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High Temperature Low Cycle Fatigue Behavior of GH4742 Alloy

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Abstract: High temperature low cycle fatigue tests on GH4742 superalloy were studied under the total strain-controlled conditions at 650 ℃. Combined with fatigue test data, fatigue properties of the alloy were analyzed. Fracture morphology and dislocation structure were observed by scanning electron microscopy and transmission electron microscopy. The results showed that fatigue life and fatigue resistance of GH4742 alloy decreased significantly with increasing total strain amplitude. The cyclic hardening, cyclic softening and cyclic stability phenomena of the alloy occurred during the low cycle fatigue process. The increasing total strain amplitude is conducive to the formation of γ' phase. Fatigue crack propagation is controlled jointly by ductile and brittle fracture. Inhomogeneous deformation and deformation restricted in slip bands are the main reasons for the reduction of fatigue life of GH4742 alloy.

Key words: superalloy; low cycle fatigue; cyclic hardening; cyclic softening; fracture morphology; dislocation structure

With the development of aviation industry, further improvement of thrust-weight ratio is an important trend in engine development. Higher requirements are put forward for rotating components with high-temperature bearing capacity used in new engines with high thrust-weight ratio such as turbine disks and turbine blades. Turbine disk is one of the most important rotating components in aero-engines, whose materials must possess high temperature strength, thermal fatigue resistance and corrosion resistance and thus can adapt to the reliable working requirements under harsh conditions such as high pressure, high speed, high temperature and corrosion. Ni-base superalloys perform well due to their excellent heat resistance, high temperature oxidation resistance, corrosion resistance, excellent creep resistance, good fatigue resistance and fracture toughness properties at high temperature. Ni-base superalloys become the key materials of high temperature components such as aero-engine combustion chambers, turbine blades, vanes, turbine disks[1]. Strain-controlled high-temperature low cycle fatigue (LCF) damage resulted from the effects of high temperature and alternating loading for a long time is the key failure mode of high temperature components[2]. The fatigue cracks gradually initiate and rapidly propagate from one part of components under high temperature oxidation corrosion conditions, which seriously reduced components service life[3,4]. Thus, the low cycle fatigue of superalloy has become a research hot spot in recent decades. Extensive researches have been conducted about the effects of cyclic frequency, strain rate, strain range, holding period, predeformation, corrosive environment and testing temperature on high temperature low cycle fatigue[5-14]. The fatigue life of GH4742 alloy depends not only on the testing temperature but also on total strain amplitude under high temperature low cycle fatigue conditions. Though a lot of studies on GH4742 alloy have been carried out, its physical nature has not been completely revealed so far. Thus, accidents, caused by low cycle fatigue damage, cannot be prevented fundamentally due to the complexity of high temperature low cycle fatigue phenomenon.

GH4742 alloy possesses high oxidation resist-

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ance, corrosion resistance, persistent strength and fatigue resistance. It is mainly used for aircraft engine turbine disks, deflectors, compressor disks and bearing rings in the temperature range of 550—800 ℃. Researches on high temperature low cycle fatigue behavior of GH4742 alloy have not been reported, and thus it is of great significance to study strain-controlled low cycle fatigue behavior of GH4742 alloy. In this work, in order to study the effect of total strain amplitude on cyclic mechanical response and microstructure of GH4742 alloy, high temperature low cycle fatigue tests were carried out under the total strain-controlled conditions at 650 ℃. Combined with fatigue test results, fatigue properties of the alloy were explored. Fracture morphology and dislocation structure were observed by scanning electron microscopy (SEM) and transmission electron microscopy (TEM) so as to investigate the fracture mechanism of low cycle fatigue.

1 Experimental

Experimental materials are obtained from large size turbine disk of GH4742 alloy. The chemical composition of GH4742 alloy is listed in Table 1. The procedure of heat treatment was as follows: 1100 ℃/8 h, AC+1000 ℃/4 h, AC+775 ℃/16 h, AC+700 ℃/16 h, AC (AC means air cooling).

Standard low cycle fatigue specimens were machined from heat-treated specimens of 6.360 mm in diameter and 60 mm in gauge length. Low cycle fatigue tests were conducted on an MTS NEW 810 fatigue testing machine through induction heating, and the temperature was controlled at 650 ℃. The total axial strain was measured and controlled by an extensometer mounted upon the ledges of the specimens. The total strain range varied from 0.3% to 0.7% with a fully reversed strain-controlled push-pull mode, i.e., $R=-1$. The loading frequency of 0.50 Hz was applied in a triangular waveform. All specimens were run to failure. In order to determine the fatigue fracture mechanism, the fracture morphology of fatigue failure specimens were observed by SEM. Specimens for TEM were obtained from thin slices (500 μm in thickness) at a distance of 1 mm away from the fracture surfaces of the failed specimens. Thin slices were ground to about 70 μm and then prepared by twin-jet electrolytic thinning.

Table 1 Chemical composition of GH4742 superalloy mass%

Element	C	Cr	Co	Ti	Al	Mo	Nb	Ni
Experiment	0.06	14.0	9.95	2.52	2.54	5.12	2.60	Balance
Standard	0.04—0.08	13.0—15.0	9.0—11.0	2.4—2.8	2.4—2.8	4.5—5.5	2.4—2.8	Balance

2 Results and Discussion

2.1 Low cycle fatigue properties

The fatigue test results are shown in Table 2. It shows that the fatigue life of alloy GH4742 significantly reduces and anti-fatigue performance significantly drops with increasing strain amplitude.

Table 2 Low cycle fatigue test results of GH4742 alloy

$\Delta\varepsilon_t/2$	$\Delta\varepsilon_e/2$	$\Delta\varepsilon_p/2$	$2N_f$
0.003	0.00295	0.00004	93626
0.004	0.00376	0.00023	16802
0.005	0.00414	0.00084	2702
0.006	0.00324	0.00275	1102
0.007	0.00386	0.00211	344

Note: $\Delta\varepsilon_t/2$—Total strain range; $\Delta\varepsilon_e/2$—Elastic strain range; $\Delta\varepsilon_p/2$—Calculated plastic strain range; $2N_f$—The number of cycle to fatigue.

The Manson-Coffin relationship is always used to describe the strain-controlled low cycle fatigue behavior. The total strain range can be separated into the elastic and plastic strain ranges and expressed by Eq. (1) combined with the Manson-Coffin relationship and Basqin relationship as below[15]:

$$\frac{\Delta\varepsilon_t}{2}=\frac{\Delta\varepsilon_e}{2}+\frac{\Delta\varepsilon_p}{2}=\frac{\sigma'_f}{E}(2N_f)^b+\varepsilon'_f(2N_f)^c \qquad (1)$$

where, σ'_f is the fatigue strength coefficient; b is the fatigue strength exponent; ε'_f is the fatigue ductility coefficient; c is the fatigue ductility exponent; E is the Young's modulus of GH4742 alloy at 650 ℃.

σ'_f and b characterize the mechanical properties of the material at the elastic deformation stage and their effects on the fatigue life of the material during the fatigue test process. ε'_f and c characterize the plastic deformation in the deformation stage and their effects on the fatigue life of the material. It can be inferred that the fatigue life of the material is mainly affected by the stress loading at the elastic deformation stage and plastic strain loading at the plastic deformation stage during the fatigue test process.

The relationship curves of the total, plastic and

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