

## Effects of Laser Cladding on Thermal Tensile Property and Fracture of Gas Turbine Engine Blade Material GH864

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**Abstract.** The consecutive layer of a nickel alloy was deposited onto a GH864 nickel-based superalloy gas turbine engine blade using laser cladding. To ensure the performance of blade, the gas turbine with laser cladding repaired blades worked two weeks and a detailed measurement and investigation were performed on chemical composition, mechanical performance, microstructure, macro-fractography and micro-fractography. The results indicate that the cracks at the inlet edge part of blade were caused by reheat crack. An inappropriate technology of laser cladding can result in the formation of incomplete fusion interface between the laser clad coating and substrate, or reheat cracking along the coarse grain boundary in the heat treatment zone. Tensile specimens were tested at both room temperature and elevated temperature. The results correlate to the conclusion that the reheat crack is the main reason for the performance degradation of the restored blade.

### Introduction

The abrasion phenomenon of the gas turbine blade is seriously affected by high temperature gas erosion. Some blades cannot be repaired even after spraying and replacing all the blades is clearly cost prohibitive. Therefore, the selection of appropriate materials, processes and methods to repair the scrapped blade can have a significant economic benefit.

Laser cladding is an alternative method to thermal spray for the restoration of blade surface[1], comparable dense layers without porosity or inclusion and heat-affected zone without reheat cracking should improve the high temperature performance[2]. However, there are some disadvantages in the laser cladding technology, such as cracks[3,4], holes[5] and slag. The cracks are the main form of the defects of laser clad coating and which is related to the laser cladding parameters, treatment conditions, deposited filler materials and matrix materials[6]. The high speed of laser heating and cooling and short time of molten pool caused oxide, sulfide and other inclusions in the pool not released easily, which was to become the crack source in the laser clad coating. In addition, with the instant solidification of the laser clad coating and the increase of grain boundary and vacancy, coagulation defect, thermal brittleness and cracking sensitivity increased[7], in the meanwhile, plasticity and toughness decreased[8,9], which lead to the formation of intergranular crack and reheat crack.

Nickel base high temperature alloy has larger welding hot cracking tendency, and the finite solubility element, such as Ni and Fe, was formed low melting point material at the grain boundary easily. In addition, Al, Ti and B have significant influence on the welding. Therefore, in order to check the microstructure and thermal property of the blade material nickel base superalloy GH864 restored using laser cladding with Ni base alloy power. The present paper investigates the root causes of the fracture suffered by a set of blades from the high pressure compressor of an aircraft engine which, shortly after having been repaired, presented a deficient in-service performance. To evaluate thermal tensile property of the blade restored using laser cladding, the tensile test at room temperature and elevated temperature are also carried out.

## Experiment Details

The chemical composition of GH864 superalloy is listed in Table 1. A scrapped gas turbine blade (about 20000 hours of using time) is adopted to experiment. There is a thumb groove near the inlet edge at blade root, the depth of groove is about 5mm and the height is 25mm. Then, the scrapped blade was restored using laser cladding and the deposited filler material is Ni base alloy power. The scrapped blade is polished with standard blade shape and checked by dye penetrant testing (PT). The scrapped blade without defects will work two weeks in the gas turbine ( $600\sim 700^{\circ}\text{C}$ ,  $0.2\sim 0.3\text{MPa}$ ) and then applied to PT testing.

Specimens for microstructure observation are machined from restored gas turbine engine blade with laser cladding repaired blades. The samples are cut from the vicinities of blade basin of turbine blades at inlet edge, as shown in Fig.1.

Table 1. Main chemical compositions of GH864 superalloy (wt%).

Element	Cr	Co	Mo	Ti	Fe	Al	C	B	Ni
wt%	20.14	7.92	6.09	3.10	0.54	1.76	0.04	0.01	Bal.

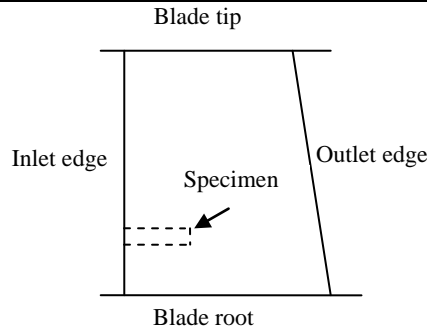


Fig. 1. The sketch of turbine blade.

