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# Application of Laser Cladding Additive Manufacturing Technology in TRT Blade Manufacturing and Repair Process

**Xiangyang Yin**[1,*]
[1] *Shaanxi Xinxing Thermal Spraying Technology Co.,Ltd, China.*

**Abstract:** TRT blades, as the core components of turbojet engines, carry huge high temperature and high pressure working environment and complex mechanical stresses, and their manufacturing and repair processes have extremely strict requirements on materials and processes. Traditional repair methods are often faced with the problems of material waste, difficulty in recovering complex geometric structures, and difficulty in guaranteeing repair results. Laser cladding additive manufacturing technology, with its precise material deposition and efficient repair process, brings new opportunities for the manufacturing and repair of TRT blades. The purpose of this paper is to explore the key technology of laser cladding technology in improving the blade performance and optimizing the repair process and its practical effect in dealing with the complex working environment through the in-depth study of the application of laser cladding technology in TRT blades.
**Keywords:** laser cladding additive manufacturing technology; TRT blade manufacture; TRT blade repair

## Introduction

Top Gas Recovery Turbine (TRT), as a core power unit in modern aviation, its performance and reliability directly affect the safety and efficiency of the aircraft. TRT blades, as a key component of the engine, are subjected to extreme operating environments such as high temperatures, high pressures, and high-speed airflow, and thus their manufacturing and repair processes have extremely stringent requirements on materials and processes. Laser cladding additive manufacturing technology has gradually become a research hotspot in the field of TRT blade manufacturing and repair due to its high precision, high efficiency and flexibility in material selection. This technology utilizes a laser beam to precisely melt and deposit metal powder or wire onto the damaged area, which not only can precisely restore the complex blade geometry, but also can significantly improve the denseness and mechanical properties of the repair layer.

## 1. The Basic Principles and Characteristics of Laser Cladding Additive Manufacturing Technology

### 1.1. The basic principle of laser cladding additive manufacturing technology

Laser cladding additive manufacturing technology using high energy density laser beam on the surface of the workpiece for local heating, so that the surface of the workpiece metal powder or wire quickly melted and solidified, so as to realize the workpiece surface coverage and repair. In the cladding process, the laser beam is focused by the optical system into a very small molten pool, which intersects with the surface of the workpiece, and the localized heating causes the material on the surface of the workpiece to rapidly heat up above the melting point. The molten metal powder or wire builds up layer by layer and fuses completely with the workpiece substrate through uniform arrangement and precise control as the laser beam moves. This layer-by-layer build-up and fusion process ensures a high-quality connection of the cover layer to the substrate, while minimizing the size of the

**Corresponding Author:** Xiangyang Yin
Shaanxi Xinxing Thermal Spraying Technology Co.,Ltd, China.
Email: sxxxrpt@sina.com

heat-affected zone and reducing material deformation and the generation of residual stresses. The molten pool morphology and fusion rate during the laser cladding process can be precisely controlled according to the specific application requirements to achieve the desired coverage quality and structural integrity. This technology is widely used in aerospace, automotive manufacturing and energy fields to enhance the wear resistance, corrosion resistance and structural strength of components, while injecting efficient and accurate repair and processing means for industrial manufacturing (Zhang et al., 2023).

### 1.2. Features of laser cladding additive manufacturing technology

Laser cladding additive manufacturing technology has outstanding features, through the high energy density of the laser beam local heating of the workpiece surface, can accurately control the melted metal powder or wire, in a very short period of time to complete the melting and solidification of the material, to achieve high-precision coverage and repair of the workpiece surface. This process not only effectively reduces the heat-affected area, thereby reducing material deformation and residual stress, but also ensures a high-quality combination of the covering layer and the substrate. With the characteristics of strong flexibility and wide adaptability, laser cladding technology can be applied to the surface treatment of workpieces of various complex shapes and sizes to meet the needs of different industries for high-performance and high-precision parts. Its precise control of cladding and efficient production speed effectively improve production efficiency and material utilization, and reduce manufacturing costs and energy consumption. In addition, laser cladding technology can also realize the local repair and remanufacturing of materials, extend the service life of the workpiece, reduce the waste of resources, and have a positive role in promoting environmental protection.

