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Microstructure and hot corrosion behavior of the Ni-based superalloy GH202 treated by laser shock processing

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ABSTRACT

The effects of laser shock processing on microstructure, the residual stress, and hot corrosion behavior of the Ni-based superalloy GH202 were investigated. The microstructures of GH202 before and after laser shock processing (LSP) were characterized by electron backscattered diffraction (EBSD) and transmission electron microscope (TEM). A large number of crystal defects (twins, dislocation arrays, and high dense tangles) were generated on the surface of GH202 treated with LSP. The cross-sectional compressive residual stress and micro-hardness of specimens treated by LSP were improved significantly. The corrosion kinetics of GH202 with or without LSP treatment at 800 °C and 900 °C were investigated. Analysis by X-ray diffraction (XRD) revealed that the corrosion products mainly consist of Cr_2O_3, TiO_2, Al_2O_3, NiO, CrS, Ni_3S_2, and Na_2CrO_4. The surface and cross-section morphologies were observed by scanning electron microscope (SEM) combined with energy dispersive spectroscopy (EDS). The results confirmed that the crystal defects induced by LSP promotes the creation of diffusion paths for elements (Cr, Al, and Ti), allowing the formation of tiny homogeneous oxidation films in a very short time. Additionally, the spallation of oxidation film on the treated specimens was alleviated significantly. Overall, the hot corrosion resistance of Ni-based GH202 induced by LSP was improved in Na_2SO_4 and NaCl molten salt from 800 °C to 900 °C.

1. Introduction

Ni-based superalloys are widely used as key components of aero-engines and gas turbines such as blades, vanes, and pipelines due to the excellent mechanical properties of these materials [1], including high temperature oxidation resistance [2] and hot corrosion resistance [3]. With the continued development of airplane industries, many components must work under extremely harsh conditions. In order to meet these requirements, surface strengthening technologies, such as shot peening [4], rolling [5], and laser shock processing (LSP) [6], are used to improve the performance of these components.

There have been recent efforts to investigate the surface morphologies, the microstructures in the affected layers, and the performances of materials after LSP. Ren X. D. et al. [7] found that LSP affected dislocation evolution and the microstructure configuration of GH2036 alloy. After LSP, the micro-hardness of the surface was increased by 16%, and the surface topography exhibited excellent stability after thermal cycling. S. G. Irizalp and Saklakoglu N. [8] found that stacking fault ribbons were enlarged and deformation twins and twin boundaries were increased in the LSP-treated 6061-T6 alloy, which exhibited both high strength and high ductility. X. Q. Zhang et al. [9] showed that the compressive residual stress of the surface was increased significantly and the fatigue crack initiation propagated from the sub-surface instead of the top surface. The fatigue striation spacing was decreased after LSP, suggesting that the rate of crack propagation slowed. Additionally, the fatigue life of fastener hole treated by LSP was 3.5 times longer than that of the un-treated sample. Y. Q. Hua et al. [10–11] attempted to improve the high temperature oxidation resistance and hot corrosion resistance of aeronautical materials. They found that the average grain size of the metals treated by LSP became finer, and the compressive residual stress was increased significantly. Highly tangled and dense dislocation arrangements and a high amount of twins were generated after LSP. The resistance of high temperature oxidation and hot corrosion of the materials treated by LSP were obviously improved from 800 °C to 900 °C. However, there are few published reports of using LSP to improve the resistance of high temperature oxidation and hot corrosion, and there are many unanswered questions.

Here, we investigated hot corrosion of the Ni-based superalloy GH202 treated by LSP from 800 °C to 900 °C. The cross-section

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microstructures of the Ni-based superalloy GH202 before and after LSP treatment were characterized by electron back scattering diffraction (EBSD) and scanning electron microscope (SEM). The surface microstructures of GH202 before and after LSP were observed by transmission electron microscopy (TEM). The kinetic analysis shows the hot corrosion resistance for GH202 treated and untreated by LSP. The composition and morphologies of the surface and cross-section of the specimens were investigated further, using XRD, SEM, and energy dispersive spectroscopy (EDS) analyses. This study provides the basis for continued studies of the required materials and process of LSP modification.

2. Materials and Method

2.1. Materials and the Specimen Preparation

The Ni-based superalloy GH202 is used in stators of rocket engines, petroleum pipelines, and nuclear industries. The chemical composition of GH202 is shown in Table 1. The γ′ phases in GH202 after solution strengthening and aging treatment are mainly Ni (Al, Ti) and Ni (W, Mo) [12–13], and range in diameter from 20 nm to 40 nm. A small amount of stacking faults were observed, as shown in Fig. 1(a). A few annealing twins exist in the grains from the double dot electron diffraction pattern, as shown in Fig. 1(b).

