[Article ID] 1003- 6326(2001)04- 0572- 04

Laser repairing surface crack of Ni-based superalloy components①

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[Abstract] Surface crack of components of the cast nickel-base superalloy was repaired with twin laser beams under proper technological conditions. One laser beam was used to melt the substrate material of crack, and the other to fill in powder material to the crack region. The experimental results show that the surface crack with the width of 0.1~0.3 mm could be repaired under the laser power of 3 kW and the scanning speed of 6~ 8 mm/s. The repaired deepness of crack region is below 6.5 mm. The microstructure of repaired region is the cellular crystal, columnar crystal dendrite crystal from the transition region to the top filled layer. The phases in repaired region mainly consisted of supersaturated α-Co with plenty of Ni, some Cr and Al, $Cr_{23}C_6$, Co_2B, Co-Ni-Mo, Ni_4B_3, TiSi and VSi. The hardness of filled layer in repaired region ranged from $HV_{0.2}450$ to $HV_{0.2}500$, and the hardness decreases gradually from the filled layer to joined zone.

[Key words] van of aviation engine; surface crack; laser repairing, nickel-base alloy
[CLC number] TN 249; TG 159.99 **[Document code]** A

1 INTRODUCTION

The cast nickel-base superalloy is the major material used for high temperature components of the air turbine engine, such as vane, turbine tray, combustor. Usually there are more than one thousand of vanes in a turbine, so a large amount of such kind of material must be needed. The vanes have to be substituted in a certain period to guarantee the safety, which causes a great amount of waste. Many countries in the world have paid a lot of attention to the research work of damaged vanes repairing and made many achievements[1,2]. According to literatures, currently main methods used to repair vanes are braze welding, flour activated bonding and melting-welding. But there isn't a reliable method for repairing surface cracks yet. Nowadays with the development of laser technology, laser processing and theories have made great progress[3~11]. There has been the possibility to repair the surface defects of components by laser. In order to search a new way of vane repairing, investigation has been carried out into repairing surface cracks of vane aviation engine by laser.

2 EXPERIMENTAL

According to the characteristics of surface crack of vane of aviation engine, cast nickel-based superalloy K417, twin laser beams were adopted. One laser beam was used to melt substrate material of crack region, and the other laser beam was used to fill powder material to the crack region to build-up welding the hollowness region. That is to say, at first, crack region was fused by itself through laser melting; then, almost at the same time powder materials were filled to build-up welding the crack region. The filled materials can be the same material as substrate or different material, wirelike material or powder material. In the experiments, Co-02 powder was used to fill to the crack region by a pneumatic powder feeder system using Ar as the carrier gas. The schematic diagram is shown in Fig. 1.

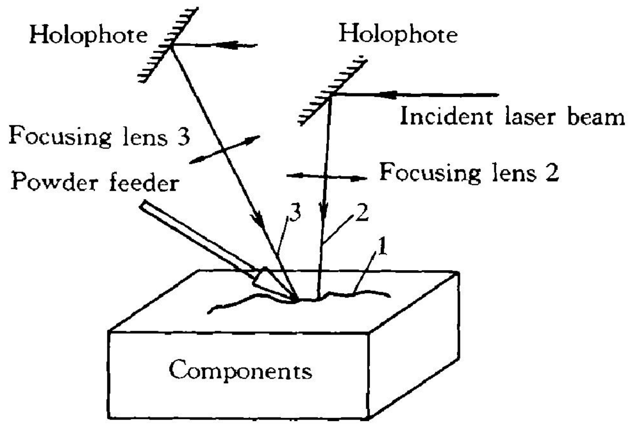

Fig. 1 Schematic diagram of laser repairing surface crack of components
1 —Surface crack; 2 —Laser beam used for melting crack region; 3 —Laser beam used for filling powder to build-up welding crack

① **[Foundation item]** Project (59906004) supported by the National Natural Science Foundation of China; Project supported by the Research Foundation of State Key Lab. of Laser Tech. at Huazhong University of Science and Technology
[Received date] 2000- 11- 27; **[Accepted date]** 2001- 02- 19

The equipment used for repairing was a 5kW continuous-wave CO_2 laser system. According to the characteristics of crack such as the variety of deepness, width, shape, the laser was operated in a range of 1.5 ~ 3.5kW. The laser beam diameter varied from 0.8mm to 2.5mm. The traverse speed of the samples ranged from 6mm/s to 8mm/s. Argon gas was used to shield the melt pool oxidation and to protect the optics from the fumes and the sputtered material.

