Surface & Coatings Technology 321 (2017) 74–80

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

Crack appearance of a laser shock-treated single crystal nickel-base superalloy after isothermal fatigue failure

G.X. Lu [a,b], J.D. Liu [b,*], H.C. Qiao [c], T. Jin [b,*], X.F. Sun [b]

[a] University of Chinese Academy of Sciences, 19 Yuquan Road, Beijing 100049, China
[b] Institute of Metal Research, Chinese Academy of Sciences, 72 Wenhua Road, Shenyang 110016, China
[c] Shenyang Institute of Automation, Chinese Academy of Sciences, 114 Nanta Road, Shenyang 110016, China

ARTICLE INFO

Article history:
Received 30 November 2016
Revised 15 April 2017
Accepted in revised form 18 April 2017
Available online 23 April 2017

Keywords:
Nickel-base superalloys
Laser shock processing (LSP)
Fatigue
Fracture

ABSTRACT

Isothermal fatigue testing was conducted on single crystal nickel-base superalloys. Distinct cracking behaviors were found to occur in the specimens treated by different laser shock processing (LSP) technologies. A crack generally initiates from the casting micropore. For the well surface strengthened specimens suffered high laser shock intensities, the crack initially grows along one or more of the {111} planes and falls on the edge of the cylindrical specimen. For the poorly strengthened specimens, the final fracture area is usually located inside.

1. Introduction

Long life and high reliability have gradually become the basic properties of most industrial parts with the increase of service requirements. Surface strengthening treatment is a feasible and effective method achieving this goal. Compared with other processes in terms of performance improvement, laser shock processing (LSP) is a relatively new surface treatment technique [1–4]. Single crystal nickel-base superalloys are extensively used in gas turbine engines. As an important aspect of superalloy applications, fatigue in high temperature has drawn many attentions [5,6]. However, in the literature to date, few of it reports the effect of LSP treatment on isothermal fatigue performance of single crystal nickel-base superalloys.

This work is part of an ongoing effort to study the fatigue mechanism of a laser shock-treated single crystal nickel-base superalloy in the future. The present study is undertaken to develop a fundamental understanding of the effects of LSP treatment on the fatigue crack appearance in a single crystal nickel-base superalloy.

2. Experimental procedure

The nominal chemical composition of the selected single crystal nickel-base superalloy was Ni, 7-9Co, 6-8Cr, 4-6W, 6-8Al, 2-4Mo, 6-8Ta and 3-4Re, in wt%. The related heat treatment was carried out on the experimental alloy as follows: homogenization (1300 °C/2 h + 1310 °C/2 h, air cooling (AC)) and two-step annealing (1130 °C/4 h, AC + 900 °C/16 h, AC) [7]. Solid cylindrical specimens 6 mm in diameter and 15 mm in length were used and their longitudinal axes were parallel to the [001] direction. In current study, the technology parameters of LSP treatment were similar to those of the publications [7,8], and the only difference was that the pulse energy was set as 6 J. For the fatigue test pieces, the LSP treatments with overlapping rate of 50% as shown in Fig. 1 were carried out. Additionally, Fig. 1 shows the used pulse sequence [9,10]. In this strategy, the treatment is started in one edge and finished in the other edge. The test pieces were processed along different longitudinal paths to achieve full coverage.

Isothermal fatigue testings were conducted under mechanical stress control in the 700 °C, and all testings were implemented with a stress ratio of $R = \sigma_{min}/\sigma_{max} = 0.1$. The isothermal fatigue behaviors of the single crystal superalloys were investigated in two distinct conditions, which would be referred to as (i) the well strengthened condition and (ii) the poorly strengthened condition. The well strengthened condition corresponded to material which, prior to the isothermal fatigue testing, was treated by LSP with 2 impact times and 6 J in laser pulse energy. The poorly strengthened condition corresponded to testings for which the material was suffered to 1 impact time. The Vickers hardnesses of the specimens treated by different LSP technologies were measured to denote the varied surface strengthen effects.

After the testings, the ruptured fatigue specimens were sectioned parallel to the longitudinal axes for microstructural investigations. These samples were prepared by the usual metallographic procedures

* Corresponding authors.
E-mail addresses: luguoxin@live.cn (G.X. Lu), jdliu@imr.ac.cn (J.D. Liu), tjin@imr.ac.cn (T. Jin).

http://dx.doi.org/10.1016/j.surfcoat.2017.04.044
0257-8972/

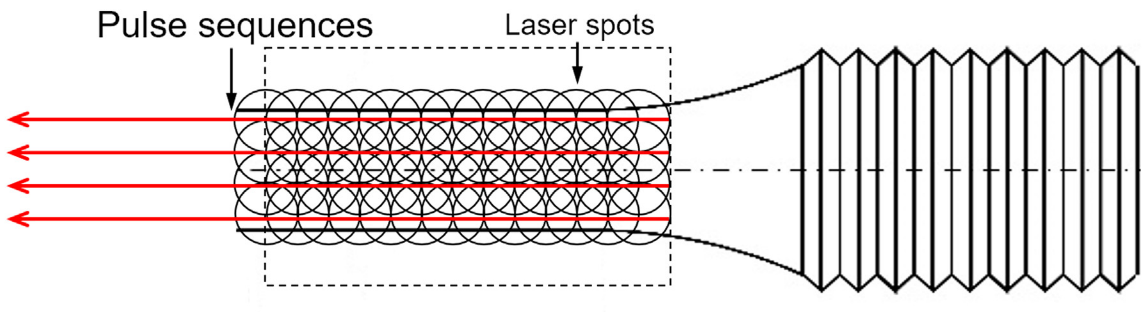
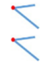
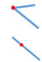
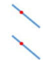
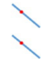
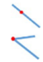


Fig. 1. Schematic of the selected strategy for LSP treatment.

