**Article title**

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**Abstract**

In contrast to conventional strain-controlled creep-fatigue interaction (CCFI) loadings, a novel hybrid stress- and strain-controlled creep-fatigue interaction (HCFI) loadings were developed on P92 steel. Dwell stresses ranging from 140 MPa to 170 MPa, and dwell periods of 300 s, 600 s and 1800 s were employed at 625℃. The test responses demonstrate that cyclic softening and hardening effects lead to complicated cyclic responses.

**Key words**

Creep-fatigue interaction loading; Cyclic responses; Life prediction

1. **Introduction**

Creep-fatigue interaction (CFI) has been widely known as a significant factor for premature failure of components at elevated temperatures in aerospace [1] and power industries [2]. High temperature components experience strain-controlled fatigue cycles as a result of thermal transients during start-up and shut-down operations. Whereas, during the steady operation period, high temperature components may be subjected to steady stress-controlled loading. For example, rotating components of aero-plane engines are subjected to constant centrifugal force and the steam pipes in power plants are subjected to static internal pressure at elevated temperature. Hence, steady operation of high temperature components may result in creep deformation. Consequently, actual loading conditions on high temperature components are hybrid stress- and strain-controlled creep-fatigue interaction (HCFI) loading.

1. **Results**

To analyze the cyclic stress responses of P92 steel under HCFI loading, the evolutions of the peak tensile stress as a function of number of cycles for four dwell stresses are plotted in Fig. 1, in which peak stress responses from pure fatigue tests with the same prescribed strain range are also plotted to demonstrate the deterioration of HCFI loading on material responses and fatigue life. As reported earlier [30], under continuous fatigue loading, P92 steel always shows cyclic softening with three distinct softening stages. However, it can be observed that the cyclic softening increases significantly under HCFI loading compared to the PF loading. This is attributed to the influence of additional creep damage.



**Fig.1** Peak tensile stress responses of HCFI tests with different dwell period and dwell stress (a) 140 MPa, (b) 150 MPa

Table 1 lists the chemical compositions of the investigated P92 steel. It is observed in this table that the dwell stress and dwell period are two important factors influencing the fatigue life of P92. To study the influences of dwell parameters on fatigue life, the test data is plotted in Fig.1, where it is observed that the fatigue life decreases with dwell stress at a higher rate for 300 s dwell period than that for dwell periods of 600 s and 1800 s. This phenomenon may be attributed to the fact that for the 300 s dwell period test, the failure life is relatively high at lower dwell stress because fatigue life is strongly influenced by the strain range of the loading cycle and weakly influenced by the creep damage accumulation. Whereas for the 600 s and 1800 s dwell period tests, creep damage accumulation predominantly influences the fatigue life and hence fatigue life is evolving almost similarly with dwell stress for these two tests as shown in Fig.1.

**Table 1** Chemical compositions of P92 steel (wt. %)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| C | Mn | Si | P | S | Cr | Mo | V | N | Ni | Al | Nb | W |
| 0.115 | 0.431 | 0.139 | 0.0082 | 0.0061 | 9.2 | 0.480 | 0.207 | 0.035 | 0.238 | 0.014 | 0.083 | 1.940 |

In terms of microstructure, lath structure stability and effectiveness in pinning dislocation motion are two primary factors that influences peak tensile stress response. It is known that the annihilation of dislocations can lead to the coarsening of lath, which is considered as the main reason for softening, while hardening corresponds to the pinning of mobile dislocations. Due to short high temperature exposure, the precipitates are hardly coarsened to affect the pinning ability. Accordingly, more mobile dislocations pinned are responsible for hardening effect. Different from constant strain range during CCFI test, the strain range of each cycle grows under HCFI loading, because the creep strain in each cycle during dwell time increases with the cycle number. Consequently, more mobile dislocations are generated, some of which annihilate to make laths coarsen but some are pinned by precipitates. The pinned part of the dislocation may induce hardening. However, with the increase of dwell stress, the lath structure stability will play an important role. In other words, the hardening generated by pinned dislocation is not enough to compensate the softening caused by coarsen lath.

1. **Conclusions**

A novel set of fatigue test data of P92 steel at 625℃ was conducted under prescribing hybrid stress- and strain-controlled creep-fatigue interaction (HCFI) loadings. Dwell stresses in the range 140-170 MPa and dwell periods of 300 s, 600 s and 1800 s were studied. In addition, a new life prediction model based on viscosity is proposed.

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