Analysis was performed mainly on the cross-sections of repaired region. Microstructure was examined under an optical microscope. X-ray diffraction (XRD) analysis was performed to identify the phases observed in the repaired region. The components in repaired region were revealed by electronprobe microanalyzer (Type: JXA-88000R).

3 RESULTS AND DISCUSSION

3.1 Technology parameters of laser repairing

As other laser processing such as laser cladding, laser heat treatment, laser welding, the power density F and energy density E are important synthetical technology parameters during laser repairing. The main technology parameters of laser repairing are as following, output power of laser P, scanning speed V, and the beam diameter D. According to the servicing conditions, different power density F and energy density E can be obtained through changing above three parameters. Here $F = P/\pi D^2$ (kW/cm^2) was used to express the power amount per unit surface, and $E = P/VD$ (kJ/cm^2) to express the energy amount per unit surface.

Because the characteristics of surface crack such as the run direction of crack, shape, deepness and width can not be controlled, and they have the randomness. The laser beams were changed especially for the cracks with the great width and deepness. In the experiments, the power density F ranged from 7.64kW/cm^2 to 149.5kW/cm^2, the energy density E varied from 6kJ/cm^2 to 62.8kJ/cm^2 when the deepness of surface crack was below 6.5mm. The experimental results show that the surface crack with the width of 0.2~ 0.3mm could be repaired under the laser power of 3kW and the scanning speed of 6mm/s. The surface crack with the width of 0.1~ 0.2mm could be repaired under the laser power of 3kW and the scanning speed of 8mm/s. The beam diameter of 0.8~ 1.0mm was used for melting crack region, the beam diameter of 2.0mm was used for filling powder to build-up welding crack, and the repaired deepness of crack region was about 4.5mm (see Fig. 2).

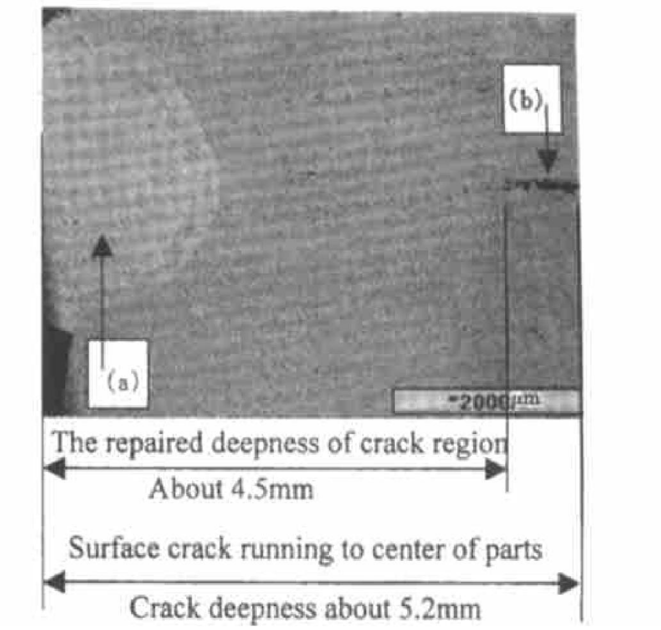

Fig. 2 Section map of repaired region of steel parts
(a) —Filled layer; (b) —Not repaired crack region

3.2 Microstructure of laser repairing region

Fig. 3 shows that there is an obvious joined zone between build-up layer and matrix of vane, i. e., there is a transition section (Figs. 3(a), (c)). Above the zone is a white thin layer consisted of cellular crystals which columnarly grew. Along the upward direction, dendrites characteristic of a typical rapid growth solidification process can be seen. The structure changes from cell (without secondary arms) to dendrite (with secondary and even ternary arms, Fig. 3(b)) from the root to the top. The orientations of the different grains are different. There exists obvious columnar structure which likely consists of parallel cells around the center of molten pool (Fig. 3(a)), and which directionally grows from the interface of the free surface to the center. The sizes of grains become more and more uniform and smaller from the interface to center. The structure of repaired region is far more finer and denser than that of vane matrix (Fig. 3(d)).

