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# LCF behavior and life modeling of DZ125 under complicated load condition at high temperature

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**Abstract** Based on the author and co-worker's systemically experimental investigation on low cycle fatigue (LCF) of directionally solidified (DS) Ni-based superalloy DZ125 at 850 and 980℃, LCF behavior analysis and life modeling are carried out here, where the influence of temperature, strain ratio, stress concentration, dwell types and dwell times on fatigue resistance is considered. (1) The steady cyclic stress/strain response is captured based on the transversely isotropic continuum elastic-viscoplasticity model. (2) For the coherent face centered cubic (FCC) structure of DS Ni-based superalloy DZ125, it is physically motivated to consider slip planes as critical plane under fatigue load, the mean stress modified Smith-Watson-Topper (SWTM) parameter $\Delta\gamma_{max}\cdot(\tau_{max}+\tau_m)/2$ on the discrete crystallographic slip planes is evaluated. The combination of the theory of critical distance and critical plane method exhibits acceptable predicted LCF life affected by stress concentration. (3) Based on SWTM parameter, Miner's linear cumulative damage theory and Larson-Miller plots, accurate life prediction on smooth LCF with complicated dwell forms is gotten. However, to predict the LCF life affected by dwells and stress concentration, the critical distance concept and the average processed creep stress is introduced, which shows acceptable accuracy of predicted LCF life.

**Keywords** Low cycle fatigue, Dwell times, Stress concentration, Theory of critical distance, Critical plane method

## 1 Introduction

Ni-based DS superalloy is increasingly being applied for turbine blades in high performance aircraft engines for superior creep and fatigue strength at high temperatures [1]. Turbine components work in harsh and vibration environments, such as increased operating temperatures, existed cooling holes on blades and vanes; dwell effects is also introduced by start-up, operation, and shut-down sequences. So life modeling of hot sections components of gas turbines is complicated by the presence of stress concentration, dwell times, elevated temperature. However, much more interest has been still precipitated in developing models to obtain accurate predicted service life for costly inspecting, servicing, and replacing of damaged components [2].

According to the literature survey, critical plane based life models and theory of critical distance are typical methods developed for predicting continuous smooth and notched LCF life of DS superalloy. Critical plane methods are originally developed for multi-axial fatigue; this method could predict not only the fatigue life but also the location and direction of the crack. With well-defined crystallographic slip planes of DS superalloy, the plastic flow takes place along the slip planes and eventually persistent slip bands start to appear, which might act as fatigue crack initiation location. So it is physical based to consider crystallographic slip planes as critical planes. Up to now, lots of critical plane approaches, such as stress based, strain based or energy based models, have been proposed [3]. Arakere and Swanson [4], Naik [5] considered the octahedral and cube slip planes as critical planes, and then correlated damage parameters on these planes with LCF behavior of PW1480/1493 and HCF behavior of PW1484. The results showed that damage parameters on critical plane were partly promising. Moreover, life prediction using the maximum peak stress or strain is often conservative for characterizing the fatigue life affected by stress concentration. The theory of critical distance is proposed by Neuber [6] and Peterson [7], who assumes that fatigue damage cannot be correctly estimated except the entire stress or strain field damaging the fatigue fracture process zone is taken into account, this method has been successfully applied to predict the fatigue life with different load conditions from the LCF to HCF region. However, lots of work still needs to be done on evaluating the accuracy and reliability of more materials systematically. For the FCC structure of DS and single crystal (SC) superalloy, when the notched component is subjected to cyclic load condition, the combination of critical plane and critical distance method is an interesting attempt. Up to now, lots of work following this combined theory has been carried out. Based on the elastic-plastic finite element analysis (FEA), Zhang Li et al [8] obtained the stress/strain condition at notch root, but just the critical plane method and isotropic material is evaluated； Zhufeng Yue et al [9] considered the slip planes as critical planes and assumed the mean stress modified resolved shear stress range as fatigue damage parameter, this method shows good prediction ability of SC superalloy DD3, but critical distance concept was not evaluated. Especially, Leidermark et al [10] carried out notch fatigue investigation on SC superalloy MD2, they found that conservative predicted life will be obtained if only the slip systems based critical plane method was adopted, but obvious improvement could be seen when the critical distance concept is introduced.

Meanwhile, when considering the influence of dwell times, not only the individual effects of fatigue and creep damages, but also effect of their interaction should be considered. Continuum damage mechanics (CDM) method [11] is a traditional one for fatigue life prediction affected by dwells. However, a simply and efficient approach is Miner’s linear cumulative damage theory [12], where the creep damage could be determined by the classic Larson-Miller plots [13].

