SMALL CRACK GROWTH BEHAVIORS AND CLOSURE EFFECTS IN A NICKEL-BASE POWDER METALLURGY SUPERALLOY AT HIGH TEMPERATURE

Xiaoguang Yang*, Qinzheng Yang

Energy and Power Engineering School, Beihang University, Beijing, China
** Presenting Author email: yxg@buaa.edu.cn*

Abstract

Crack closure effects play an important role in dominating small crack propagation behaviors, which were rather less well investigated, especially at high temperature in the air. Based on photomicroscopy and digital image correlation, small crack growth behaviors and growth rates are investigated both at 600℃ and RT in air for a Powder Metallurgy superalloy, then the crack displacement fields are measured. Two max. stress levels and two stress ratios are considered in order to understand their effects on small crack growth behaviors. The experimental results reveal the crack growth behaviors ranged from 80 μm to ~1000μm. With the help of EBSD at the grains of the crack growth path, links of this particular growth behaviors with the microstructure features, such as the orientation, grain boundary, are discussed. Using DIC-measured crack opening displacement with the crack growth, the roles of oxides and roughness induced crack closure in early small crack propagation at high temperature are analyzed. Finally, a crack closure model is proposed including the combined effects of oxide-induced, roughness-induced and plasticity-induced crack closure (OICC, RICC and PICC).

1. Introduction

Nickel-base powder metallurgy superalloys have been widely used in manufacturing turbine disks. Inherent defects in P/M superalloys, i.e., non-metallic inclusions, frequently serve as the preferred origin of fatal crack, especially under fatigue loading. Those defects are always so small that the initiated crack will experience the small crack growth phase first. Small crack propagation behaviours at room temperature were reported in many metallic materials. However, studies on small crack behaviours in superalloys at high temperature in air are rather limited. To reveal the propagation rate and closure behaviours of small cracks (0.06~1.0mm) in a P/M superalloy FGH96, small crack propagation experiments and full-field displacement measurements based on digital image correlation (DIC) were carried out at 600℃ in air using an in-situ high temperature experimental system. Crack opening displacement was measured and opening stress intensity factor (SIF) was calculated. The all efforts are devoted to reveal the complex small crack growth behaviors and understand the mechanism with the microstructure features, and finally to develop a physically-based crack closure model.

2. Results

Small crack propagation and displacement measurement experiments were carried out based on photomicroscopy. High-temperature stable mesoscale speckles were acquired by applying laser surface roughness modification. A rounded rectangular-shaped surface crack initiator (~65um) was fabricated on the gauge surface. In COD measurement, the speckle pattern was fabricated around the crack initiator.

Small crack growth rates were shown in Fig.1. No discernible difference between overall crack growth rates with R=0.1 and R=0.3 was observed. This is consistent with our previous room temperature study in which crack closure is accounting for the effects of stress ratios.

RICC also played a role in determining crack closure levels at high temperature in air. As shown in Fig.3, the delayed opening of the crack face, which arose from RICC, was directly observed. The randomness of RICC contributed to the oscillation of Kop at the early growth stage. Plasticity induced crack closure (PICC) appeared to continue arising and dominating the crack closure after its values exceed the underlying closure induced by RICC and OICC. Therefore, Kop increased monotonously finally.

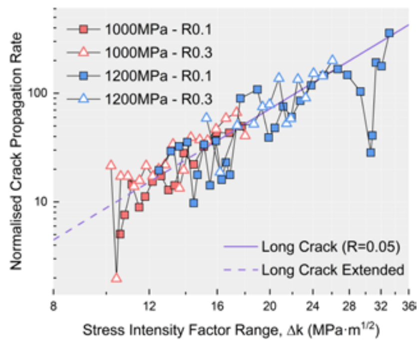

Fig.1 Small crack growth rates at 600℃ in air

Fig.2 (a) shows the measured full-field displacement at 86000cycles. CODs were measured at 10, 20 and 30 pixels behind the left and right crack tips. Based on CODs, opening SIF (K_{op}) was calculated, as shown in Fig.2 (b). Values of opening SIF oscillated with the crack propagation until 84000cycles after which it increased monotonously. This indicates the alternation of the closure mechanism. Based on oxidation dynamics, the theoretical K_{op} range by OICC was calculated (shaded area in Fig.2 (b)). It overlapped the lower value region of K_{op}s, indicating OICC constitutes the base value of K_{op}.

