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Exploration of the Application of Laser Cladding Technology in Teaching Materials Processing in Colleges and Universities

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Abstracts: Laser cladding technology has been developed continuously since the 1970s and has been widely used in aerospace, automobile manufacturing, energy, and other fields, and its technical advantages have been gradually recognized and promoted. At present, the teaching of materials processing in colleges and universities mainly relies on traditional theory lectures and experimental operations, but with the rapid development of industrial technology, this mode of teaching is gradually exposed to many shortcomings. The purpose of this paper is to discuss the application methods and modes of laser cladding technology in the teaching of materials processing in colleges and universities. Through the overview of the development of this technology and its case study in actual teaching, it shows how to effectively integrate laser cladding technology into the teaching system to meet the current situation and needs of materials processing teaching in colleges and universities.

Keywords: laser cladding; colleges and universities; material processing; teaching;

Introduction

In the teaching of materials processing in colleges and universities, the existing teaching equipment and experimental content are often out of touch with the latest industrial technology, resulting in students in the actual work being difficult to adapt to the requirements of the modern manufacturing industry. At the same time, the traditional teaching method is based on the teacher's lecture, and the lack of sufficient opportunities for practical operation makes it difficult for students to fully grasp the complex processing technology. As a cutting-edge technology, laser cladding technology is introduced into the teaching of material processing in colleges and universities, which can not only make up for the lack of existing teaching resources but also provide students with a rich practical platform to improve their hands-on ability and innovative consciousness.

1. Theoretical basis of laser cladding technology

1.1 Technical principle

Laser cladding technology is an advanced surface modification technology, that uses a high energy density laser beam as a heat source to make the covering material (powder or filament material) on the surface of the substrate material rapidly melt and partially mix with it to form a dense covering layer, the key to this technology lies in the precise control of the laser beam, which can rapidly heat the added material above the melting point and cool it down quickly without damaging the substrate (Zhu, 2022). This rapid melting and cooling process produces a microstructure that is typically more detailed and homogeneous than conventional heat treatment or plating techniques and can therefore significantly improve the wear, corrosion, and fatigue resistance of the material, as well as its resistance to high temperatures. The control and accuracy of the energy input to the laser cladding process is critical to the quality of the coating and is usually optimized by adjusting parameters such as laser power, scanning speed, powder feed rate, and trajectory overlap. Laser cladding can also be used to achieve targeted improvement of specific properties by

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selecting different additive materials, such as hardness enhancement through the addition of cemented carbide powder or heat resistance enhancement through special alloy compositions.

1.2 Technical characteristics

Laser cladding technology has the process advantages of high automation and precise process control, making it very attractive for many industrial applications. Its main technical features include very low heat input and a small heat-affected zone, which helps the material maintain its original performance characteristics while adding new surface properties (Xie et al., 2023). Due to the ability of the laser to be highly focused, it enables very detailed and precise material processing for parts of complex shapes and sizes. In addition, laser cladding enables multi-material compatibility, supporting the covering of a variety of metals, alloys, ceramics, and other different materials, which enhances the functional versatility of the part. Laser cladding is also particularly well suited for repairing expensive or critical components, as it can add material precisely and treat only the areas where improved performance is required, resulting in significant material and cost savings. The technology also exhibits excellent repeatability and consistency, ensuring process stability and product quality consistency. These features make laser cladding a cost-effective and efficient surface modification solution that is widely used in aerospace, automotive, mold and die manufacturing, and medical devices.

