Development of Plasticity Model for Steel Ratcheting Simulation

Lt Kyriakos Kourousis, Lt Ilias Lappas
Hellenic Air Force
kourousi@central.ntua.gr

Aircraft Structural Integrity Program (ASIP) Conference
December 2-4 2008, San Antonio, Texas

Abstract

The problem of ratcheting, defined as the progressive plastic strain accumulation in cyclic loading, is considered to be one of the unsolved difficulties of plasticity and furthermore fatigue modeling. Towards this direction many models within the frame of constitutive plasticity, based on the well known Armstrong and Frederick (AF) kinematic hardening rule have been introduced. In this paper further implementation of the multiplicative AF kinematic hardening model proposed in ASIP Conference 2007 and by Dafalias et el, is performed more extensively in the area of ratcheting simulation. Uniaxial experimental results, extracted from published results, were used for the validation, as well as for the assessment in terms of its capability to predict ratcheting response in steel alloys. In addition, the results of the commonly used Chaboche model with Threshold term have been compared with the relevant results of the multiplicative AF model, indicating an improved response. This model has been formulated for use in multiaxial loading cases, yet ratcheting simulation in specific published bi-axial results is an ongoing project and is expected to be presented in future works.

Background

Stress controlled loading mode: plastic deformation causes ratcheting (plastic strain accumulation cycle-by-cycle)

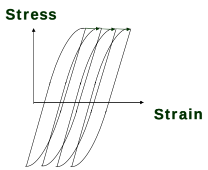

Figure 1. *Typical metal ratcheting response induced by stress controlled loading scheme*

The ratcheting phenomenon is very sensitive to the exact shape of the unloading/reloading curves and such sensitivity created the need for further modification of the additive back stress decomposition model, introduced by Chaboche et al [2].

- The additive back stress decomposition model has certain problems with the simulation of partial reverse loading/reloading and simultaneously of the ratcheting response.
- Chaboche [3] introduced a enhancement of this model through the incorporation of the so-called threshold term.
- The Chaboche with threshold model improved considerably reverse loading/reloading and ratcheting simulation

Model Formulation

Introduction of alternative scheme, known as multiplicative Armstrong & Frederick (AF) [1] hardening rule [4]

Kinematic hardening (multiaxial formulation):

$$\dot{\boldsymbol{a}} = \dot{\boldsymbol{a}}_1$$

$$\dot{\boldsymbol{a}}_1 = \langle \lambda \rangle \left[\sqrt{\frac{2}{3}} c_1 + \sqrt{\frac{2}{3}} c_1^* \left(\sqrt{\frac{2}{3}} a_1^{*s} - \boldsymbol{a}_1^* : \boldsymbol{n} \right) \right] \left(\sqrt{\frac{2}{3}} a_1^s \boldsymbol{n} - \boldsymbol{a}_1 \right)$$

$$\dot{\boldsymbol{a}}_1^* = \langle \lambda \rangle \sqrt{\frac{2}{3}} c_1^* \left(\sqrt{\frac{2}{3}} a_1^{*s} \boldsymbol{n} - \boldsymbol{a}_1^* \right)$$

The variable coefficient is enhanced by expressions related to the AF type evolution equations of other dimensionless second order internal variables, called the multipliers.

The multiplicative scheme can be in principle used in other formulations which do not necessarily use the back stress decomposition, because in essence it is a scheme that allows for a realistic variation of coefficients depending on the direction of loading.

Multiplicative AF hardening rule combined with additive back stress decomposition can offer improvement in ratcheting response simulation.

Results

The model was numerically implemented for the case of uniaxial loading histories.

Validated and compared against existing experimental data.

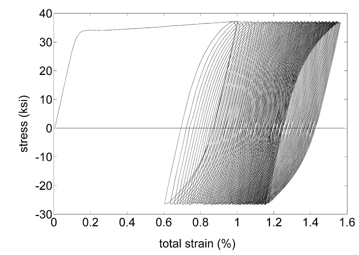

Figure 1. *SS304 Uniaxial cyclic loading experiment* [4].

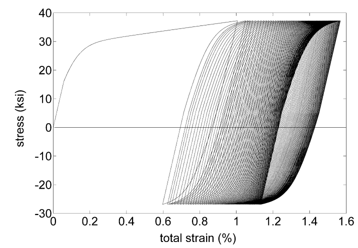

Figure 2. *SS304 Uniaxial cyclic loading simulation of data in Fig.1 by the multiplicative AF kinematic hardening model* [4].

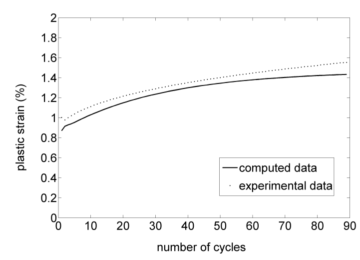

Figure 3. *Experimental and simulated ratcheting in terms of plastic strain at positive peak stress per cycle versus number of cycles for SS304* [4].

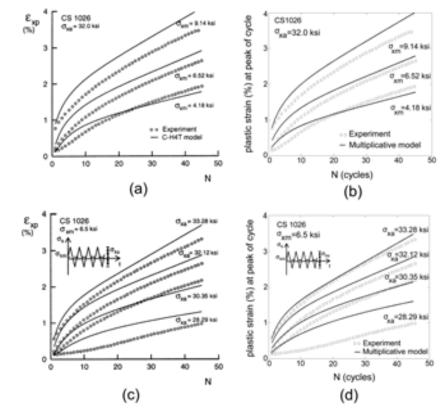

Figure 4. *Uniaxial experimental data for CS1026 and simulations by the Chaboche with threshold model (C-H4T) and the multiplicative AF kinematic hardening scheme for (a) and (b) ratcheting for fixed stress amplitude and various mean stress levels; (c) and (d) ratcheting for fixed mean stress level and various stress amplitudes* [4].

Conclusions

- Slight improvement in ratcheting simulation compared to Chaboche with threshold model.
- Application in multiaxial loading cases on-going project.
- Expected improvement in multiaxial ratcheting simulation.

References

[1] Armstrong, P. J. and Frederick, C. O., 1966. A Mathematical Representation of the Multiaxial Bauschinger Effect. GEGB Report No.RD/B/N731.
[2] Chaboche, J.L., Dang-Van, K. and Cordier, G., 1979. Modelization of Strain Memory Effect on the Cyclic Hardening of 316 Stainless Steel. In: Transactions of the 5th International Conference on Structural Mechanics in Reactor Technology, no. Div L in 11/3, Berlin.
[3] Chaboche, J.L., 1991. On Some Modifications of Kinematic Hardening to Improve the Description of Ratcheting Effects. International J. of Plasticity 7 661-678.
[4] Dafalias Y.F., Kourousis K.I., Saridis G.J., 2007, Multiplicative Backstress Rate Decomposition in Plasticity, *Int. J. Solids Structures 45, 2008, 2861-2880.*