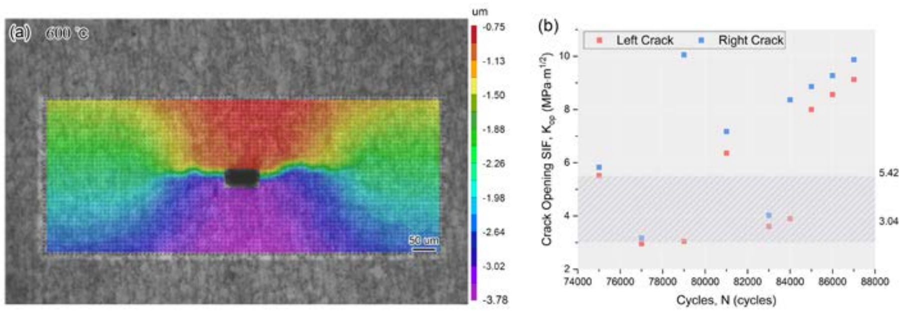

Fig.2 Small crack full-filed displacement at 86000cycles (a) and opening SIF(b). (Shaded area in (b) represents the theoretical calculated Kop by OICC)

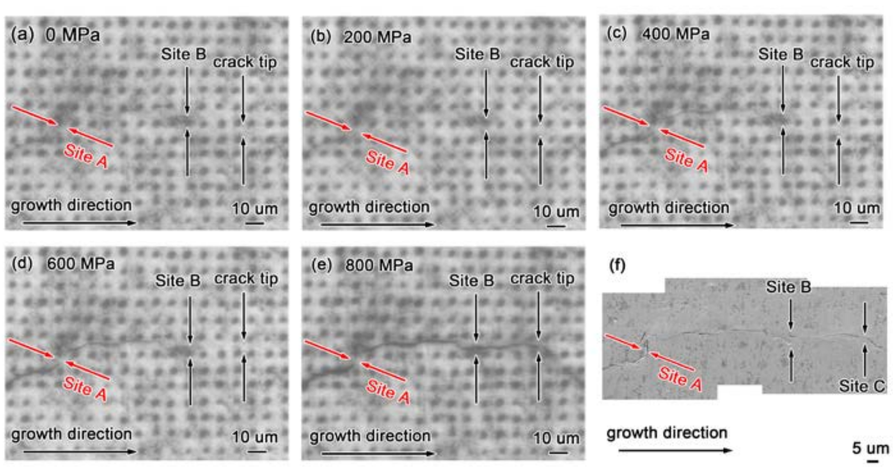

Fig.3 The delayed opening of crack face at Site-A (a-e) and SEM image (f)

3. Conclusions

The small crack growth behaviors are investigated experimentally at 600℃, which exhibit the zig-zag propagation path that are mainly controlled by the slip in grains at crack tip and grain boundary. Meanwhile, the experimental results reveal a regular crack propagating and arresting regardless of stress levels and stress ratios. Based on the DIC-measured displacement field and crack opening displacement, the closure mechanisms and evolution are discussed. At the first, stress ratios have little effects on the crack closure, secondly, OICC level is low, but consist of a basic part of Kop. The delayed opening of the crack face indicates RICC existed, combined with OICC, which mainly contributed to Kop at the early propagation stage. Eventually, the transition length concept was proposed and the small crack closure level and its evolution were modelled.

Acknowledgements
This work was supported by the National Science and Technology Major Project (2019-IV-0017-0085); the National Natural Science Foundation of China (Grant Nos. 12172021, 52105156).