DZ125 is DS superalloy exhibits excellent high temperature thermo-mechanical properties. For the typical load condition of turbine blades, much more interest of our research group on DZ125 has been precipitated on experimental investigation, constitutive modeling and life prediction, which mainly consider the influence of temperature, strain ratio, stress concentration, dwell types and dwell times. Although lots of research of DZ125 has been carried out [14, 15], life modeling of LCF on smooth and notch components with and without dwells are still needed. Therefore, based on the experimental investigation of DZ125 [16-18] at high temperatures, one purpose of this study is focused on LCF behavior analysis. The other purpose seeks to develop acceptable approaches for predicting the LCF life under complicated load condition. The slip systems based critical plane method, combined with critical distance concept and Miner's linear cumulative damage theory are adopted to evaluate their feasibility on those complicate load condition.

## 2 LCF behavior of DZ125 at elevated temperatures

The chemical compositions (wt %) of DZ125 are 0.07-0.12C, 8.4-9.4Cr, 9.5-10.5Co, 6.5-7.5W, 1.5-2.5Mo, 4.8-5.4Al, 0.7-1.2Ti, 3.5-4.1Ta, 0.01-0.02B, 1.2-1.8Hf and balanced Ni. The alloy roughcast is melted in vacuum induction furnace, the solution and aging heat treatment procedure is as follows: 1180℃/2h +1230℃/3h/AC +1100℃/4h/AC +879℃/20h/AC (AC means air cooling). As shown in Fig. 1, the microstructure of DZ125 superalloy mainly contains γ-matrix and γ' -reinforced phase. Up to now, the author and co-worker have carried out systemically experimental investigation work on low cycle fatigue (LCF) tests of DZ125 at high temperatures. As is shown in Table 1, the experimental work is focused on exhibiting the influence of temperature, strain ratio, stress concentration, dwell types and dwell times on fatigue resistance. It is worth notice that the expression of dwell forms, such as $T_t/T_c$, means holding $T_t$ seconds at tensile peak and $T_c$ seconds at compressive peak. Smooth round bar, U-type and O-type notched plate specimens were adopted, their geometries are shown in Fig. 2. Corresponding experimental results is shown as follows.

### 2.0 Cyclic stress response

Cyclic stress response at 850 and 980℃ at longitudinal (L) orientation is shown in Fig. 3, the cyclic stress range changes obviously at the early cycles for each strain range, and then tends to be stable soon. The strain range related cyclic hardening behavior is observed at 850℃, the larger the strain range is, the more obvious cyclic hardening phenomenon happened. However, this material also seems to be strain range independent slight cyclic softening at 980℃. Those cyclic behaviors observed above are similar to that of Ni-based superalloy CM247LC [2].

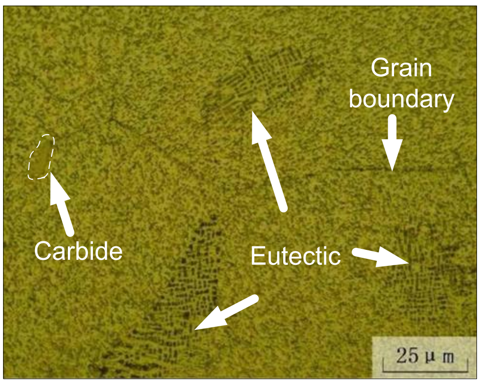



Fig. 1 Microstructure of DZ125 after heat treatment

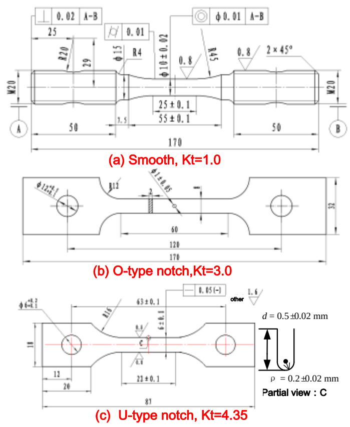



Fig. 2 Geometries and dimensions of specimens

Table 1 LCF test matrix of DZ125 at high temperature

| Affected factors of LCF | | Specimen type | Temperature | Load ratio | Load direction | Strain or stress range(MPa) | Hold times |
|---|---|---|---|---|---|---|---|
| Temperature | | Round | 850 | -1 | L | ±0.5%, ±0.55%, ±0.6%, ±0.7%, ±0.8% | 0/0 |
| | | | | | T | ±0.8% | 0/0 |
| | | | | | 45 | ±0.8% | 0/0 |
| | | | 980 | -1 | L | ±0.3%, ±0.35%, ±0.4%, ±0.6%, ±0.8%, ±1.0%, ±1.5% | 0/0 |
| Strain ratio | | Round | 980 | 0 | L | 0.6%, 0.8%, 1.0%, 1.2%, 1.4%, 1.6% | 0/0 |
| Strain hold | Tensile hold | Round | 850 | -1 | L | ±0.8% | 60/0,120/0,300/0 |
| | | | 850 | 0 | | 1.60% | 60/0,120/0,300/0 |
| | | | 980 | -1 | | ±0.35%, ±0.4%, ±0.6%, ±0.8%, ±1.0% | 60/0 |
| | | | | | | ±0.6% | 120/0,300/0 |
| | | | 980 | 0 | | 1.20% | 60/0,120/0,300/0 |
| | Compression hold | Round | 980 | -1 | | ±0.35%, ±0.4%, ±0.6%, ±0.8%, ±1.0% | 0/60 |
| | Balanced hold | Round | 980 | -1 | | ±0.35%, ±0.4%, ±0.6%, ±0.8%, ±1.0% | 30/30 |
| Stress hold | Tensile hold | Round | 850 | 0 | L | 0-560 | 0/0,1/0,60/0,120/0,240/0 |
| | | | 980 | 0 | | 0-260 | 0/0,1/0,60/0,120/0,240/0 |
| Stress concentration | | U-type notch plate | 850 | 0.1 | L | 40-400,50-500,60-600,70-700 | 0/0 |
| | | O-type notch plate | | 0.05-0.1 | | 42-500,21-489,21-411,16-372,17-320 | 0/0 |
| Both stress concentration and stress hold | | O-type notch plate | 850 | 0.05-0.1 | L | 25-412,25-375,25-322 | 120/0 |