3.3 Components and phases in repaired region

Fig. 4 indicates that the microstructure in repaired region consisted mainly of dendritic skeleton 1 and black solid solution 2 filled in the space of skeleton. Table 1 shows that dendritic skeleton 1 is composed of elements Co, Ni, Cr, Al, Mo, Ti, Fe, Si, etc. The composition elements of black solid solution filled in the space of skeleton are the same as the dendritic skeleton 1. But Ni, Al and Fe in solid solution 2 increase in the content, Co, Cr, Mo, Ti and Si in solid solution 2 decrease in the content.

X-ray diffraction analysis reveals that dendritic skeleton is the supersaturated α-Co which contains plenty of Ni, some Cr and a little Al. These elements can reinforce the strength of the matrix of repaired region through solution strengthening, and increase the hardness and resistance-wear property of repaired region. The activity of Al can be improved when Cr

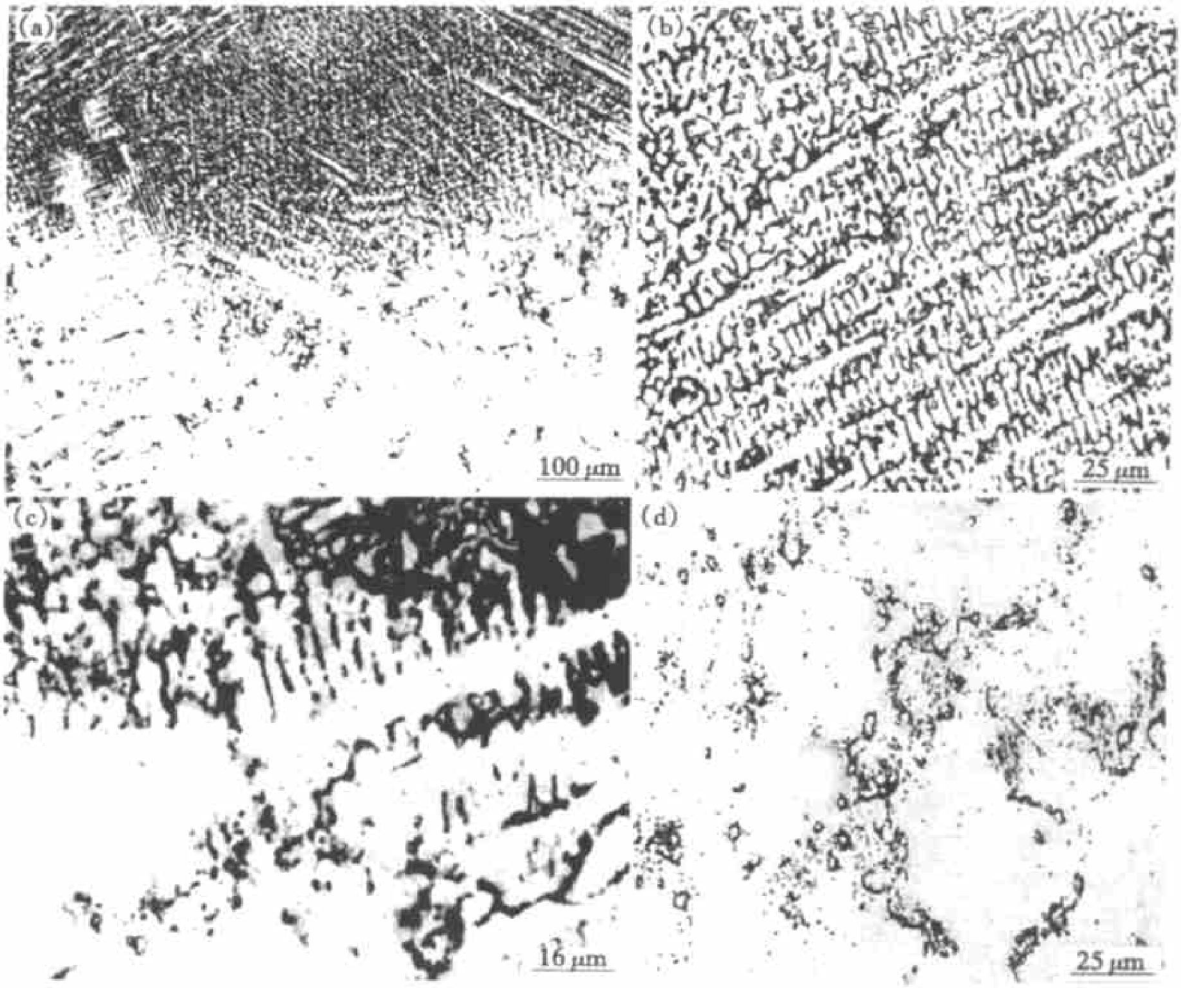

Fig. 3 Microstructures of repaired region of vane
(a) —Whole cross-section of repaired region; (b) —Build-up layer;
(c) —Join zone of build-up layer and matrix of vane; (d) —Matrix of vane

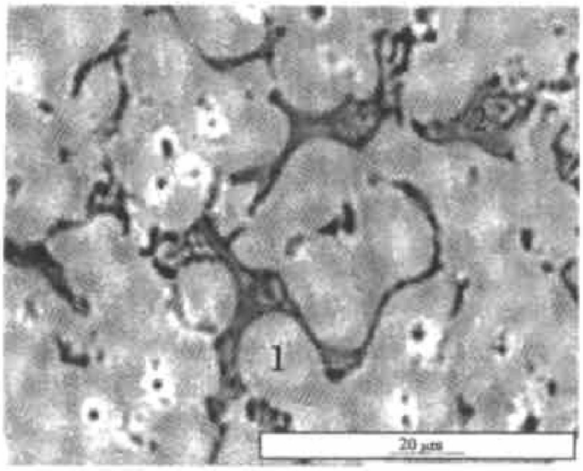

Fig. 4 Compositions of phases presented in filled region revealed by electronprobe microanalyzer