The GH202 specimens (10 mm × 10 mm × 5 mm) were manufactured on by wire cut electrical discharge machining (WEDM). Prior to the LSP treatment, the surface of the specimens were ground from 600 to 1500 grade using SiC sandpapers, and then polished with nylon cloth. All of the specimens were then washed by an ultrasonic cleaner, washed with ethanol, and finally dried.

2.2. LSP Experiments

The LSP experiments were performed in a Q-switched Nd3+: YAG laser operating at 0.5 Hz repetition rate at a wavelength of 1.06 μm. A water layer 1–1.5 mm thick was used as the confining layer that prevented the diffusion of the high temperature plasma and increased the pressure of the shock wave. A professional Al tape, 150 μm thick, was used as an absorbing layer to protect the surface of the alloy from the ablation of high power laser beams [14]. The technological parameters of laser shock processing are shown in Table 2.

Table 1
Chemical composition of superalloy GH202.

Elements	Cr	Ti	Al	W	Mo	C	Ni
wt.%	20.39	2.02	1.38	5.62	4.08	0.06	Bal.

Table 2
The parameters of laser shock processing of GH202.

Parameters	Laser beam size (mm)	Pulse energy (J)	Pulse duration (ns)	Overlapping rate
Value	Φ5	18	30	50%

2.3. Test of the Residual Stress and Hardness

The electrochemical corrosion method was used to remove the surface of specimens treated by LSP. The residual stress of the peeled surface can be detected using a stress instrument (X-350A) with X-ray diffraction. The thickness of the treated specimen was controlled to reduce 30 μm by electrochemical corrosion to 450 μm. After corrosion, the residual stress of the surface was measured and recorded, and these data were used to obtain the distribution of the cross-sectional residual stress. In addition, the cross-sectional hardness of the specimens before and after LSP treatment was tested using a micro-hardness tester (HV-1000) with a load of 1.96 N for15 s.

2.4. Hot Corrosion Experiments

Several Al_2O_3 crucibles with the mixed powders (Na_2SO_4: NaCl = 3:1, mass ratio) were placed into a box-type furnace at 800 °C and 900 °C. After being heated for 1 h, the GH202 specimens with or without LSP treatment were added into the crucibles with the molten salts. The furnace was cooled to room temperature after 1 h, 3 h, 5 h, 7 h, 10 h, 12 h, 15 h, 17 h, or 20 h respectively, and the specimens were withdrawn from the crucibles and kept in air. The weight changes of the specimens with the corrosion layer cleaned were measured using a balance with an accuracy of 10^{-4} g.

2.5. Equipment and Methods for Measurement

The microstructures of the specimen surface of the untreated and LSP-treated samples were characterized by transmission electron microscopy (TEM). The cross-sectional microstructure was observed by electron backscattered diffraction (EBSD). The surface and cross-section morphologies of the specimens after hot corrosion were observed by scanning electron microscope (SEM) with energy dispersive spectrometer (EDS). The corrosion products on the surface of the specimens after

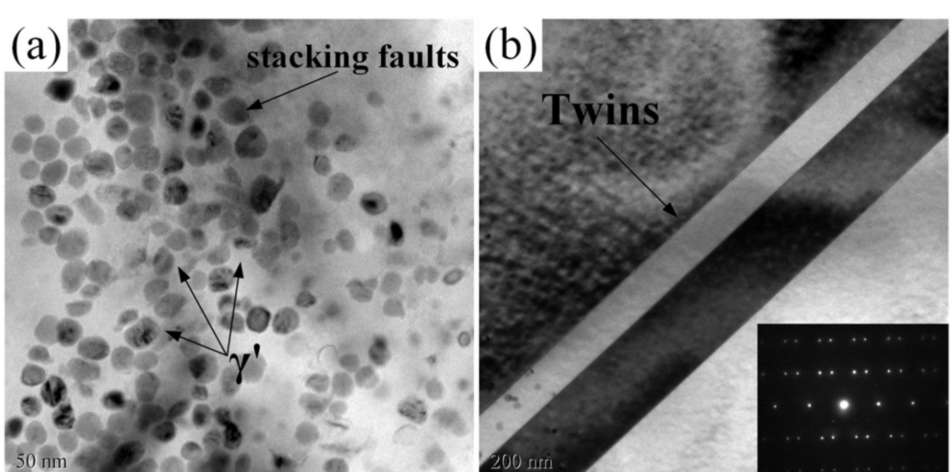

Fig. 1. TEM images of GH202 microstructures, (a) γ′ phase and stacking faults, (b) annealing twins.