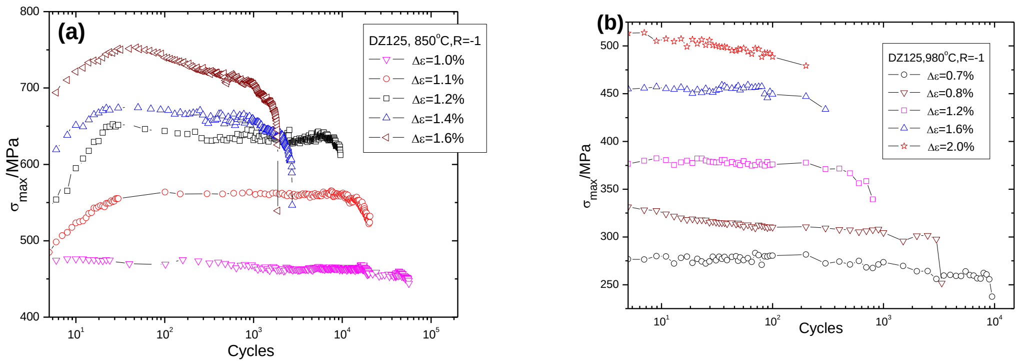



Fig. 3 The cyclic stress response curves, (a) 850°C, (b) 980°C

## 2.1 Effect of temperature and stress ratio on LCF

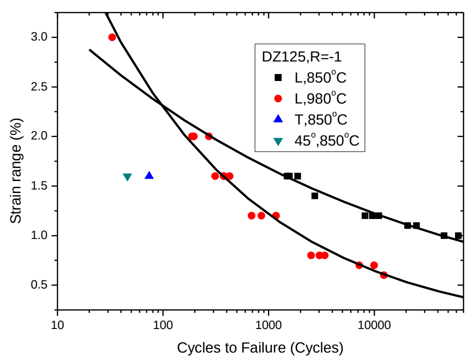



Fig. 4 The influence of temperature and load orientation on LCF

LCF results at 850 and 980°C are shown in Fig. 4. Generally, fatigue life at 850°C is larger than that at 980°C, the fatigue resistance at transverse and 45 ° orientation is much lower than longitudinal orientation. However, there existing an obvious transition life at short life region, the potential reason may be due to the different cyclic stress response at 850 and 980°C. Although slight cyclic softening phenomenon is happened at 980°C, obvious cyclic hardening phenomenon is happened at 850°C, especially at high strain range (short life region), so maybe the competition between the cyclic hardening induced increased stress and temperature leads to the transition life. All the solid lines in figures are fitted by a power fitting function, $f(N)=aN^b$.

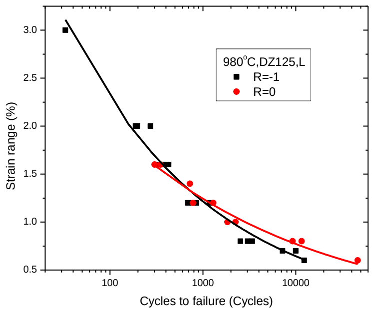



Fig. 5 The effect of stress ratio on LCF

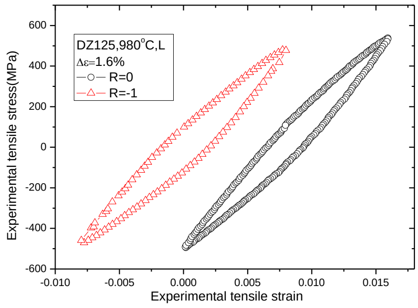



Fig. 6 The strain-stress curves

LCF results at 980°C with different strain ratio are shown in Fig. 5. It is interesting to found that little difference could be found at short life region, on the contrary, better fatigue life are obtained with strain ratio $R_\varepsilon=0$ at long life region where obvious mean stress existed. The potential reason for the slight difference may be due to the similar area of steady-state hysteresis loop at 980°C shown in Fig. 6, which also exhibits similar mean stress.

