Sborník vědeckých prací Vysoké školy báňské - Technické univerzity Ostrava
číslo 1, rok 2006, ročník LII, řada strojní
článek č. 1501

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RATCHETING SIMULATIONS WITH MODIFIED ABDELKARIM-OHNO CYCLIC PLASTICITY MODEL

SIMULACE RATCHETINGU UŽITÍM UPRAVENÉHO MODELU CYKLICKÉ PLASTICITY ABDELKARIM-OHNO

Abstrakt

Při hledání modelu cyklické plasticity, vhodného k simulaci ratchetingu v oblasti kontaktní únavy, byly ověřeny modely Chaboche a AbdelKarim-Ohno na souboru experimentálních dat uniaxiálního a biaxiálního ratchetingu převzaté z literatury. Bylo zjištěno, že je velice obtížné simulovat zároveň uniaxiální i biaxiální ratcheting užitím modelu AbdelKarim-Ohno [Int. J. Plasticity 16 (2000) 225]. Tento problém byl vyřešen modifikací modelu AbdelKarim-Ohno, která je v článku stručně popsána. Navržený model byl implementován do konečnoprvkového programu Ansys úpravou uživatelské subrutiny napsané v jazyce Fortran. Modifikovaný model cyklické plasticity ve všech simulovaných případech uspěl velmi dobře.

Summary

In a search for a constitutive model for ratcheting simulations in rolling contact fatigue domain, the models by Chaboche and AbdelKarim-Ohno and the modificiation of AbdelKarim-Ohno model have been evaluated against a set of uniaxial and biaxial ratcheting responses of steel CS1026. It is difficult to simulate simultanously the uniaxial and multiaxial ratcheting responses with the AbdelKarim-Ohno model [Int. J. Plasticity 16 (2000) 225]. This problem has been removed by modification described in the paper. The proposed model was implemented into the FE code Ansys using Fortran user's subrutin. The proposed cyclic plasticity model simulates all solved cases very well.

Introduction

When materials are subjected to cyclic plastic loading with nonzero mean stress, strain usually accumulates in the direction of mean stress with the increase of the number of cycles. This kind of strain accumulation is called cyclic creep or ratcheting. The ratcheting is an important factor in the design of structural components. The effect of ratcheting occurs for example in piping components and some cases of rolling contact. Since ratcheting is the progressive deformation accumulating cycle by cycle, it is not easy to predict the development of ratcheting accurately. Classical models of cyclic plasticity, implemented in the most of FEM software, are very poor in predicting ratcheting. Hence, searching for a more accurate model is necessary. In the previous study [1] some modifications of model AbdelKarim-Ohno [2] were investigated for better description of ratcheting in axial/torsional tests. The present task is verification of the proposed model on cases of biaxial loading history with internal pressure subjected to piping part of the specimen.

Time independent cyclic plasticity modelling

The cyclic plasticity constitutive models employed for ratcheting analysis with the assumption of rate-independent material's behavior consist of von Mises yield criterion

$$f = \sqrt{\frac{3}{2}(\mathbf{s}-\mathbf{a}):(\mathbf{s}-\mathbf{a})} - \sigma_Y = 0 \quad , \tag{1}$$

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the associative flow rule

$$d\boldsymbol{\varepsilon}_p = d\lambda \frac{\partial f}{\partial \boldsymbol{\sigma}} \tag{2}$$

and the kinematic hardening rule

$$d\mathbf{a} = g\left(\boldsymbol{\sigma}, \mathbf{a}, \boldsymbol{\varepsilon}_p, d\boldsymbol{\sigma}, d\boldsymbol{\varepsilon}_p, etc.\right) \quad , \tag{3}$$

where $\boldsymbol{s}$ is the deviatoric part of stress tensor $\boldsymbol{\sigma}$, $\boldsymbol{a}$ is the deviatoric part of back-stress $\boldsymbol{\alpha}$, $\boldsymbol{\sigma}_Y$ is the initial size of the yield surface, $\boldsymbol{\varepsilon}_p$ is the plastic strain tensor and $d\lambda$ is the plastic multiplier, which is equal to the equivalent plastic strain increment dp. The symbol : denotes the inner product between tensors ($\mathbf{x} : \mathbf{y} = x_{ij} y_{ij}$.).