Table 1
Material data of the isothermal fatigue test specimens.

Group	Specimen	σ_{max} (MPa)	N (cycles)	Fracture initiation type	Active slip planes	Fatigue initiation	Final fracture	
							Site	Area fraction
LSP1	2	600	1.5e5		4	Micropore	Inner	≈1/4
	3	500	3.8e5		4	Micropore	Inner	≈1/12
	4	460	1.2e6		1	Micropore	Implicit	–
LSP2	7	550	1.7e5		2	Micropore	Edge	≈1/3
	1	500	4.1e5		2	Micropore	Edge	≈1/5
	5	460	9.7e6		3	Micropore	Edge	≈1/10

(grinding and mechanical polishing) and analyzed using scanning electron microscopy (SEM).

3. Results

3.1. The isothermal fatigue behavior

Results for the isothermal fatigue behaviors of the selected single crystal superalloys are given in Table 1. As seen in Table 1, the poorly strengthened specimens (LSP1) have a lower number of cycles to failure for the given maximum stresses compared to the well strengthened specimens (LSP2), despite the narrow margins in fatigue life for the two slightly higher maximum stresses.

3.2. Crack initiation and fracture surface appearance

The general fracture appearances of the selected single crystal superalloy during the isothermal fatigue can be seen in Fig. 2. The fracture surfaces of different specimens are purely crystallographic and occur along one or more of the {111} planes, meaning that the deformation

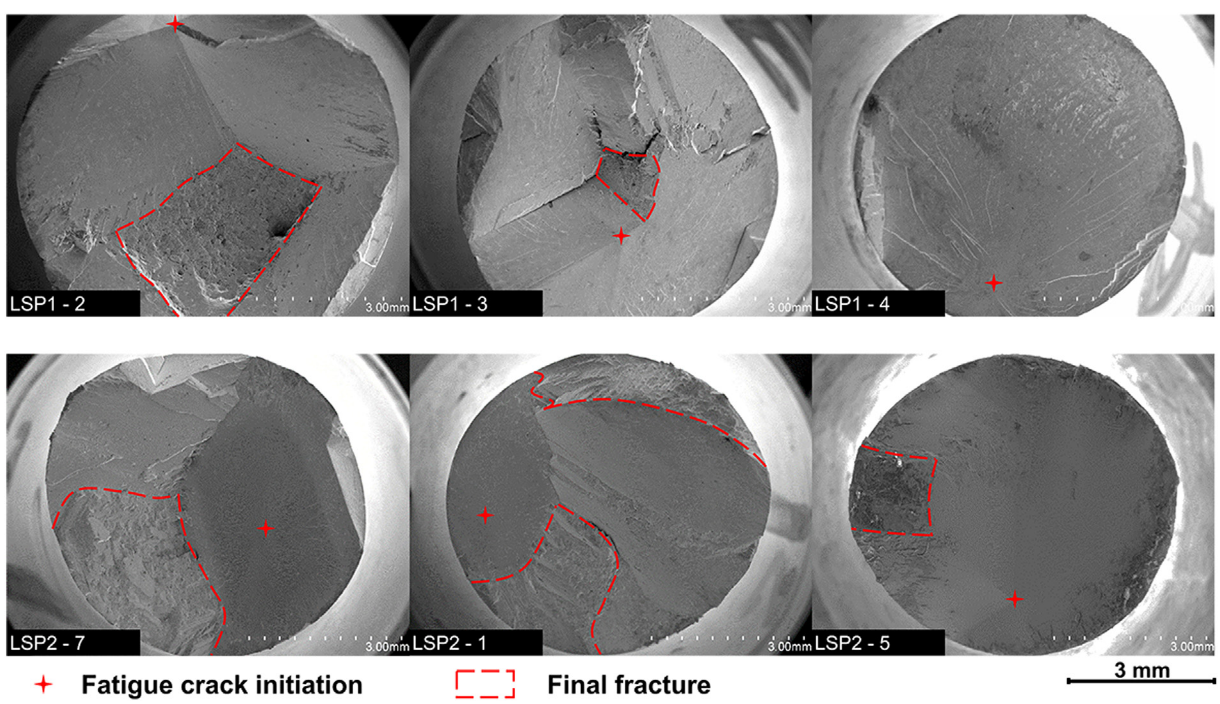


Fig. 2. Fracture surface of the failed fatigue specimens. Graphical representation showing the fatigue crack initiation sites and the final fracture regions respectively.