

3.2 Biofunctionally Graded Materials

Animal teeth, bones, joints, etc. are the perfect combination of inorganic and organic materials, with light weight, good toughness, and high hardness. Teeth, bones, joints, etc. made of functionally graded materials can better meet the above requirements. For example, for teeth made of functionally graded materials, the part embedded in the living body is made of porous ceramics that have good compatibility with the human body, and the pores are reduced from the outside to the inside. The exposed exterior is high-hardness ceramics, and the center part is made of high-toughness ceramics to maintain strength.

3.3 Chemical Engineering Functionally Graded Materials

This material is mainly used in high-performance separation membranes and catalysts in the chemical industry, as well as corrosion-resistant reaction vessels.

Electronic engineering functionally graded material gradient manufacturing technology is very suitable for manufacturing electronic components, such as substrate integrated components, two-dimensional composite electronic products and so on.

4 Main Preparation Methods of Functionally Graded Materials

4.1 Self-combustion Synthesis Method

This method is a method that uses the heat of chemical reaction of the material itself to consolidate the material. Once the reaction begins,

The heat of reaction spreads to the entire sample, and the powder is sintered into a material through the heat of reaction. It is suitable for the synthesis of heat-generating compounds, such as AIN, TiN, TiC, etc. Okuo University in Japan used this method to make Nb-N gradient materials. This method can prepare large-volume gradient materials, but the prepared functionally graded materials have a higher porosity and lower mechanical strength.

4.2 Powder Metallurgy

In this method, granular materials such as metals, ceramics, and whiskers are successively laid into a layered structure, which is compacted and sintered to produce functionally graded materials. This process is more suitable for preparing large-volume materials. The main disadvantage is that the process is more complicated. The prepared gradient material has a certain porosity. The National Defense Research Institute of Japan has developed a new powder metallurgy method to manufacture PSZ/TiA1 functionally graded materials. The process is composed of organically fused to produce high-quality amorphous TiA1 powder and low-stress plasma sintering. According to reports, the process has short sintering time, low pressure, no cracks in the product, and is completely dense.

4.3 Centrifugal Casting Method

The centrifugal casting method uses the weight difference of different alloy components under the action of centrifugal force to make the solidified composition show one or more composition gradient changes from the outside to the inside to prepare functionally graded materials. The key to this method is the design The composition makes the ductile and secondary phases generated at the initial stage of solidification continuously distributed along the radial gradient under the action of the centrifugal force field. The density difference causes Al3Fe to be enriched on the outer wall, and a gradient material with Al3Fe structure distributed along a radial gradient and transitioning to a eutectic structure at a remote step is prepared. This method can prepare high-density, large-size gradient materials, but cannot prepare high-melting ceramic functionally graded materials.

5 Prospect of FGM Preparation Technology

FGM has developed rapidly since its creation in the mid-1980s, and the preparation technology of FGM has also been greatly improved, but it is still basically in the basic research stage, especially the domestic research with targeted application goals is not much. There are still many problems in the practical application of the preparation technology of functionally gradient materials. But its general development trend can be summarized as follows:

(1) Develop FGM preparation technology of large size and complex shape. Because large FGM is often required in engineering, the United States and Japan regard the development of large size FGM as their important development goals.

(2) Develop more precise control of gradient composition technology, such as a computer-controlled gradient bedding system, which is a key technology for preparing FGM and directly affects the quality of FGM.

(3) Expansion of production scale and processing technology

6 Conclusion

The preparation and development of FGM is an important part of material-related scientific research, and it is also an urgent need for high-tech functional materials, aviation, aerospace, nuclear industry, and biological engineering. Due to its extensive research, FGM's functions continue to extend. In fact, among many advanced materials, FGM will be the field with the fastest development and the greatest progress before 2000. Our country's scientific and technological workers should keep track of the world's advanced level in time to promote the development of my country's FGM technology.

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