### 2.2 Effect of dwell types and dwell times on LCF

#### *2.2.1 Dwell types*

LCF life with and without dwell times at 980°C are shown in Fig. 7. Compared with continuous fatigue, all the three dwell types with the same dwell times lead to obvious life degradation. Roughly, no obvious difference of these three dwell types could be found except that the balanced dwell type gets the entirely shortest life, the bigger area of simulated hysteresis loop of balanced dwell type 30/30 in second paragraph is much more big than the other ones, which maybe the potential reasons; the tensile dwell type with reduced mean stress shows predominant fatigue property at low strain range but bad fatigue resistance at high strain range, the possible reason is the competition between mean stress related fatigue damage and creep damage.

#### *2.2.2 Dwell times*

Fig. 8 shows the evolution curves of cyclic peak stress with different dwell times at 850°C. As the mentioned cyclic stress response before, cyclic hardening behavior could be observed with no dwell times, but it turns to be cyclic softening behavior with dwell times. Especially the relaxation of cyclic peak stress is also associated with dwell times. Firstly, with the increased dwell times from 0s to 60s, increased stress relaxation is obtained. However, with the increased dwell times reach up to 120s and 300s, similar relaxation curves are exhibited.

Compared with the fatigue life with no dwell times, the introduction of increased dwell times leads to an obvious gradually life degradation with strain ratio equals to -1 at both 850 and 980°C shown in Fig. 9, except for the abnormal fatigue life with 300s dwells at 980°C; however, when $R_\varepsilon=0$, no obvious fatigue life degradation could be distinguished at 850°C but not for 980°C. The observed dwell-times-related cyclic peak stress relaxation behavior in Fig. 3 maybe could explain the similar fatigue life with 120s and 300s dwell times at 850°C. The potential reason for the influence of strain dwell times may be due to the competition between fatigue and creep damage, where the fatigue damage is decreased with the relaxed peak stress but creep damage increases with added dwell times.

Meanwhile, based on the similar fatigue life between $R_\varepsilon$=0 and -1 with no dwell times at both 850 and 980°C shown in Fig. 9, we can conclude that, compared with zero strain ratio, the continuous fatigue with $R_\varepsilon$=-1 is more sensitive to dwell times and exhibits low fatigue life, this difference is more visible at 980°C.

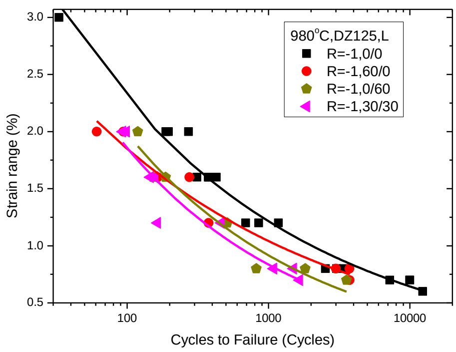



Fig. 7 The influence of dwell types on LCF

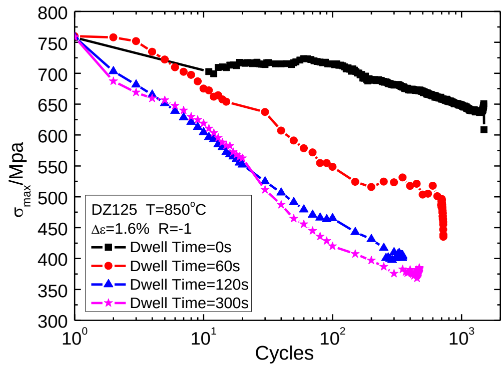



Fig. 8 The stress relaxation with dwells

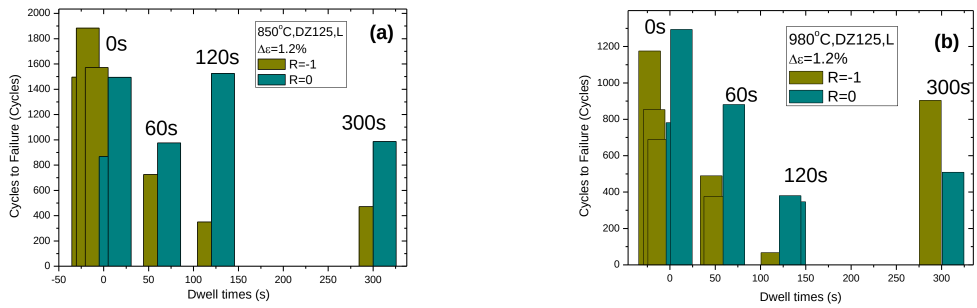



Fig. 9 The influence of strain dwells at different strain ratio on LCF, (a) 850°C; (b) 980°C

LCF results under different stress tensile dwell times at 850 and 980°C are shown in Fig. 10, all the introduced dwells lead to a degradation of fatigue life; persistent degradation is obtained under the increased dwells, which is more obvious at 980°C.