Specimens are grounded and polished, then etched with solution of  $3\text{gCuSO}_4 + 8\text{gFeCl}_3 + 80\text{ml HCl} + 80\text{ml C}_2\text{H}_5\text{OH}$ . Microstructures are observed using OLYMPUS BX51M optical microscopy (OM), JSM5800 and Quanta 200F scanning electron microscopy (SEM). Compositions of the phases in the alloys are analyzed by energy dispersive spectrometry (EDS).

Tensile tests are carried out using MTS880 100kN hydraulic servo materials testing machine at both room temperature and elevated temperature, with a constant strain rate of  $0.5\text{mm/min}$ . The heating process of elevated temperature tests is conducted by chamber electronic furnace installed with the testing machine. Tensile sample is designed as Fig.2. Tensile samples are divided into two types, one type is blade material GH864 and another type is GH864 restored by laser cladding (The thickness of coating is  $1\text{mm}$ ). Fracture surfaces are examined by SEM.

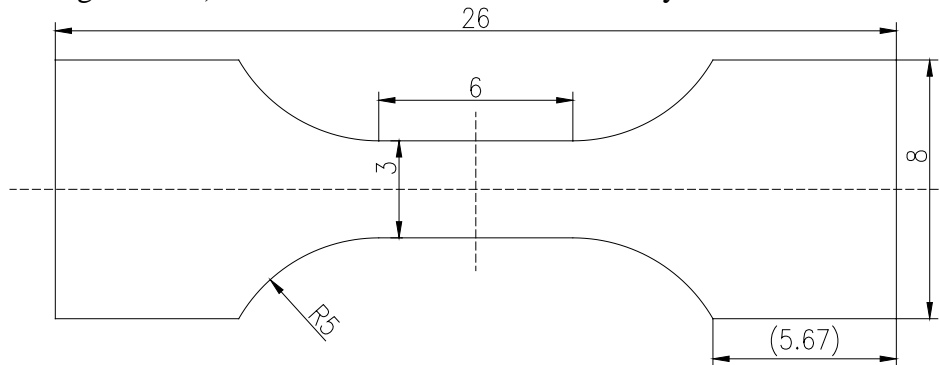


Fig. 2. The sketch of tensile test sample.

## Results and Discussion

### Penetrant Testing of Restored Blade after Worked Two Weeks

The blade restored by laser cladding, which was worked two weeks, has been checked by penetrant testing (Fig. 3). It can be seen that cracks were appeared at the inlet edge of the blade using penetrant testing. It means that cracks were appeared during operation time, the material property and the operation condition resulted in this case of cracks.



Fig. 3. Blade crack position.

### Microstructure Analysis

It is observed that the crack originated from the inlet edge of the blade basin. The SEM image in the figure 4 reveal the microstructure at the crack origin. The material at the top of the picture is substrate, which shows intergranular fracture characteristics. The material at the bottom of the picture is laser clad coating, it is clearly observed that there is a oxidation at the region between the substrate and laser clad coating, the crack is initiated at the oxidation zone. According to the measurement, it can be seen that the length of oxidation zone is exceeding 6.5mm and the depth is 1.5mm.

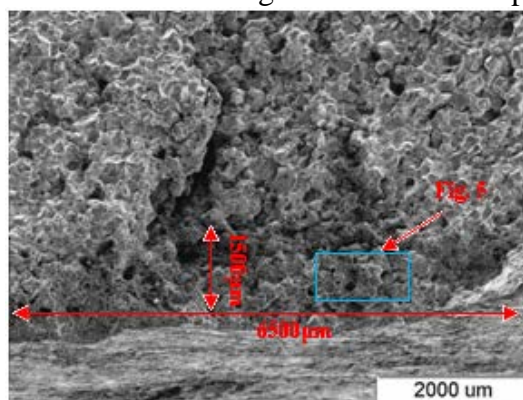


Fig. 4. SEM image of the crack origin.