## 2. Laser Cladding Additive Manufacturing Technology in the TRT Blade Manufacturing and Repair Process Advantages and Challenges

### 2.1. Laser cladding additive manufacturing technology in the TRT blade manufacturing and repair process application advantages

Laser cladding additive manufacturing technology in the TRT blade manufacturing and repair process shows significant application advantages. Firstly, the technology can precisely control the melted metal powder or wire to form a uniform and dense covering layer on the blade surface, which improves the wear resistance and corrosion resistance of the blade. Secondly, the heat-affected area in the laser cladding process is small, which reduces the deformation and internal stress of the blade material and ensures the stability of the blade structure and the recovery of the original performance during the repair process. At the same time, the technology can quickly respond to the needs of blade damage repair, reducing downtime and production costs, improving efficiency and resource utilization. Laser cladding technology also has the characteristics of strong flexibility, adapting to a variety of complex blade structure and material requirements, can be customized according to the actual situation of the repair program, to ensure that the repair effect reaches the best state (Lu et al., 2022). Most importantly, by repairing the aging or damaged blades, the service life of the blades is extended, and the maintenance and replacement costs are reduced, which is of great significance for improving the overall equipment reliability and economic benefits.

### 2.2. Challenges in the application of laser cladding additive manufacturing technology in the manufacturing and repair process of TRT blades

Laser cladding additive manufacturing technology in the TRT blade manufacturing and repair process faces a number of challenges, first, the thermal management of the cladding process is a key issue, because the local heating of the high energy density laser beam is likely to lead to a sharp increase in the temperature of the surface of the blade and the molten pool area, which may cause thermal stress and deformation problems, affecting the accuracy and performance of the repaired blade. Secondly, the selection and matching of the cladding material needs to be precisely grasped, and the compatibility and performance matching with the blade matrix material is crucial, otherwise it may lead to weakened or non-uniform interfacial bonding. Third, the complex blade structure and curved surface make the laser cladding path planning and process parameter control challenging, and the technical problems of material melting uniformity and cover layer thickness consistency need to be overcome. Fourth, defects such as porosity and cracks that may occur during the cladding process need to be effectively managed and repaired through strict quality control and follow-up treatment to ensure the overall quality and performance of the repaired blade. Fifth, the high cost and operational complexity of laser equipment are also obstacles to be overcome in the application, especially for small and medium-sized enterprises that may face the challenge of high technical investment and training costs.

## 3. Application of Laser Cladding Additive Manufacturing Technology in TRT Blade Manufacturing

### 3.1. Design and modeling

The design and modeling process of laser cladding additive manufacturing technology in TRT blade manufacturing is the key application link, the design phase through the CAD software for three-dimensional modeling of the blade, to accurately determine the geometry and structural characteristics of the blade, including the curvature of the blade, the thickness distribution, and the internal cavity and other design elements. Numerical simulations are then generated based on the design model, and Computer Aided Engineering (CAE) software is used to perform flow field analysis and stress analysis to evaluate the force and thermal response of the blade under operating conditions. This step not only helps to optimize the blade design to ensure its stability and performance under high-temperature and high-pressure environments, but also guides the optimization and selection of subsequent manufacturing processes. In the modeling stage, CAM software is used to plan and optimize the machining path of the blade. The characteristics of the laser cladding process make it possible to precisely control the path of the laser beam and the deposition of the cladding material through the CNC laser system according to the cross-section information of each layer of the design model.

### 3.2. Material selection and cladding process

For material selection, engineers choose suitable metal powder or wire as the cladding material according to the working environment and performance requirements of the blade. These materials usually have good wear resistance, high-temperature strength and corrosion resistance, and can maintain stable mechanical properties and durability under complex working conditions. In the cladding process, the laser beam is precisely controlled by a numerical control system, focused and moved by an optical system to precisely deposit the melted metal powder or wire onto the blade surface (Chen et al., 2020). The high laser energy density in this process can melt and solidify the material in a very short time to form a uniform and dense covering layer. The key to the cladding process is the precise control of the laser's focal position and travel path, as well as the control of the melt pool formation and cooling process. Engineers need to adjust the laser power, scanning speed and thickness of the cladding layer through precise process parameterization to ensure the quality and bonding strength of each layer of the cladding material. Especially for complex curved structures and internal cavities like TRT blades, the accuracy and controllability of the cladding process is especially critical, and the uniformity of material deposition and bonding quality in each area need to be fully considered.