1.3 Scope of application

The scope of application of laser cladding technology covers a wide range of fields from industrial manufacturing to medical devices. In the industrial manufacturing field, this technology is especially suitable for the surface treatment of components with strict requirements for wear resistance, corrosion resistance, and high-temperature performance. For example, in the aerospace industry, laser cladding is used for surface enhancement of turbine blades and engine components, which can significantly extend their service life and improve their efficiency; in the automotive industry, laser cladding is used to improve the wear resistance and load carrying capacity of key components such as gears and bearings; in the mold manufacturing industry, laser cladding is used for repairing and reinforcing the surfaces of high-value molds and improving the mold's resistance to abrasion and fatigue cracking; in the medical field, laser cladding is used for the surface treatment of parts that have strict requirements for wear resistance and high-temperature performance. In the medical field, laser cladding is used to manufacture and repair high-performance medical devices, such as artificial joints and surgical tools, to ensure their reliability and durability under high loads and strict aseptic environments; the technology also provides surface enhancement solutions for drilling and mining equipment in the energy industry, effectively resisting extreme wear and corrosive conditions (Chen et al., 2022). Due to its high adaptability and customization capabilities, laser cladding technology provides modern industry with an extremely effective way to meet the complex challenges of material surface performance enhancement, driving innovation in materials science and manufacturing technology.

1.4 Application advantages

As a highly efficient surface modification method, laser cladding technology provides extremely high material utilization because the laser can very precisely control the deposition position and layer thickness of the cladding material, which greatly reduces material waste. Laser cladding is also able to effectively improve surface properties, such as increased hardness, and improved wear and corrosion resistance, without affecting the macrostructure of the substrate material, which is critical for extending component life and improving overall equipment reliability. In addition, laser cladding technology supports the combined use of multiple materials to achieve multifunctional surface properties on a single component, such as good heat and oxidation resistance at the same time, and this multi-material functional integration provides the possibility of designing and manufacturing high-performance components with specific functional requirements (Hao et al., 2022). The process of laser cladding is fast and highly automated, which makes it suitable for in-line production and improves productivity. Due to its small heat-affected area, laser cladding is particularly advantageous when working with sensitive or complex components, allowing for fine surface modifications without damaging the substrate material. These advantages make laser cladding an attractive technological option, particularly suitable for applications in the aerospace, energy, medical, and high-end manufacturing industries, providing an innovative technological path for surface engineering of traditional and advanced materials.

2. The Application of Laser Cladding Technology in the Teaching of Materials Processing in Colleges and Universities

2.1 Teaching content setting

In the teaching of materials processing in colleges and universities, the teaching content of laser cladding technology should focus on the combination of theory and practice, through well-designed teaching modules and case studies, to help students gain a deeper understanding of the principles of the technology and its application, such as the course can be set up from the basic principles of laser physics, and then transitioned to the laser cladding of the selection of process parameters, material behavior, process monitoring, and post-processing technology. Taking laser cladding repair engineering in the aerospace industry as an example, students will learn how to use laser cladding technology to repair damage to aero-engine turbine blades. The teaching activity first requires the identification and analysis of the type of blade damage, and the instructor guides the students to understand the influence of different types of damage (e.g., cracks, corrosion, or abrasion) on the selection of the repair process. Next, students will calculate the required laser parameters (e.g., laser power, scanning speed, and material feeding rate) as well as select an appropriate cover material, such as titanium alloy or nickel-based superalloy, to ensure compatibility and performance consistency with the original blade material. Students will then use the laser cladding equipment in a simulated environment to perform real-world operations, including setting parameters, loading material, and monitoring the cladding process. The focus of this session is to enable students to enhance their hands-on skills and ability to solve real-world engineering problems. After completing the cladding, students need to carry out post-processing on the repaired blades, such as heat treatment and surface finishing, as well as performance tests, such as hardness testing and microstructure analysis, to evaluate the repair results. Through this case, students not only learn the operational procedures and critical control points of laser cladding technology but also gain an in-depth understanding of how materials science and engineering technology interact with each other in real-world applications.

