I-180 THE EVALUATION OF LOW-CYCLE FATIGUE STRENGTH

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I. Introduction

Structural components are often subjected to general complex loading cycles such as combined bending, torsion and tensile/compressive loads. Even under single loading conditions, complex stress states may exist at notches or geometrically discontinuous locations. Therefore, the assessment of multiaxial fatigue strength of materials is an important design consideration.

In this study, the concept of plastic work is utilized in low cycle fatigue evaluation. The calculations of the plastic work and another parameter are carried out in conjunction with the development of the constitutive modeling for the complex loading conditions (particularly for nonproportional loadings).

II. Evaluation of Low-cycle Fatigue by Plastic Work Approach

Recent studies have resulted in two promising approaches to deal with the low-cycle fatigue evaluation of structural metals under nonproportional loadings:(1) Critical plane concept and (2) Plastic work concept. The critical plane concept, developed only recently, relates the critical plane to the crack growth. On the contrary, the energy criterion used since the fatigue problem was explored, was extended by Garud[1] to multiaxial stress state with the development of advanced plasticity modeling for nonproportional loadings.

The plastic work per cycle, W_p, may be generally defined as

$$W_p = \int_{cycle} dW_p = \int_{cycle} \sigma_{ij} d\epsilon_{ij}^p \quad (1)$$

where σ_{ij} and ϵ_{ij}^p are the stress tensor and the plastic strain tensor respectively. The followong power law was proposed by Garud for complex stress condition:

$$N_f = A(W_p^*)^B \quad (2)$$

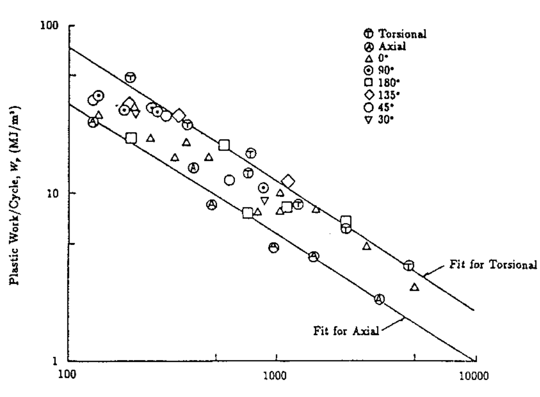

Fig. 1 Plastic Work per Cycle vs. Life

where A and B are material constants empirically determined from experiments, and N_f and W_p^* are the number of cycles at failure and the modified plastic work/cycle(the plastic work by shear stress was weighted by a half). Typical experimental results[2] are presented in Fig. 1(copy of Garud's work) in terms of number of cycles at failure vs. plastic work per cycle. The results are scattered and bounded by torsional(upper bound) and axial results(lower bound). The rest of results under biaxial straining conditions lie between these bounds.

Since this type of weighting factor does not have any physical meanings, the criterion based on plastic work concept was modified as follows.

$$N_f = \alpha(\sigma_1)^{\beta}(W_p)^{\gamma} \quad (3)$$

where σ_1 and W_p are the maximum tensile principal stress and the plastic work per cycle, respectively. α, β and γ are constants. First, the hysteresis was compared as shown in Fig. 2 in order to check the applicability of the plasticity model[3] to calculate the plastic work per cycle. Without modifying the plastic work concept, the best fit curve for all of the results is given by

$$N_f = 9.85 \times 10^3(W_p)^{-1.10} \quad (4)$$

and the scatterness of all the data in terms of observed life from experiment vs. predicted life is a ±2.0 on-line life variation as shown in Fig. 3. Using the maximum tensile principal stress in the evaluation, the best fit curve is given by

$$N_f = 2.55 \times 10^8(\sigma_1)^{-1.67}(W_p)^{-0.976} \quad (5)$$

The scatterness is reduced up to about ±1.5 on-line life variation as shown in Fig. 4.

III. Conclusions

The low-cycle fatigue strength was evaluated by the plastic work approach, where the maximum tensile principal stress was taken as a second parameter.

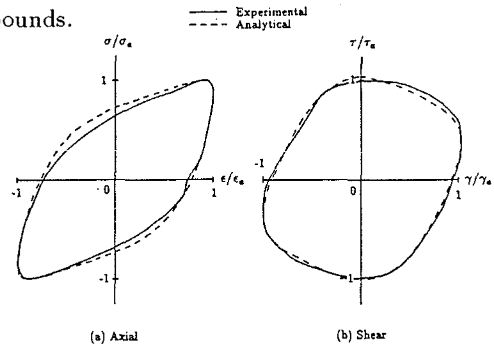

Fig. 2 Stress-Strain Curves by Proposed Model

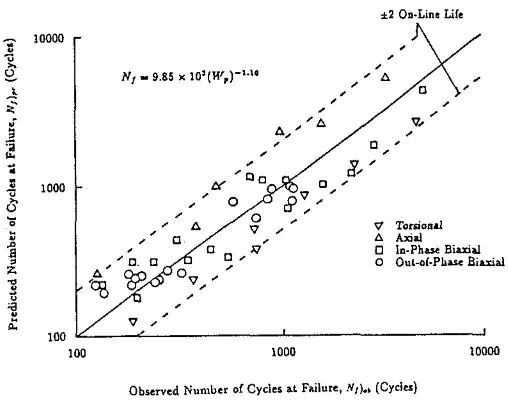

Fig. 3 Prediction of Life without Modification

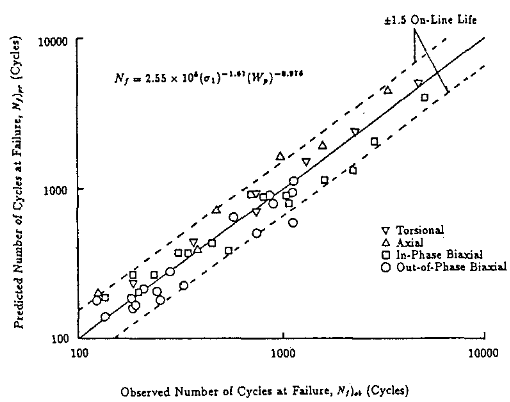

Fig. 4 Prediction of Life with Modification

References

1) Garud, Y.S., "A New Approach to The Evaluation of Fatigue under Multiaxial Loadings," Journal of Engineering Materials and Technology, ASME, Vol.103, Apr., 1981, pp.118-125

2) Brown, M.W. and Miller, K.J., "Biaxial Fatigue Data," Report CEMR1/78, Department of Mechanical Engineering, University of Sheffield, UK, 1978

3) Sugiura, K., Lee, G.C. and Chang, K.C. (1987),"Endochronic Theory for Structural Steel Under Nonproportional Loading," Journal Of Engng. Mech. Div., ASCE, 113(12), pp. 1901-1917.