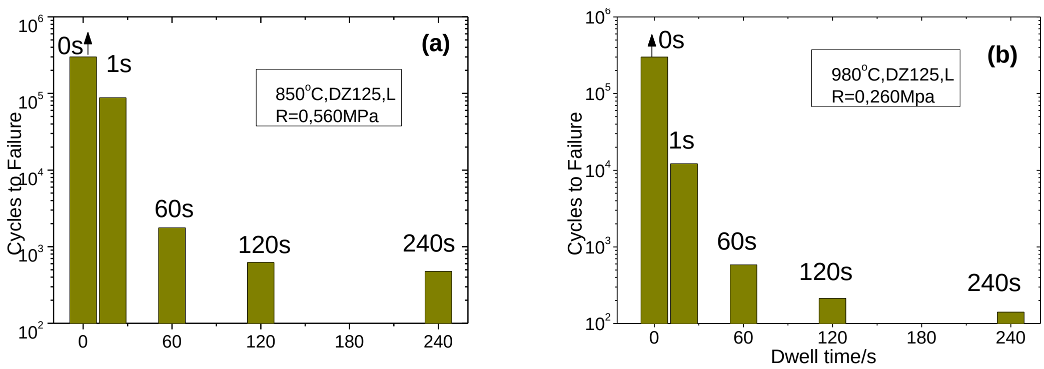
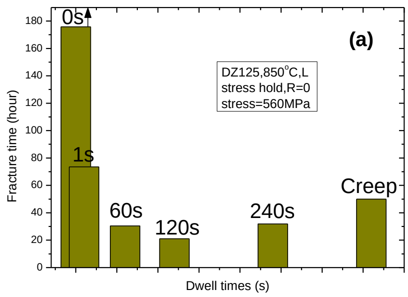



Fig. 10 The influence of stress dwell times on LCF life, (a) 850°C; (b) 980°C

Except for the above mentioned influence of dwell times on fatigue life, a contrary attempt is considering the influence of cyclic load on creep life. As is shown in Fig. 11, at the first stage, the total fracture time is decreased with increased dwell times, but the minimum fracture time is obtained with dwell times equals to 120s at both 850 and 980°C. Then the fracture time is gradually increased as the increased dwell times, at last the static creep life is obtained.



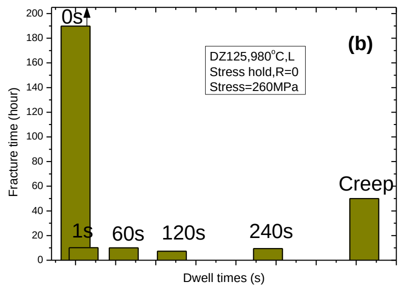




Fig. 11 The influence of stress dwell times on fracture time, (a) 850°C; (b) 980°C

## 2.3 Effect of dwell times and stress concentration on LCF

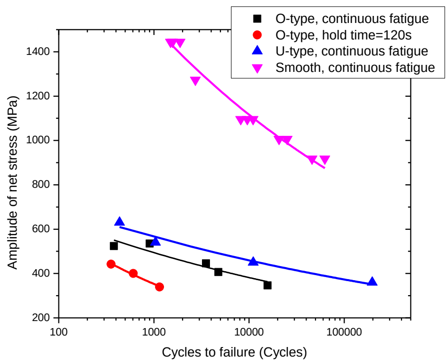



Fig. 12 The relationship between amplitude of net stress and fatigue life

Compared with the continuous fatigue life of smooth round bar specimens at 850°C shown in Fig. 12, obvious life degradation is induced by stress concentration of notched U-type and O-type plates. Furthermore life degradation is still happened for the stress dwell times at peak tensile stress.

## 2.4 Cyclic stress/strain response

In this paper, the cyclic stress/strain response of smooth and notched DZ125 components affected by dwell times at high temperatures, based on the modified Chaboche constitutive model [19], is carried out. This constitutive model is implemented as an ABAQUS user material (UMAT) subroutine. Totally 22 material parameters existed in this model, the Levenberg-Marquardt optimization method is employed and the material parameters are fitted by experimental curves of isothermal tension and creep load at high temperature. Moreover, it is necessary to note that the 11-22 plane of symmetry and 33 normal are represented by transverse and longitudinal orientations.

Compared with the experiment curves, this elastic-viscoplastic constitutive model shows acceptable accuracy on predicting stress/strain response of continuous fatigue, which is shown in Fig. 13. The simulated strain/stress response with three strain dwell types is shown in Fig. 14, obvious dwell-time-induced mean stress could be found, the hysteresis loop area of the dwell type 30/30 is bigger than the other two, and this is the potential reason for shorter fatigue life of dwell type 30/30 shown in Fig. 7. As shown in Fig. 15, the strain/stress response with stress dwells, which could reveals dwell time's effect on deformation, the hysteresis loop area is also increased with the increased dwell times, which is the possible reasons for gradually life degradation with increased stress dwells shown in Fig. 10.