2.2 Teaching resource allocation

The allocation of teaching resources for laser cladding technology in materials processing teaching, first of all, needs to establish a perfect laboratory environment, including the configuration of high-power lasers, alloy powder supply system, high-precision numerical control platform, and the corresponding safety protection equipment, the configuration of this equipment not only meets the needs of teaching but also provides hardware support for scientific research. Secondly, we should prepare detailed experimental guidebooks covering the basic principles of laser cladding, equipment operation procedures, safety precautions, and experimental data collection and analysis methods, which not only provide theoretical support for the students but also guide them in the actual operation of how to avoid common errors and improve the experimental efficiency and safety. Taking the laser cladding treatment of nickel-based alloy powder on the surface of an ordinary steel plate as an example, the teacher can make students understand the basic principle and operation process of laser cladding technology through theoretical explanation and multimedia demonstration. Subsequently, students enter the laboratory in groups and operate in accordance with the requirements of the experimental guidebook, and each group of students completes the pretreatment of the steel plate surface, the selection and preparation of alloy powder, the setting of laser parameters and the actual cladding operation in turn. During the operation, the instructor guides the whole process to ensure that each student can accurately understand and execute each step, and the students need to pay special attention to the laser beam path setting and scanning speed control, which directly affects the quality and performance of the cladding layer. After completing the cladding operation, the students conduct performance tests on the treated steel plate to measure the changes in wear resistance and corrosion resistance and organize and analyze the experimental data to write an experimental report, in which the students not only describe the experimental process and results, but also need to analyze the experimental problems and solutions.

2.3 Teaching methods and modes

Traditional teaching methods are usually limited to theoretical lectures, while the introduction of laser cladding technology provides a wealth of practical opportunities for teaching so that students can understand and master the advanced material processing technology in a real experimental environment, through the Problem-Based Learning (PBL), the teacher integrates the laser cladding technology into specific project tasks, so that the students, in the process of completing the project, can not only master the theoretical knowledge but also Enhance the practical ability. For example, the teacher designed an experimental task on improving the surface wear resistance of metal parts, the teacher first taught the basic principles of laser cladding, equipment operation procedures, and safety precautions in the classroom, and through the video demonstration and on-site operation, so that students intuitively understand the technical details. Afterward, students carry out group project design, each group needs to select the appropriate alloy powder, set the laser parameters, and design the experimental process, students need to carry out laser cladding treatment under the guidance of the teacher, personally operate the laser equipment, the selected alloy powder cladding to the surface of the metal parts, the teacher monitors the process in real-time and gives guidance to ensure that the experiments are safe and carried out smoothly. After the completion of the experiment, students conducted performance tests on the cladding parts, such as measuring their hardness, wear resistance, and corrosion resistance, and compared with the untreated parts, and then the students were required to write a detailed experimental report, including the purpose of the experiment, the steps, data analysis and discussion of the results, with a focus on analyzing the impact of the laser parameters and the choice of powder on the performance of the cladding layer. Through this project, students not only mastered the practical application of laser cladding technology but also learned how to design and implement experiments and analyze and solve practical problems.

3. Challenges and Countermeasures of Laser Cladding Technology in Teaching and Learning

3.1 Technical complexity and operational difficulty

The introduction of laser cladding technology in the teaching of materials processing in colleges and universities provides students with the opportunity to get in touch with cutting-edge technology, but it's technical complexity and operational difficulty bring a series of teaching challenges, which involves the high-precision operation of the equipment and meticulous parameter regulation, which requires teachers not only to have profound theoretical knowledge but also need to have a wealth of practical experience. The high cost of laser equipment also restricts universal teaching applications, as not all educational institutions can afford the purchase and maintenance costs of such high-end equipment. Colleges and universities can utilize the resources of enterprises for teaching or practical training through cooperation with enterprises, which not only reduces the burden of equipment costs but also allows students to learn in the actual production environment and better understand the practical application and effect of laser cladding technology (Kong et al., 2023). Colleges and universities should also strengthen the practical teaching links, design more simulation training projects, through step-by-step teaching demonstrations, and increase the number of operation exercises, gradually guiding students to understand and master the key operating skills of laser cladding. In addition, virtual simulation software can be used to create a virtual operating environment for laser cladding, allowing students to understand and practice various aspects of the technology without the risk of actual operation (Mao, 2022). Colleges and universities should also strengthen interdisciplinary curriculum design, such as materials science, mechanical engineering, automation technology, and other related courses and laser cladding technology teaching, to help students fully understand the scientific principles behind the technology and its engineering applications.

