CRACK PROPAGATION AND INITIATION
IN LOW CYCLE STRAIN CONTROLLED FATIGUE*)

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Experimental techniques for crack extension measurements in cylindrical specimens, subjected to tension-compression strain cycling, are described. Both electrical resistivity and compliance techniques are applicable and yield information on crack growth as well as crack initiation.

Crack propagation follows the relationship
\[ \frac{dc}{dN} = A \cdot c \cdot \left( \frac{\varepsilon_{TR}}{\varepsilon_p} \right)^{n+1} - \frac{\varepsilon^*}{2} \]

with \( n \) close to unity. (Here \( c \) is the crack length, \( A \) a constant and \( \varepsilon_p \) a critical strain characteristic of the material; \( \varepsilon_{TR} \) is the total strain range.) The Manson-Coffin equation could be regarded as a consequence of this crack propagation relationship, though the value of the strain hardening exponent \( n \approx 1 \) will require further verification and clarification.

From preliminary tests it appears that crack initiation in notched specimens is also governed by a Manson-Coffin type relationship, especially if the effective plastic strain at the notch root can be properly computed from
\[ \varepsilon_{TR,\text{effective}} = K_e \cdot \varepsilon_{TR} - \varepsilon^* \]

where \( K_e \) is the proper strain concentration factor, \( \varepsilon_{TR} \) the total nominal strain range and \( \varepsilon^* \) the elastic component under consideration of the plastic constraint at the notch root.

1. INTRODUCTION

The search for mechanisms responsible for fatigue might appear particularly promising for the field of high amplitude, strain controlled low cycle fatigue; first, because the suspected damage process could be easily followed from cycle to cycle and second, because of the good agreement of the results for most metals and alloys with the Manson-Coffin relationship \([1, 2]\), so that any mechanism proposed must necessarily be in agreement with the Manson-Coffin law. This well known relationship states that

\[ N_f \varepsilon_p = \text{const.} \]

where \( N_f \) is the number of cycles to failure, \( a \) approximately 0.5 to 0.6 and \( \varepsilon_p \) the plastic strain range. The constant on the right-hand side of Eq. 1 has the character of a strain and has been related to the tensile fracture strain. It is a material constant and represents the strain value \( \varepsilon_p \) extrapolated according to the Manson-Coffin relationship to \( N_f = 1/4 \) cycle and will be referred to as \( \varepsilon^* \) in the following \([3]\). The

*) The work reported here was sponsored by the U. S. National Aeronautics and Space Administration, Grant No. NGR-33-022-023. The authors gratefully acknowledge the continued interest and support given by Mr. S. S. Manson of NASA's Lewis Research Center, Cleveland, Ohio.

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agreement of $\varepsilon_p^0$ with the tensile fracture strain varies strongly from material to material [4]. Thus equation (1) may be regarded as a summation rule for the damage with failure occurring when a critical value $\varepsilon_{F1}$, the low cycle fatigue fracture strain, is reached, i.e. low cycle fatigue might be regarded as a case of cumulative strain exhaustion.

This argument was further supported by the experimental results of the effects of mean strain or pre-strain. In strain controlled fatigue, mean strain is synonymous to pre-strain since there is no difference between cycling with $\varepsilon_p$ around a mean strain $\varepsilon_0$ or prestraining first to $\varepsilon_0$ and then cycling symmetrically between $\pm \varepsilon_p/2$. The experimental data are in excellent agreement with the relationship

$$ N_f [\varepsilon_p^0 - \varepsilon_0/\varepsilon_{FR}]^{1/\alpha} \quad \alpha = 1/2. $$

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i.e. the low cycle fatigue fracture strain is reduced by the amount of the mean or pre-strain, as illustrated in Fig. 1 [3].

The hypothesis of strain exhaustion was tested more directly by measuring the remaining tensile fracture strain, $\varepsilon_{FR}$, after strain cycling for $N_x$ cycles, $N_x < N_f$.

![Fig. 1. Comparison of strain cycling experimental results for A 302 and A 225 steels with theoretical curves derived from equation 2 using $\varepsilon_{FR}$ instead of $\varepsilon_p$ as the elastic component is small. Monotonic tension $\varepsilon_p$: $\bigcirc$ — A 302, $\bigtriangleup$ — A 225.

Dashed lines according to:

$$ N_f = \frac{[\varepsilon_p^0 - \varepsilon_0/\varepsilon_{FR}]^{1/\alpha}}{a} \quad \alpha = 1/2. $$