and Al coexist. The protective alumina film can be formed when the content of Al is lower. So the resistance-corrosion property at the high temperature can be improved. The phases between skeletons are α-CO, $Cr_{23}C_6$, Co_2B, Co-Ni-Mo, Ni_4B_3, etc. The educts located at dendritic skeleton are TiSi and VSi

Table 1 Components of filled region (build-up layer) in repaired region of vane (mass fraction, %)

Location	Al	Si	Ti	V	Cr
1	2.43	1.11	1.89	0.37	19.36
2	3.25	0.91	1.04	0.35	17.35

Location	Fe	Co	Ni	Mo
1	1.21	39.61	32.39	1.73
2	1.29	37.69	36.90	1.21

(black) which are formed in-suit (Fig. 4).

The results of line scanning in the joined zone show that along the direction towards vane matrix, Al and Ni contents increase, Si content decreases; but the content of Si increases obviously in the white region (Fig. 5). The contents of Mo, Ti, V are obvious higher than those in two sides, which is the results from vane matrix melting and diffusion of Mo, Ti, V. These are the reasons that more hard phases TiSi and VSi are produced in-situ. Another, the content of Cr, Fe and Co increase along the direction towards van matrix, which is led by the mass-pass at liquid and the diffusion at high temperature when the

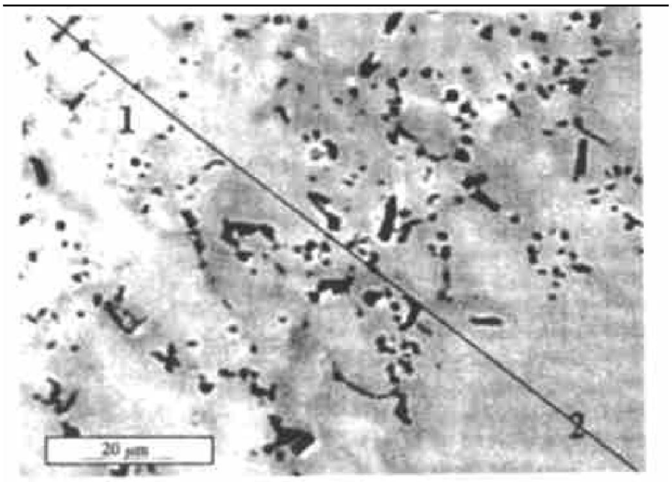

Fig. 5 Line canning results in joined zone by electronprobe microanalyzer

matrix is melted slightly under the action of laser beam, i. e. these are because of the dilution of vane matrix.