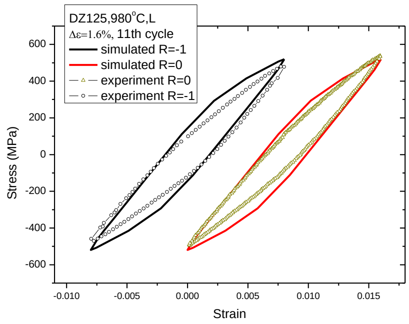
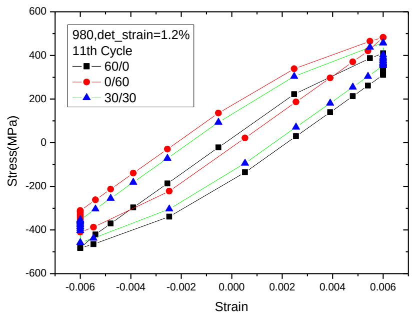



Fig. 13 Simulated hysteresis loop of continuous fatigue



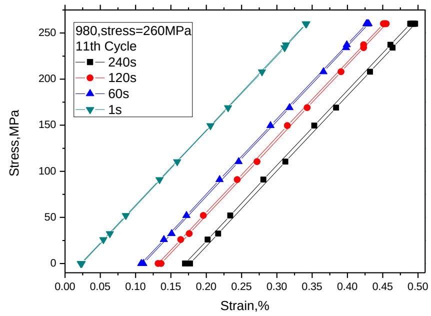




Fig. 14 The strain/stress response with strain dwells

Fig. 15 The strain/stress response with stress dwells

The evolution of tensile stress and deformation at notch tip with 120s dwell time is shown in Figs. 16 and 17, where we can see obvious stress relaxation with the peak stress decreased from 850 to 725 MPa, especially the location of the maximum tensile stress is changed from notch surface to inner surface, and obvious creep deformation is happened near the notch tip.

## 4 Life modeling

A physical based method considering crystallographic slip planes as critical planes and corresponding damage parameters is evaluated here on LCF life prediction; The critical distance concept is introduced for the load condition with stress concentration. Furthermore, the Larson-Miller plots and Miner's linear accumulative damage accumulative theory are adopted for life prediction affect by dwell times; The life prediction affected by stress concentration and dwell times is also carried out here.

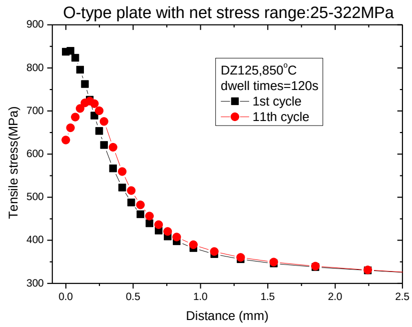



Fig. 16 The evolution of tensile stress with dwell times at notch tip

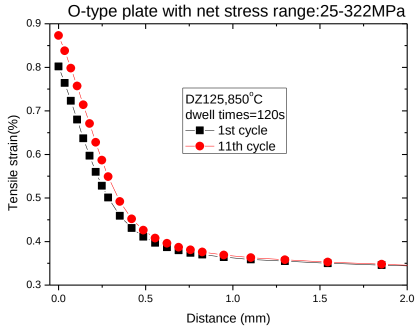



Fig. 17 The evolution of tensile strain with dwell times on notch tip

## 4.1 SWTM Parameters

Critical plane based methods are originally developed for multi-axial fatigue, with well defined crystallographic slip planes and corresponding plastic flow mechanism of DS superalloy, a physical based method is considering crystallographic slip planes as critical planes. The mean stress modified SWT parameter $\Delta\gamma_{max}\cdot(\tau_{max}+\tau_m)/2$ on the discrete crystallographic slip planes are evaluated, which could consider the influence of anisotropic properties and mean stress. In this paper, the slip systems both on the octahedral and cube planes including totally 30 slip systems are utilized, i.e. 12 primary and 12 secondary slip systems come from the octahedral planes, the rest 6 slip systems are located on cube planes. The analytical procedure of obtaining the resolved shear stress/strain on these slip systems is referenced to Arakere and Swanson's literature [4]. The life model is shown in Eq. 1:

$$\Delta\gamma_{\max} \bullet \frac{\tau_{\max}+\tau_m}{2} = a(2N_f)^b \tag{1}$$

$$\begin{aligned} 850℃: \Delta\gamma_{\max} \bullet \frac{\tau_{\max}+\tau_m}{2} &= 11.08252(2N_f)^{-0.16864}, R^2 = 0.92947 \\ 980℃: \Delta\gamma_{\max} \bullet \frac{\tau_{\max}+\tau_m}{2} &= 29.86975(2N_f)^{-0.36556}, R^2 = 0.92348 \end{aligned} \tag{2}$$

Where $a$ and $b$ are model parameters fitted by experimental data from smooth specimens, $N_f$ is fatigue failure life. Although few experimental data is carried out at T and 45 °orientations, the model parameter at 850 and 980°C is well fitted shown in Fig. 18, the influence of anisotropic properties and mean stress are well considered and Eq. 2 is obtained.