The local amplification of the oxidation was carried out, it is shown in figure 5. It can be seen that the oxidation region oxidized seriously, formed many holes. The EDS scanning conducted in the oxidation region showed that the oxidations were substrate with high O content. The gas turbine blade was working in the gas environment without oxygen, so that the oxide layer is not formed in the working time. It is observed that the oxidation zone is existed at the junction of substrate and laser clad coating, which distributed uniformity and unchanged in the thickness direction. It is indicated that the oxidation zone is the reheat crack formed during laser cladding.

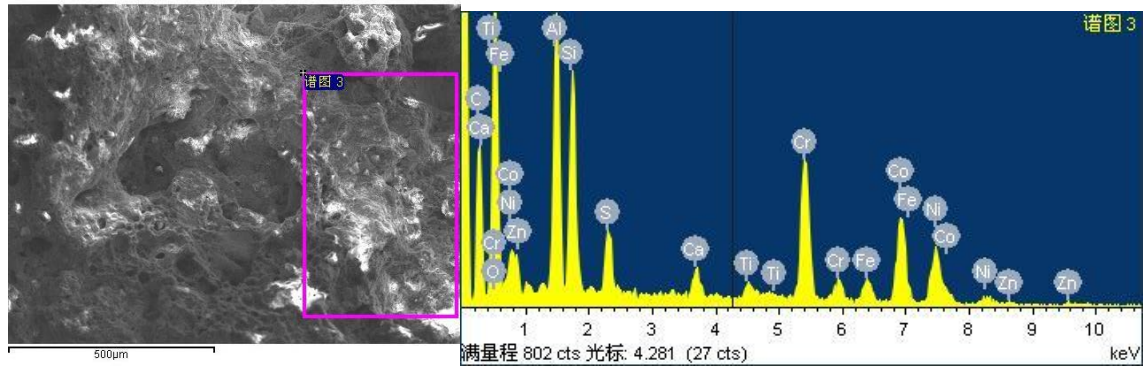


Fig. 5. SEM image of the oxide at crack origin and EDS of the oxide.

Figure 6a, b and c show the optical micrographs examined at of cladding thin wall in the cross-section, respectively. It can be seen clearly that there are three microstructure at the cladding thin wall, laser clad coating marked one, transition layer marked two and substrate marked three. The microstructure of base material consist of austenite, twin crystal and the strengthening phase distributed uniform. According to the observation of laser clad coating, it can be seen that the dendrite of laser clad coating is uniform and dense, the transition layer, which is in the middle of laser clad coating and substrate, connected naturally, no obvious stratification or layer.(a