3.2 Equipment cost and maintenance

The initial purchase cost of high-end laser cladding equipment and its operation and maintenance costs are a big burden for universities with limited education budgets. Laser cladding equipment also involves precision technology, which requires professional technicians to carry out regular maintenance to maintain good performance and extend the service life of the equipment, which increases the difficulty and cost of operation and maintenance. To address these challenges, universities can consider working with industrial partners to share resources. Through the establishment of a university-enterprise cooperation model, schools can utilize the laser cladding equipment of enterprises for teaching and research, while enterprises can obtain R&D support and talent training, which is mutually beneficial. Colleges and universities can also consider introducing equipment leasing services instead of direct purchase, which can reduce long-term capital investment and enable schools to flexibly adjust teaching resources and update equipment according to the latest technology. In addition, colleges and universities can negotiate long-term maintenance contracts with equipment suppliers to reduce the cost of sudden repairs through fixed maintenance costs and ensure the stable operation of equipment. In terms of improving internal maintenance capability, universities should strengthen the professional training of relevant technicians and train their maintenance teams, so that they can solve some routine maintenance and troubleshooting problems internally and reduce the cost of relying on external services (Cui, 2022). At the same time, universities can attract external funds by carrying out relevant research projects, such as applying for government research funds or industry support programs, to provide financial support for high-cost equipment acquisition and maintenance. In addition, colleges and universities should prioritize the inclusion of laser cladding technology in the curriculum and research projects to ensure the maximum efficiency and economic benefits of the equipment, to strengthen the skills training of students through practical applications, and to promote the development of the discipline.

3.3 Curriculum and teaching staff

The professionalism and complexity of laser cladding technology in the teaching of materials processing in colleges and universities require that the course content should not only cover the basic theories but also in-depth the advanced operation skills and engineering applications, which requires the syllabus to be carefully designed to ensure that the students can fully grasp the principle and technology of laser cladding and its applications. However, the existing teaching materials and teaching resources are not always updated in time to reflect the latest technological advances, leaving a gap between the teaching content and the industry's needs. However, the existing teaching materials and teaching resources are often not updated to reflect the latest technological advances, resulting in a gap between the teaching content and the industry needs. In addition, the challenge in terms of faculty is that there is a relative lack of teachers with professional knowledge and practical experience in laser cladding in universities, which limits the depth and breadth of the curriculum. Universities need to establish close partnerships with leading industry companies and research organizations, regularly update textbooks and lab guides, and introduce the latest industry cases and research results. They can also directly invite industry experts into the classroom by organizing workshops, seminars, and guest lectures so that students can learn cutting-edge technologies and market dynamics from frontline engineers and researchers (Ding et al., 2022). To address the challenge of faculty strength, universities should invest in the continuous professional development of faculty and support their participation in relevant technical training and industry exchanges to enhance their teaching and research capabilities. In addition, HEIs can consider adopting a dual-faculty teaching model, which combines professional and technical staff with industry backgrounds and academic faculty, to make up for the shortcomings of a single faculty background and provide a learning environment that emphasizes both theory and practice. Colleges and universities should also actively explore the development of interdisciplinary courses, such as combining laser cladding technology with courses in the fields of mechanical engineering, materials science, automation, and computer science, and offering thematic research projects and teamwork courses, to promote the cultivation of students' comprehensive ability in solving complex engineering problems.

Summary

In summary, the teaching of materials processing in colleges and universities has not only enriched the teaching means through the introduction of laser cladding technology, but also enhanced the students' practical ability and innovative consciousness. The application of this technology provides students with the opportunity to contact cutting-edge processing technology, makes up for the shortcomings of the traditional teaching mode, and meets the demand for high-quality talents in the modern manufacturing industry. The successful implementation of laser cladding technology demonstrates its great potential in improving the quality of teaching and cultivating composite talents. In the future, colleges and universities should continue to explore the application of new technologies in teaching and constantly update the teaching content and methods to adapt to the fast-developing industrial technology and market demand.

Conflict of Interest

The author declares that he has no conflicts of interest to this work.

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