Evolution laws

Cyclic plasticity models differ basically in the kinematic hardening rules they employ. For example, Chaboche [3] introduced "decomposed" nonlinear kinematic hardening rule in the form

$$\mathbf{a} = \sum_{i=1}^{M} \mathbf{a}_i \ , \ d\mathbf{a}_i = \frac{2}{3} C_i d\boldsymbol{\varepsilon}_p - \gamma_i \mathbf{a}_i dp \ , \tag{4}$$

where C_i and γ_i are material constants. Indeed, it was found by Bari and Hassan [3], that the Chaboche model overpredict biaxial ratchetting responses. Therefore, AbdelKarim and Ohno have proposed this modification of kinematic hardening rule

$$\mathbf{a} = \sum_{i=1}^{M} \mathbf{a}_i \ , \ d\mathbf{a}_i = \frac{2}{3} C_i d\boldsymbol{\varepsilon}_p - \mu_i \gamma_i \mathbf{a}_i dp - \gamma_i H\left(f_i\right)\left\langle d\lambda_i \right\rangle \mathbf{a}_i \ , \tag{5}$$

where

$$f_i = \frac{3}{2} \mathbf{a}_i : \mathbf{a}_i - \left(\frac{C_i}{\gamma_i} \right)^2 \tag{6}$$

and

$$d\lambda_i = d\boldsymbol{\varepsilon}_p : \frac{\mathbf{a}_i}{C_i / \gamma_i} - \mu_i dp \ . \tag{7}$$

The symbol $\langle x \rangle$ denotes the McCauley bracket ($\langle x \rangle = x + |x| / 2$).

The parameters μ_i set a ratcheting rate. The AbdelKarim-Ohno model can simulate well only materials with slight transient ratcheting behavior, i.e. ratcheting with steady-state [2]. Assuming the only one parameter for ratcheting $\eta = \mu_i$ and his evolution by equation

$$d\eta = \omega\left(\eta_\infty - \eta\right) dp \ , \tag{8}$$

transient effect in initial cycles could be introduced [4]. Two material constants ω and η_∞ from (8) could be determined by fitting at least one uniaxial ratcheting test. Further, it is difficult to simulate simultaneously the uniaxial and multiaxial ratcheting responses with the AbdelKarim–Ohno model as was found by Chen et al. [4]. This problem was solved by introduction of nonproportional term in ratcheting parameters

$$\mu_i = \eta \left| \frac{\partial f}{\partial \boldsymbol{\sigma}} : \frac{\mathbf{a}_i}{\overline{a}_i} \right|^{\chi} \text{, where } \overline{a}_i = \sqrt{\frac{3}{2} \mathbf{a}_i : \mathbf{a}_i} \ . \tag{9}$$

Material constant χ in (9) should be determined from a multiaxial ratcheting test.

Performed simulations

Subject of solutions is the same set of ratcheting responses used in the earlier works by a lot of authors (for example [3]). This data set on cyclically stabilized carbon steel CS1026 is acquired from Hassan and Kyriakides [5], Hassan et al. [6] and Corona et al. [7]. All test specimens were tubular, with a test section of 25,4 mm outside diameter and 1,27mm wall thickness. To reduce cyclic hardening of used steel, all test specimens were cyclically stabilized by axial strain symmetric cycling in the range of ±1%.

All solved cases was simulated by the proposed cyclic plasticity model and Chaboche model, which is included in the used FE package Ansys 8.0. Material parameters of the two models are defined in table 1. The same elastic constants and yield stress were used for both models $E = 181470MPa, \nu = 0.302, \sigma_Y = 130MPa$. Material constants C_i and γ_i were determined from hysteresis loop - Fig.1.

Table 1 – Model parameters

Chaboche model	$C_{1-3} = 414000,88706,3140\ MPa$
	$\gamma_{1-3} = 20000,800,9$
Proposed model	$C_{1-3} = 380040,52132,22235\ MPa$
	$C_{4-6} = 7398,2418,1700\ MPa$
	$\gamma_{1-6} = 8423,1839,744,334,156,30$
	$\omega = 10, \eta_0 = 0.6, \eta_\infty = 0.4, \chi = 1.3$

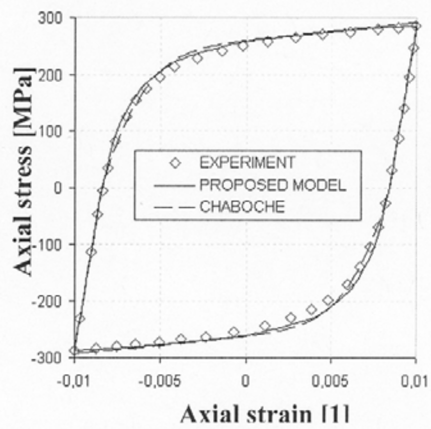

Fig. 1 – Closed hysteresis loop

In the first instance, uniaxial ratcheting response was simulated. The influence of the amplitude stress σ_{xa} on ratcheting response was studied (see Fig.2).