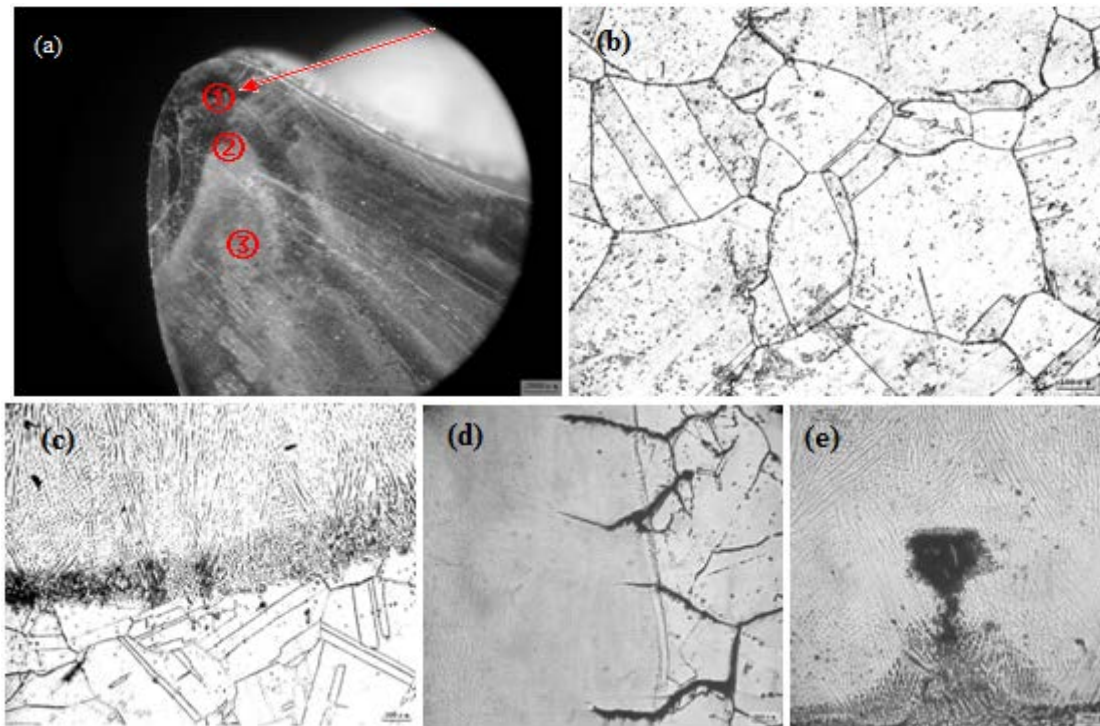


Fig. 6. Optical micrograph taken in the cross-section of the cladding thin wall at crack position; (a) cross-section; (b) substrate; (c) fusion interface; (d) reheat crack; (e) hole.

The microstructure of defects in the transition layer and the cladding laser is presented in Figure 6d and e, respectively. Micro-cracks were found in the optical micrographs. The images show hole with very larger scale. It can be seen that many intergranular cracks are distributed in the heat treatment zone of the substrate, some of which has been extended to the laser clad coating, formed penetrated crack.

The widest points of the intergranular cracks are at the middle of the cracks, which are at the surface of substrate near the laser clad coating, both ends of the crack is fine. The boundary of crack touched with laser clad coating and substrate is clear, and there is no deposited filler filling phenomenon at the junction of crack and laser clad coating, this indicated that there is no

intergranular crack before laser cladding. If the cracks have been existed before cladding, the crack at the surface of substrate will be filled by deposited filler material.

The formation of the crack can be described as following: during laser cladding, the grain boundary strength of grains at the substrate heat treatment zone is decreased with the temperature increasing. The surface temperature of the substrate is higher than the core temperature, so that the stress state of the substrate surface is tensile stress, it is easy to form crack at grain boundary. Similarly, the temperature of laser cladding coating is much higher, it is also tensile stress state during cooling and solidification, the crack can be extended from substrate to laser clad coating. Therefore, the substrate intergranular crack is the reheat crack forming during laser cladding.

There are many reheat cracks in the substrate and laser clad coating, which is multidirectional, different size, different orientation and random distribution. When one crack direction perpendicular to the blade stress direction, the crack is likely to expanded and caused fracture.

### Thermal Tensile Property

Tensile tests of GH864 alloys were carried out at both room temperature and elevated temperature. The results are shown in Fig.7. Tensile strengths of GH864 and GH864 restored using laser cladding with 1mm laser clad coating are prone to reduce with temperature increasing.

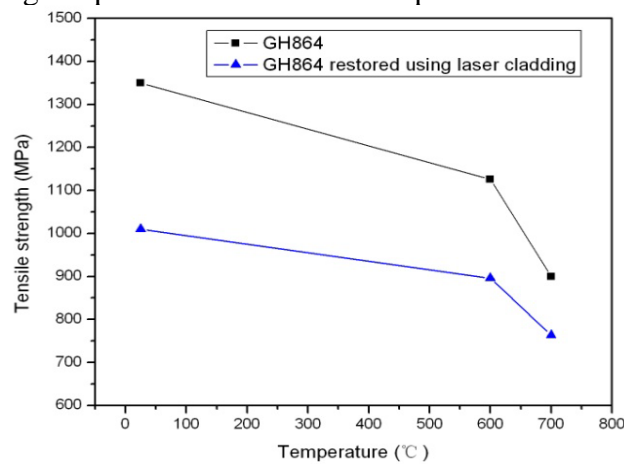


Fig. 7. Tensile test results of GH864 alloys.

The fractographs of ambient temperature specimens are displayed in Fig.8. Typical fracture morphology of the substrate specimens exhibits a large amount of shear dimples, which indicates good ductility. Fracture surface of the specimens subjected to laser clad coating is mainly covered by dimples, but the dimples of the substrate sample are deeper and larger than that of the coating one.

When the tests were carried out at elevated temperature, all specimens have remarkable necking. The fracture surfaces of substrate specimens mainly contain grains, which displays a obvious brittle fracture mode. On the contrary, fracture surface of coating specimens displays a complex fracture mode with fractured ductile dimples enveloped in the brittle cleavage matrix.