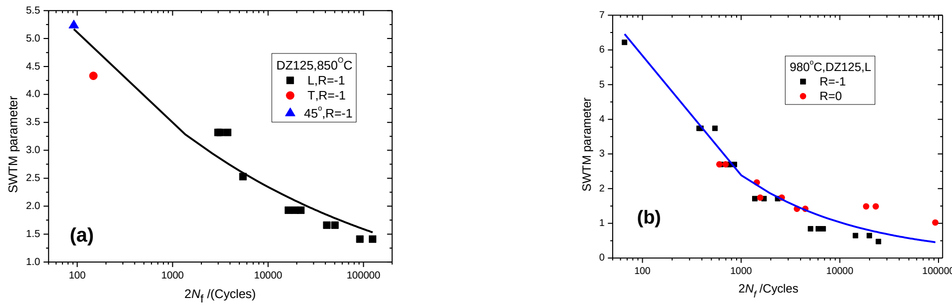



Fig. 18 The SWTM parameter versus LCF lives, (a) 850℃; (b) 980℃

## 4.2 Life prediction

### *4.2.1 Life prediction under stress and strain dwelsl*

LCF life prediction with strain and stress dwells is carried out based on Miner's linear cumulative damage theory shown in Eq. 3, where the pure fatigue life $N_f$ is determined by the above-mentioned SWTM parameter. The static creep fracture time is determined by traditional Larson-Miller plots shown in Eq. 4, where $\theta$ is temperature with units ℃, σ is the tensile stress, $b_0$, $b_1$, $b_2$, $b_3$, $b_4$ are four material parameters confirmed by materials engineering manual [20].

$$\sum_{i=1}^{n}\frac{N_i}{N_f}+\sum_{j=1}^{m}\frac{t_j}{t_c}=1 \qquad (3)$$

$$\begin{aligned} \lg t &= b_0 + b_1/T + b_2X/T + b_3X^2/T + b_4X^3/T \\ T &= (9\theta/5+32)+640 \\ X &= \lg\sigma \end{aligned} \qquad (4)$$

As is shown in Fig. 19(a), the LCF life at 850℃ with tensile strain dwell and tensile stress dwell at different strain and stress ratio is predicted, a factor of three is still obtained in spite of the complicated tensile dwell forms. Moreover, life prediction with tensile, compressive and balanced strain dwells at 980℃ are further investigated, a factor of three is also obtained shown in Fig. 19(b). So we can conclude that, based on SWTM parameter, Miner's linear cumulative damage theory and Larson-Miller plots, acceptable predicting accuracy of fatigue life affected by dwell times is obtained.

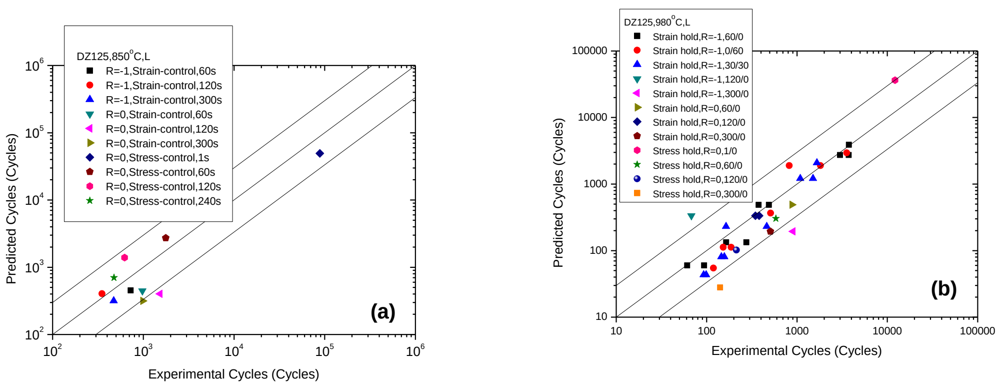



Fig. 19 Experimental life under dwell times versus predicted life, (a) 850°C; (b) 980℃

### *4.2.2 Life prediction under stress concentration*

To predict a more appropriate fatigue behavior, combined with the slip systems based SWTM parameter, the critical distances concept is used; concretely the Point Method (PM) is used here. The critical distance is determined as following: the experimental fatigue life should be inserted into Eq. 2 to obtain the SWTM parameter, and then based on the resolved shear strain/stress at the middle line of notched plate, the experimental critical distance could be determined with the solved SWTM parameter. The experimental critical distance is shown in Fig. 20.