### 3.3. Manufacturing process quality control

#### 3.3.1. Layered manufacturing

In the layered manufacturing process of laser cladding additive manufacturing technology in TRT blade manufacturing, quality control is a key link to ensure the performance and stability of the final product. In order to effectively control the quality of the manufacturing process, it is first necessary to accurately control the parameter settings of the laser cladding system (Liu et al., 2010). This includes the optimization of laser power, scanning speed, laser focal length and other parameters to ensure the uniformity and denseness of the cladding layer. Secondly, real-time monitoring of the temperature field and residual stress distribution during the melting and cladding process is essential. Through high-precision temperature sensors and stress monitoring equipment, real-time feedback of thermal state changes and stress accumulation in the cladding area can be provided, and process parameters can be adjusted in a timely manner to avoid thermal cracks and excessive internal stress. In addition, advanced testing equipment such as optical microscopes and electron microscopes are utilized to analyze the microstructure and composition of the fused cladding layers to ensure the molding quality and stability of the metallurgical structure of each layer. Finally, a comprehensive non-destructive testing (NDT) methodology is implemented to inspect the overall blade, including ultrasonic testing, magnetic particle flaw detection, and thermal imaging to ensure that the overall integrity and quality of the blade meets design requirements.

**3.3.2. Real-time monitoring**

During the process, engineers use advanced sensor technology and real-time monitoring systems to accurately monitor and collect data from the laser cladding process. These sensors can detect the power of the laser beam, the focal point position and the formation and size of the molten pool in real time, as well as monitor the deposition of the cladding material and surface temperature changes. Through the real-time monitoring system, engineers can instantly access critical data during the process and perform real-time analysis and feedback control. For example, the monitoring system can detect the stability of the laser beam and the accuracy of the focal point position in real time, and promptly adjust the laser power and scanning speed to ensure the uniformity and quality of each layer of the molten material. At the same time, monitoring the formation and cooling process of the melt pool can predict and avoid possible defects such as poor melt pools or cracks, ensuring the perfect bonding of the cladding layer with the substrate. Real-time monitoring can also help engineers to accurately control and optimize the processing process, through the collection and analysis of a large number of real-time data, you can identify potential problems and bottlenecks in the processing process, timely adjustment of process parameters and equipment settings, to maximize production efficiency and product quality (Quan et al., 2021).

**3.3.3. Post-processing**

After the completion of cladding, the blade needs to go through a series of fine post-treatment steps to improve its surface quality, mechanical properties and durability. Common post-treatment methods include heat treatment and surface treatment. Heat treatment adjusts the internal organization and grain structure of the blade by controlling its heating and cooling process, enhances the hardness and abrasion resistance of the material, and improves the stability of the blade under high-temperature and high-pressure working environment. Surface treatment covers a variety of techniques such as shot peening, polishing and plating. Shot peening removes oxidized skin and impurities generated during the cladding process, purifies the blade surface, and provides good adhesion and protection for subsequent surface coatings. The polishing process can further enhance the finish and flatness of the blade surface, reduce surface roughness and defects, and improve the aerodynamic and hydrodynamic properties of the blade. For the specific needs of the blade surface, such as corrosion and wear resistance or reduction of the coefficient of friction, suitable surface coating technologies can be selected, such as thermal spraying, electroplating or chemical vapor deposition. These coatings not only enhance the surface hardness and wear resistance of the blade, but also improve its oxidation resistance and chemical stability, prolonging the blade's service life and performance retention cycle.

