A PHYSICALLY BASED MODEL FOR PREDICTING LCF LIFE UNDER CREEP FATIGUE INTERACTION

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ABSTRACT

Modifications are made on our model [1] for predicting LCF life to include the wave shape and annealing effect and to eliminate the uncertainty that occurs by using original basic equation. The model was checked successfully by experiments on the AISI 304 L stainless steel. It was shown that the influence of different cavity growth models on the predicted life in this case is negligible.

BASIC CONCEPT OF THE MODEL

Unstable crack advance occurs if the crack advance per cycle becomes approximately equal to the spacing of the nucleated intergranular cavities [1,2]. The crack tip opening displacement may be seen as the upper bound to crack growth [2] and the relation can be written as

\[ \frac{da}{dN} \leq \frac{\delta}{2} = \lambda - 2r \]  

where \( \lambda \) is the cavity spacing and \( r \) is the radius of \( r \)-type cavity. Since it was found that not every precipitation necessarily produce a cavity, experimental constant \( \alpha \) has been used to adapt the observation in our former model. However the empirical constant \( \alpha \) could reduce the versatile character of the basic concept on unzipping of cavitated material as the failure criterion.
NUCLEATION OF CAVITIES AND CAVITY SPACING

Under repeated loading we assume that the number of created cavities depends on the number of cycles. In analogy to the Manson-Coffin relationship, we postulate a cycle-dependent cavity nucleation under cyclic creep and low-cycle fatigue condition with superimposed hold time. Assuming that only the plastic strain imposed is responsible for cavity nucleation and disregarding stress dependency, the number of cavities is given by

\[ n = p N^\beta \Delta \epsilon_p \]  

where \( \Delta \epsilon_p \) is the plastic strain range, \( N \) is the number of cycles, \( p \) is the cavity nucleation factor, and \( \beta \) is the cyclic cavity nucleation exponent. \( p \) was taken from direct experimental observation of cavities [7,8]. Therefore it is not necessary to consider the influence of precipitation on the nucleation of cavities.

Cavity nucleation under creep-fatigue condition is favored on grain boundaries perpendicular to the load axis and the cavity spacing \( \lambda \) can be written as

\[ \lambda = \frac{1}{\sqrt{n}} \]  

CAVITY GROWTH

Nucleation of cavities is governed by a deformation of the matrix, and the cavity growth is controlled by diffusion. Most of the cavity growth models [3,4,9] may be written in the form of

\[ \frac{dr}{dt} = \text{Const.} \cdot F(r, \lambda, t, T, \sigma) \]  

where

\[
\begin{align*}
r &= \text{cavity radius}, \\
t &= \text{time}, \\
\lambda &= \text{cavity spacing}, \\
T &= \text{absolute temperature}, \\
\sigma &= \text{tensile stress}
\end{align*}
\]

INCOMPLETE HEALING UNDER COMPRESSIVE STRESS

The cavities nucleated by tensile stresses can be healed during periods of compressive stress if the compressive stress is applied for a long enough time. It has been observed that the time required to heal the cavity by compressive stress is up to six times longer than the time to nucleate the cavity by tensile stress [5].

The incomplete healing response can be modelled as [6] where sign (\( \sigma \)) is the signum function defined as