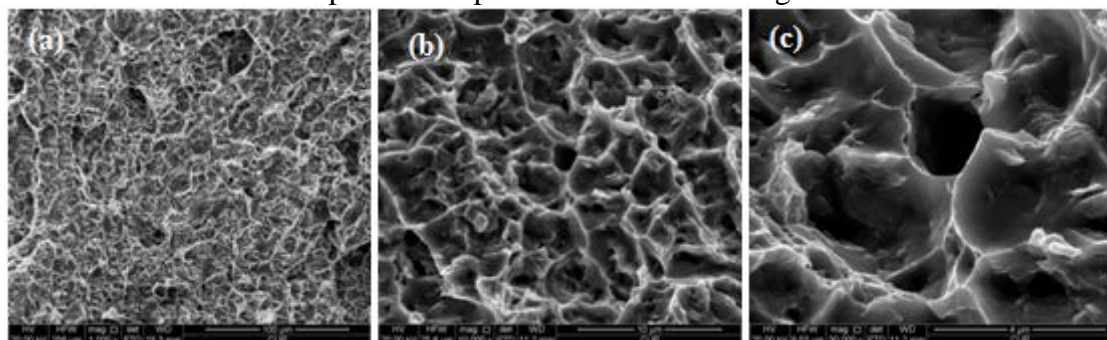


Fig. 8. Fractographs of ambient temperature specimens; (a) GH864; (b)(c) coating.



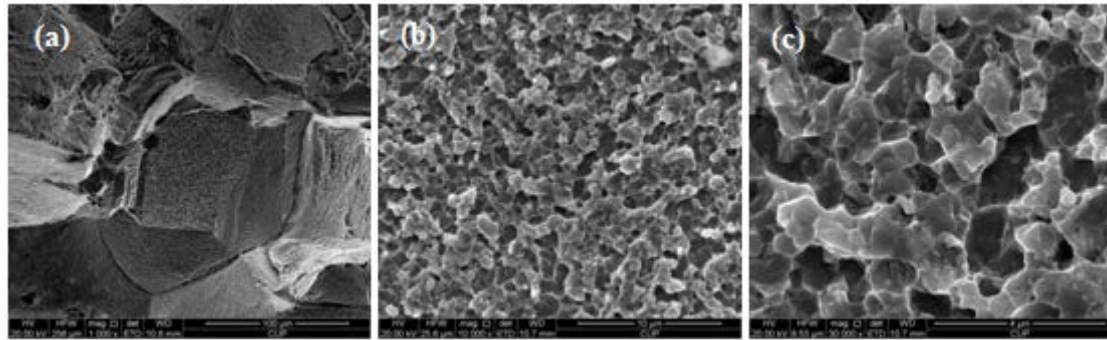


Fig. 9. Fractographs of specimens at 700°C; (a) GH864; (b)(c) coating.

It is concluded that thermal expansion behavior of laser clad coating is quite different from substrate. In addition, cracks often initiate at grain boundaries of substrate due to stress concentration resulting from reheat crack. On the other hand, penetrated reheat crack, not only weakens the strengthening effect of coating, but also provides the path for crack propagation, which leads to performance degradation of GH864 alloy.

## Summary

In this study, repair of turbine blade using laser cladding process was investigated. Based on the results obtained, following conclusions can be drawn:

The repaired inlet edges area contains a cluster of defects, such as micro-cracks, micro-voids and undense microstructure. The existences of these defects are allowed inside the blade, however, it is susceptible to failure when the defects exist near the blade root where stress concentration results in fatigue crack initiation.

There are three microstructures at the cladding thin wall, laser clad coating, transition layer and substrate: many intergranular cracks are distributed in the heat treatment, some of which have been extended to the laser clad coating.

The substrate intergranular crack is the reheat crack forming during laser cladding, which not only weakens the strengthening effect of coating, but also provides the path for crack propagation, which leads to performance degradation of GH864 alloy.

The reason of reheat cracks formation is the temperature gradient of substrate and coating during laser cladding.

The laser cladding can achieve refined micro-structure compared to the substrate with low porosity, but some defect, such as reheat cracks and holes, will be appeared caused by an inappropriate technology of laser cladding.

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