Cyclic Elastoplastic Response of Aluminium Alloy 7050 to Low-cycle Fatigue

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Abstract

The challenge of developing a generalized mathematical pattern to describe the plastic behaviour of metals, lead researchers to propose various constitutive models, especially in the field of cyclic plasticity, where phenomena with particular importance to Low Cycle Fatigue (LCF), appear. The prescribed remote load history, linked to the locate stress and strain at geometrical discontinuities, with the use of an appropriate rule, act as input data for the constitutive model dictating the material elastoplastic response and hence the corresponding damaged incurred. A general overview of kinematic and isotropic hardening models is performed, within the framework of rate-independent plasticity. This study proposes a new constitutive model based on the Armstrong & Frederick rule. The concept of the backstress additive decomposition, as suggested by Chaboche, is altered in this model and performed in a multiplicative fashion [1,2], laying emphasis on achieving maximum simplicity in defining the material parameters. Existing experimental data on Aluminium Alloy 7050 [3], corresponding to strain uniaxial loading histories, were used for the validation of the model. Numerical application of the model was executed for the simulation of uniaxial cyclic mean stress relaxation response of the material in focus. Examination of the derived results indicates that the current modelling methodology can perform quite well in fitting uniaxial experimental data, and has the potential to simulate successfully multiaxial loading data, an issue to be addressed in other works.

Introduction

- Accurate description of inelastic behaviour of metals dictated by practical engineering problems - Low Cycle Fatigue (LCF) & High Cycle Fatigue (HCF).

- Successful prediction of fatigue life limit requires input strain–strain response as constitutive relation (current stress computation from given stress/strain history at point of interest).

- In LCF regime, cyclic deformation behaviour represented by cyclic stress–strain curve, cyclic hardening/softening, stress–strain hysteresis loops.

- Cyclic response curves needed for life prediction methods and correlation between macroscopic and microscopic features of materials.

- Engineering components - structures are subjected to cyclically varying loads with mean stress/strain. Fatigue process is sensitive to superposed tensile mean stress in HCF & LCF regimes.

- When investigating the effect of mean stress, tests run in two modes: strain-controlled cycling with constant mean strain, or stress-controlled cycling with constant mean stress (Fig.1).

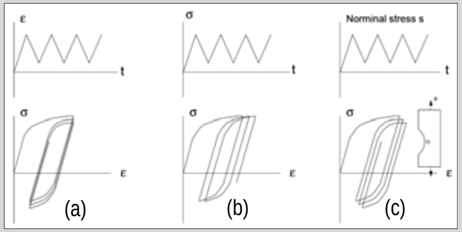

Figure 1. *Elastoplastic deformation behaviour subjected to (a) constant cyclic strains (b) constant cyclic stresses and (c) remote constant nominal cyclic stresses [2].*

- If response mainly elastic during cycling (HCF), the two types of test are equivalent, and can be used to study the effect of mean stress on fatigue life of materials.

- If cyclic response is elastic-plastic (LCF), the two types of test may produce quite different results.

- For strain-controlled mode, occurrence of plastic deformation causes mean stress relaxation. For the stress-controlled mode, the plastic deformation causes ratcheting strain (cyclic creep).

Background

- Time-independent plasticity appropriate for modelling deformation behaviour of most metallic structural alloys at room temperature

- von Mises yield surface (Kinematic & Isotropic hardening)

Kinematic hardening

- Prager $\dot{\boldsymbol{a}} = c\,\dot{\boldsymbol{\varepsilon}}^p$
- Armstrong & Frederick $\dot{\boldsymbol{a}} = c\left[a^s\dot{\boldsymbol{\varepsilon}}^p - \dot{\bar{\varepsilon}}^p\boldsymbol{a}\right]$
- Chaboche $\boldsymbol{a} = \sum_{i=1}^{m}\boldsymbol{a}_i$

Isotropic hardening

(non linear rule) $\dot{k} = c_k\left(k^s - k\right)\dot{\bar{\varepsilon}}^p$

Model Uniaxial Formulation

Proposed kinematic hardening model based on Armstrong & Frederick model, introducing MULTIPLICATIVE [1,2] backstress decomposition combined with additive decomposition (Chaboche).

- von Mises yield criterion: $f = |\sigma - a| - k = 0$

- Kinematic hardening backstress a,

$$\dot{a} = c\left[a^s\dot{\varepsilon}^p - \left|\dot{\varepsilon}^p\right|a\right] \quad , c \text{ variable}$$

Multiplier variable b (backstress type),

$$\dot{b} = h\left[b^s\dot{\varepsilon}^p - \left|\dot{\varepsilon}^p\right|b\right]$$

c depends on evolution of b

$$c = h_o + h\left[b^s - \left(\mathrm{sgn}\left(\sigma - a\right)\right)b\right]$$

backstress evolution rule,

$$\dot{a} = \left\{h_o + h\left[b^s - \left(\mathrm{sgn}\left(\sigma - a\right)\right)b\right]\right\}\left[a^s\dot{\varepsilon}^p - \left|\dot{\varepsilon}^p\right|a\right]$$

- Isotropic hardening variable k

Numerical Application

- Alluminium Alloy 7050-T7451 stress controlled test results [3]: Cyclic mean stress relaxation – plastic shakedown simulation

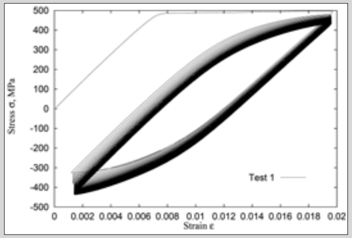

Figure 2. *Experimental data for AA 7075 mean stress relaxation under strain controlled loading scheme [3].*

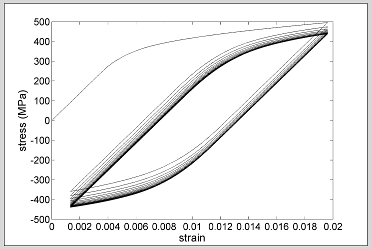

Figure 3. *Multiplicative model computed data for AA 7075 mean stress relaxation.*

E = 69 GPa		
		Kinematic hardening
$a_1' = 15$ MPa	$c_1 = 2000$	*Armstrong & Frederick*
$a_2' = 50$ MPa	$c_2 = 400$	
$a_3' = 320$ MPa	$c_3 = 30$	
$b' = 0.16$	$h = 5000$	*Multiplicative backstress*
$a_3' = 65$ MPa	$h_o = 1800$	
		Isotropic hardening
$k' = 292$ MPa	$c_k = 17.5$	

Table 1. *Material parameters for Multiplicative model.*

Conclusions

- Produced simulations considered fairly acceptable.

- Further investigation needed on:
  - Validation with more experimental data
  - Ratcheting simulation
  - Multiaxial implementation

References

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[3] Hu W., Wang C.H., Barter S., 1998, Analysis of Cyclic Mean Stress Relaxation and Strain Ratcheting Behaviour of Aluminium 7050, DSTO-RR-0153, Aeronautical and Maritime Research Laboratory, DSTO, Victoria, Australia.