Effect of Temperature on High-Cycle Fatigue Behavior of A W-rich Nickel-Based Superalloy

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Abstract: The influence of temperature on the high-cycle fatigue behavior of a W-rich nickel-based superalloy has been comprehensively investigated. Results indicate that dislocations predominantly slip within the matrix channels forming dislocation networks and deformation dislocations shear the γ′ phase. With an increase in the applied temperature, the dislocation density within the matrix channels escalates, and dislocation pairs shearing the γ′ phase were evident at 1000°C. Additionally, fatigue initiation primarily occurs at micropores located on the alloy's surface and subsurface. This leads to the formation of slip lines with varying orientations in the crack propagation area. These slip lines tend to converge at locations such as eutectics, carbides, and grain boundaries, which facilitates crack initiation. As fatigue advances, cracks propagate through the interdendritic region, culminating in cleavage fractures within the instantaneous fracture zone.

Keywords: W-rich nickel-based superalloy; High-cycle fatigue; Deformation mechanism; Fracture characteristics; Microstructure

1 Introduction

Nickel-based superalloys are pivotal in the fabrication of high-temperature components, notably in advanced aero-engines and gas turbines [1]. In challenging high-temperature environments, the interplay between temperature and oscillating loads significantly contributes to high-cycle fatigue damage, leading to the deterioration of these materials [2]. Recent studies indicate that the high-cycle fatigue properties of alloys are intrinsically linked to their chemical composition, microstructural characteristics, and metallurgical defects [3]. Typically, fatigue cracks in nickel-based superalloys initiate and propagate predominantly on the alloy surface, subsurface regions, and at carbides [4]. The fatigue fracture is conventionally characterized by a fatigue source, a fatigue zone, and a rapid failure zone [5]. Owing to the unforeseen nature of fatigue fractures that can lead to severe mishaps, studying the fatigue behavior of blade materials holds profound implications for alloy design and life expectancy predictions [6]. The alloy under investigation is a high-tungsten nickel-based superalloy, distinguished by its superior thermal corrosion resistance and thermal fatigue resilience. This study focuses on evaluating the impact of temperature on the high-cycle fatigue behavior of the high-tungsten Ni-based alloy.

2 Experimental procedure

Using a 10 kg vacuum induction melting furnace, a W-rich master ingot was remelted and subsequently cast into an equiaxed crystal test bar. The alloy's nominal composition (by mass fraction) was as follows: C 0.13%, Cr 4.90%, Co 6.82%, Nb 2.06%, Al 5.75%, W 16.3%, Ti 1.00%, Hf 1.00%, with the remainder being Ni. The specimens underwent high-frequency axial fatigue testing under controlled loads using the PLG-100C fatigue testing machine. The testing parameters included experimental temperatures of 800 ℃, 900 ℃ and 1000 ℃, an applied frequency of approximately 140 Hz, a stress ratio (R) of -1, and a sinusoidal loading wave.

3 Result and discussion

The relationship between high-cycle fatigue stress and fatigue life for the alloy under varying temperature conditions is illustrated in Fig. 1. The fatigue limits of the alloy at 800°C, 900°C, and 1000°C were calculated to be 196 MPa, 207 MPa, and 186 MPa, respectively.

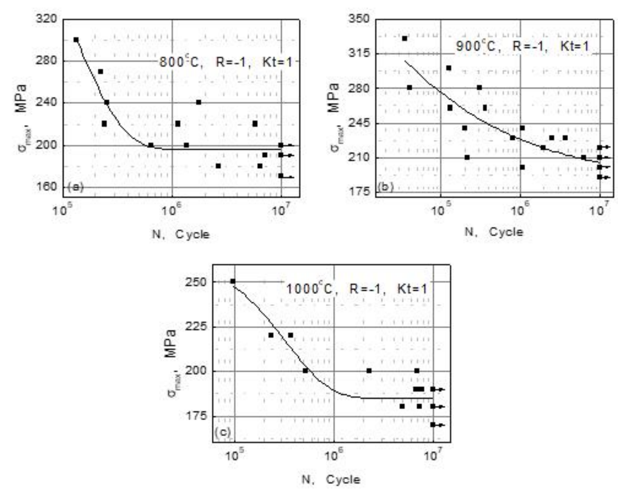

Fig. 1 High-cycle fatigue S-N curve of the alloy at different temperature: (a)800 °C, (b)900 °C and (c)1000 °C

The SEM morphology of high-cycle fatigue-fractured specimens at different temperature is presented in Fig. 2. The fracture of the alloy is relatively flat, and there is loose aggregation at the fatigue source. The massive M_6C carbide remain with the micro-cracks at the fracture. On the other hand, more slip traces remain in the eutectic and the cracks extend along the eutectic interface.

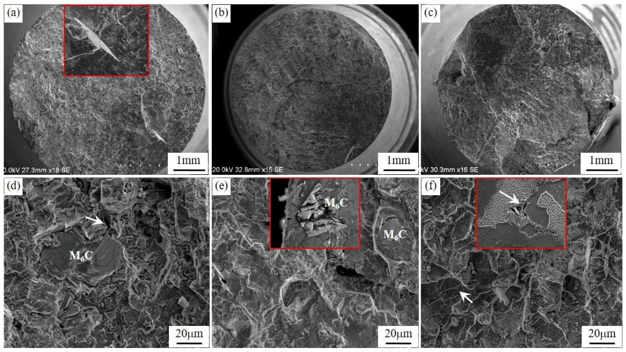

Fig. 2 SEM morphology of the alloy after high-cycle fatigue fracture at different temperature: (a)(d)800 °C, (b)(e)900 °C and (c)(f)1000 °C

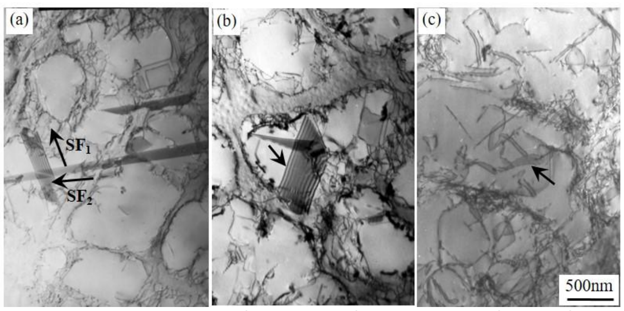

Fig. 3 TEM morphology of the alloy after high-cycle fatigue fracture at different temperature: (a)800 °C, (b)900 °C and (c)1000 °C

The TEM morphology of high-cycle fatigue-fractured specimens at different temperature is presented in Fig. 3. The results indicate that deformation dislocations predominantly slipped within the γ matrix channels forming dislocation networks or tangles and shear the γ′ phase forming stacking faults. At a temperature elevation to 1000°C, the deformation mechanism transitioned from stacking fault formation to dislocation pairs.

4 Conclusion

1. At temperatures of 800°C, 900°C, and 1000°C, and a stress ratio of R=-1, the high-cycle fatigue limit of the W-rich Ni-based alloy was measured at 196 MPa, 207 MPa, and 186 MPa, respectively.

2. Deformation characteristics during high-cycle fatigue revealed that, deformation dislocations predominantly slipped within the γ matrix channels forming dislocation networks or tangles and shear the γ′ phase forming stacking faults. At a temperature elevation to 1000°C, the deformation mechanism transitioned from stacking fault formation to the generation of dislocation pairs.

3. The principal fatigue source originated from micro-pores located on and beneath the alloy's surface. Slip lines of diverse orientations were identified within the crack propagation zone, converging notably at the eutectic, carbide, and grain boundaries.

Acknowledgments

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