3.4 Hardness in repaired region

The examinatorial results indicate that the hardness at the filled layer (build-up layer) in repaired region of vane varies from $HV_{0.2}$450 to $HV_{0.2}$500. Then the hardness gradually decreases from the filled layer to joined zone, the values of hardness keep basically invariable to the vane matrix. The hardness of repaired region is influenced by components, microstructure, phases, hard grain, etc. The nonuniformity of distribution of microstructure and components decides the fluctuation of distribution of the hardness. So there is the difference among the values in the repaired region. Further more, the hardness of dendritic skeleton is higher than that of space between dindritic skeletons because they are the prophases with the high molting point. And the hardness at the location of hard grain is higher than that of other locations.

4 CONCLUSIONS

1) It is feasible that twin laser beams were adopted to repair the surface crack of vane of aviation engine, cast nickel-based superalloy K417. One laser beam was used to melt substrate material of crack region, and the other was used to fill powder material to the crack region to build-up welding the hollowness region.

2) The surface crack with the width of 0.1~0.3 mm could be repaired under the laser power of 3 kW and the scanning speed of 6~8 mm/s. The repaired deepness of crack region is below 6.5 mm.

3) The microstructure of repaired region is that the cellular crystal, colummar crystal and dendrite crystal form the transition region to the top filled layer. The phases in repaired region is mainly consisted of supersaturated α-Co with plenty of Ni, some Cr and Al, $Cr_{23}C_6$, Co_2B, Co-Ni-Mo, Ni_4B_3, TiSi and VSi.

4) The hardness of filled layer in repaired region ranges from $HV_{0.2}$450 to $HV_{0.2}$500. Then the hardness decreases gradually from the filled layer to joined zone.

[REFERENCES]

[1] Melntyre M. Laser hardfacing of RB211 turbine blade shroud interlocks [A]. Proc 2nd Int Conf on Appl of Laser in Materials Processing [C]. Los Angels, 1983. 320-324.

[2] Brauny P. Repair of air cooled turbine vanes of high performance aircraft engine-problems and experience [J]. Material Science and Technology, 1985, 1(9): 719-722.

[3] HU Xiang, CHEN Zhen-hua, ZHU Bei-di, et al. Average density in laser cladding processing with a powder injector [J]. The Chinese Journal of Nonferrous Metals, 1997, 7(2): 136-139.

[4] ZENG X Y, WU X W, TAO Z Y, et al. Heat damage of laser clad Ni-based WC coating [J]. Acta Metallurgica Sinica, (in Chinese), 1997, 33(12): 1281-1288.

[5] LI Qiang, LEI Ting-quan, WANG Fu-chi, et al. Microstructural characterization of laster clad TiC partices reinforced Ni-Cr-B-Si-C composite coating [J]. The Chinese Journal of Nonferrous Metals, 1998, 8(3): 420-426.

[6] WU Bao-lin, WANG Yi-nong, HU Guang-yong, et al. Recrystallization texture in Cu-30% Zn alloy heated by laser beam [J]. The Chinese Journal of Nonferrous Metals, 1999, 9(Suppl. 1): 41-44.

[7] SONG Ren-guo, HU Wang-zhao, HUANG Wei-dong, et al. Effects of laser surface remelting on microstructure and hydrogen permeation resistance of thermal spraying aluminum coatings [J]. The Chinese Journal of Nonferrous Metals, 2000, 10(2): 179-184.

[8] Kopel A, Reitz W. Laser surface treatment [J]. Advanced Material & Processes, 1999, 156(3): 39-41.

[9] LIANG Gong-ying, WANG T T, SU Jun-yi, et al. Amorphous structure in a laser clad Ni-Cr-Al coating on Al-Si alloy [J]. Transactions of Nonferrous Metals Society of China, 2000, 10(2): 220-223.

[10] XIE Chang-sheng. Evaluation of alloy element redistribution within laser-melted layer [J]. Surface and Coatings Technology, 1999, 113: (1-4).

[11] JIA Jun-hong, ZHONG Min-lin, LIU Wen-jin, et al. The effect of titanium addition on generating composite coatings reinforced by laser cladding on the surface of Fe-C alloy [J]. Applied Laser, 2000, 20(4): 145-154.

(Edited by HE Xue-feng)