A method for determining the critical distance is proposed by Susmel and Taylor [21], who assumes that the critical distance is dependent on the number of cycles to failure, which is successfully applied to LCF issues. The relationship between critical distance $D_{PM}(N_f)$ and failure life $N_f$ is shown in Eq. 5， the fitted curve is shown in Fig. 20 and Fig. 21 shows a factor of two in life prediction.

$$D_{PM}(N_f) = 0.31133 \bullet N_f^{\ -0.08153} \tag{5}$$

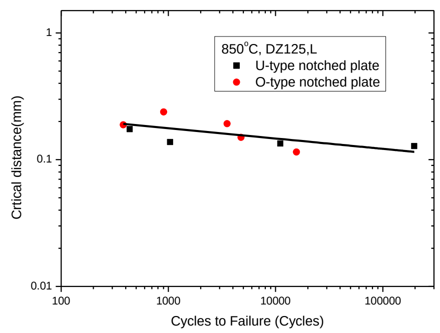



Fig. 20 The experimental critical distances for each test specimen

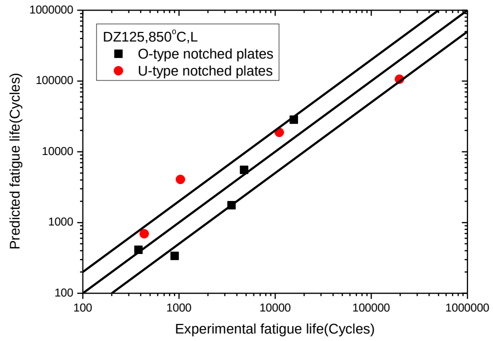



Fig. 21 Experimental life with stress concentration versus predicted life

*4.2.3 Life prediction under both stress concentration and dwells*

Based on SWTM parameter, Miner's linear cumulative damage theory and Larson-Miller plots, acceptable life prediction on LCF with dwell times could be gotten. However, to predict LCF life affected by both stress concentration and dwell times, firstly the fatigue damage is calculated based on the critical distance concept in obtained Eq. 5, then the concentrated stress should be average processed for determining creep damage; the equivalent stress is confirmed by the tensile strain weighted correction shown in Eq. 6, where the integration interval is on the middle line of notched plate. As is shown in Table 2, this method shows acceptable accuracy for LCF life affected by both dwell times and stress concentration.

$$\sigma_{creep,eq} = \int \sigma_{33} d\varepsilon_{33} \Big/ \int d\varepsilon_{33} \tag{6}$$

Table 2 Experimental life with concentrated stress and dwells at 850°C versus predicted life

| $\Delta\sigma_{net}$/ MPa | Predicted $D_{PM}$/mm | Predicted pure fatigue life/Cycles | Equivalent stress/MPa | Predicted creep life/hour | Hold time/s | Predicted life/Cycles | Experimental life/Cycles |
|---|---|---|---|---|---|---|---|
| 25-321 | 0.1235 | 83964.85 | 560.825 | 46.6051 | 120 | 1375.3 | 1150 |
| 25-375 | 0.1348 | 28696.96 | 636.728 | 14.5199 | 120 | 429.1 | 609 |
| 25-412 | 0.1431 | 13822.23 | 689.174 | 6.8279 | 120 | 201.8 | 355 |

## 5 Conclusion

Based on the author and co-worker's systemically experimental investigation work on smooth and notch fatigue behavior of DZ125 at high temperatures with and without dwell times, LCF behavior analysis and life modeling considering the influence of temperature, dwells and stress concentration is carried out. The main conclusions are summarized as follows:

(1) The influence of temperature, strain ratio, stress concentration, dwell types and

dwell times on fatigue resistance is obvious. ① The cyclic stress response of DZ125 is temperature dependent. At 850℃ it is cyclic hardening, but it seems to be slight cyclic softening at 980℃. ② The fatigue resistance at 850℃ is better than 980℃ in long life region, but worse fatigue strength is obtained at 850℃ in short life regime. ③ Roughly, the introduction of compressive, tensile and balanced strain dwell times can all lead to obvious fatigue life degradation, but the balanced dwell type gets the entirely shortest life, the tensile dwell type with reduced mean stress shows predominant fatigue property at low strain range but bad fatigue resistance at high strain range. ④ The cyclic hardening behavior could be observed with no strain dwell times, but it turns to be cyclic softening behavior with dwell times. Especially the relaxation of cyclic peak stress is also closely associated with dwell times. ⑤ Based on the similar fatigue life between $R_\varepsilon$=0 and -1 with no dwell times at both 850 and 980℃, the continuous fatigue with strain ratio equals to -1 is more sensitive to dwell times. Compared with smooth fatigue life at 850℃, obvious life degradation is induced by stress concentration. Furthermore life degradation is happened with added stress dwell times.

(2) The critical method is used and damage parameters on critical plane is the modified SWT parameter; Moreover, the failure cycles related critical distance concept is combined for predicting fatigue life affected by stress concentration where a factor of two is obtained. Based on SWTM parameter, Miner's linear cumulative damage theory and Larson-Miller plots, a factor of three is obtained in spite of the complicated dwell forms on smooth specimens. Furthermore, with added critical distance concept and confirmed creep equivalent stress, the prediction LCF life affected by both dwell times and stress concentration is successfully carried out.

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