## 4. The Application of Laser Cladding Additive Manufacturing Technology in the TRT Blade Repair Process

### 4.1. Blade damage detection and assessment

The application of laser cladding additive manufacturing technology in TRT blade repair, especially in the blade damage detection and assessment, has an important application value (Li & Sui, 2013). During the inspection process engineers utilize advanced non-contact inspection techniques, such as laser scanners and thermal imaging equipment, to perform a comprehensive damage inspection of the blade. These devices are able to accurately measure the blade surface geometry, dimensions and surface defects such as cracks, wear and corrosion. And through data analysis and imaging processing software, engineers are able to quantitatively analyze and evaluate the detected damage, assessing the depth, extent and impact of the damage. Once the location and nature of the damage has been determined, laser cladding technology can be utilized to its advantage. Using a precisely controlled laser cladding system, engineers are able to target the damaged area for replenishment and repair. During the laser cladding process, the high energy density of the laser beam rapidly melts the selected metal powder or wire and deposits it precisely onto the damaged surface, enabling localized repair of the damaged area.

### 4.2. Repair materials and process selection

The key to the application of laser cladding additive manufacturing technology in TRT blade repair lies in the precise matching of repair materials and process selection. Usually, the repair material needs to have similar chemical composition and mechanical properties as the original material to ensure the stability and reliability of the repaired blade in the high temperature and high pressure working environment. With laser cladding technology, engineers are able to precisely control the melting and deposition of the repair material. Laser cladding systems utilize a high energy density laser beam to rapidly melt metal powder or wire and precisely deposit it onto the damaged surface. This fine-tuned repair process not only enables localized repairs, but also allows the thickness and shape of the repair layer to be adjusted to meet the complex geometrical requirements and operational performance needs of the blade. During the selection of repair materials and processes, engineers need to consider a variety of factors, such as the size, shape, and depth of the repair area, the functional requirements of the repaired blade, and the challenges and limitations that may be encountered during the repair process (Mi & Wang, 2014).

### 4.3. Repair process

#### 4.3.1. Pre-treatment of damaged parts

In the application of laser cladding additive manufacturing technology in the TRT blade repair process, the pretreatment of the damaged area is a key part. First, engineers will thoroughly clean and prepare the surface of the damaged area. This step is very important because the damaged area usually has oxides, dirt or other impurities, which can affect the adhesion of the subsequent repair material and the repair effect. Secondly, through mechanical methods such as grinding, lapping or sandblasting, engineers are able to remove the surface layer of the damaged area, ensuring that the repair process has direct access to a clean metal substrate. This delicate pre-treatment improves the adhesion of the repair material and the surface roughness of the damaged area, which lays a good foundation for the subsequent laser cladding repair process. During the pretreatment process, engineers need to be careful not to damage the surrounding healthy material and to ensure that the geometry and dimensions of the damaged area remain stable. Through precisely controlled pretreatment techniques, engineers are able to effectively prepare the damaged area to provide an ideal working surface for the laser cladding repair process (Lu & Quan, 2021).

#### 4.3.2. Laser cladding repair

In the application of laser cladding additive manufacturing technology in the TRT blade repair process, laser cladding repair is the key technical link. In the repair process need to choose the appropriate repair material, usually metal powder or wire, its chemical composition and mechanical properties need to be matched with the original material, in order to ensure that the repaired blade in the high temperature and high pressure working environment with stability and reliability. At the same time, the laser cladding system utilizes a high energy density laser beam to rapidly melt the repair material and accurately deposit it onto the damaged surface to achieve localized repair of the damaged area. Precise control of the laser parameters is critical in this process, as engineers can adjust the laser power, focus diameter and scanning speed to accommodate the complex geometry and damage characteristics of different blade sections. Through a real-time monitoring system, engineers are able to provide instant feedback on the repair process and adjust the repair strategy to ensure the uniformity and integrity of the repair layer. Laser cladding repair technology not only restores the structural integrity of the blade, but also improves its mechanical properties and durability under operating conditions.

## Summary

To summarize, laser cladding additive manufacturing technology has demonstrated significant technical advantages and application potential in the manufacturing and repair of TRT blades. The basic principles of laser cladding technology and its specific applications in the repair process of TRT blades were analyzed in depth above. From the material selection and optimization of the cladding process to the subsequent treatment and performance evaluation, we systematically discussed the innovative results of this technology in improving the efficiency of blade repair, reducing the consumption of resources and extending the service life of the blade. Future research directions include further optimization of laser cladding parameters, development of new repair materials, and enhancement of real-time monitoring and quality control techniques to meet changing industrial demands and improve the overall performance of TRT blades.

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## Conflict of Interest

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

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