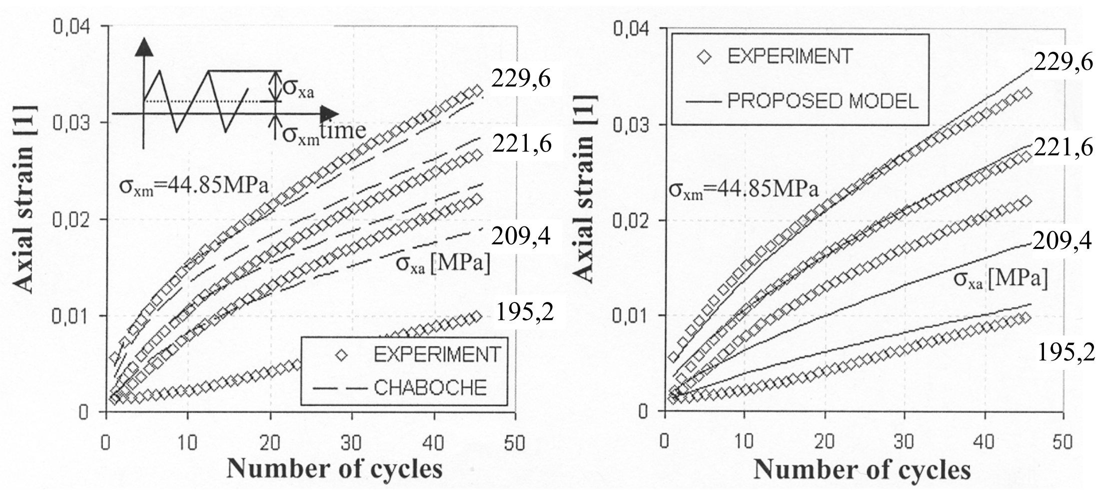

Fig. 2 – Uniaxial ratcheting response of CS1026 and simulations (experiments from [5])

The stress-strain curve retrieved from uniaxial experiment and numerical analysis for case σ_{xm}=44.85MPa, σ_{xa}=221.6MPa are plotted in Fig.3.

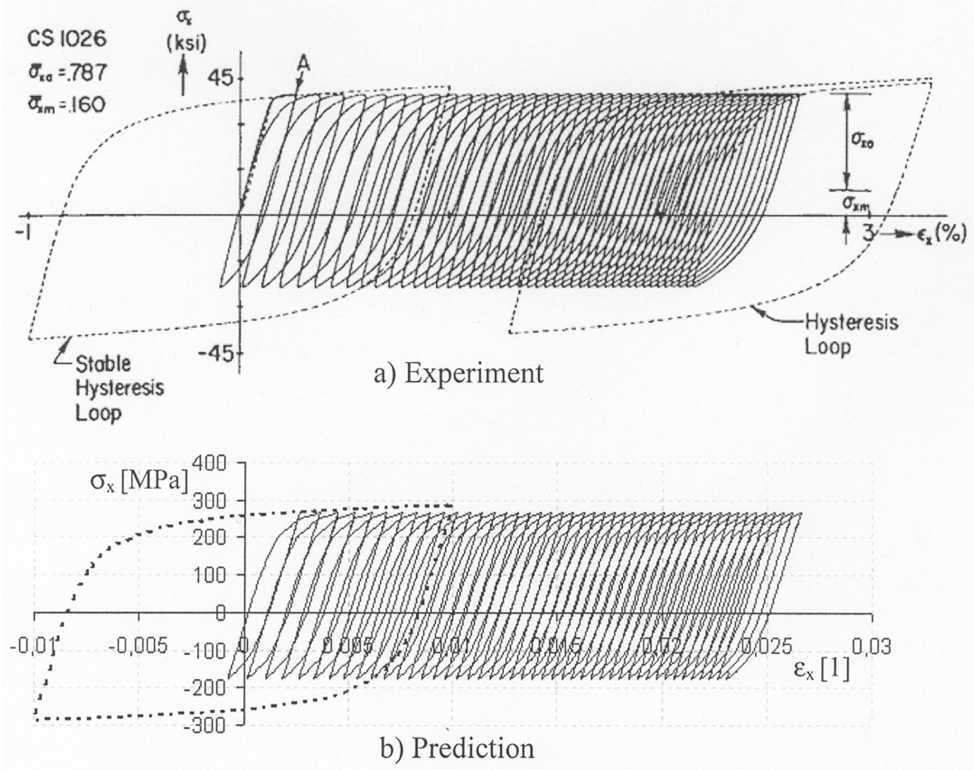

Fig. 3 – Uniaxial ratcheting of CS1026 (σ_{xm}=44.85MPa, σ_{xa}=221.6MPa)

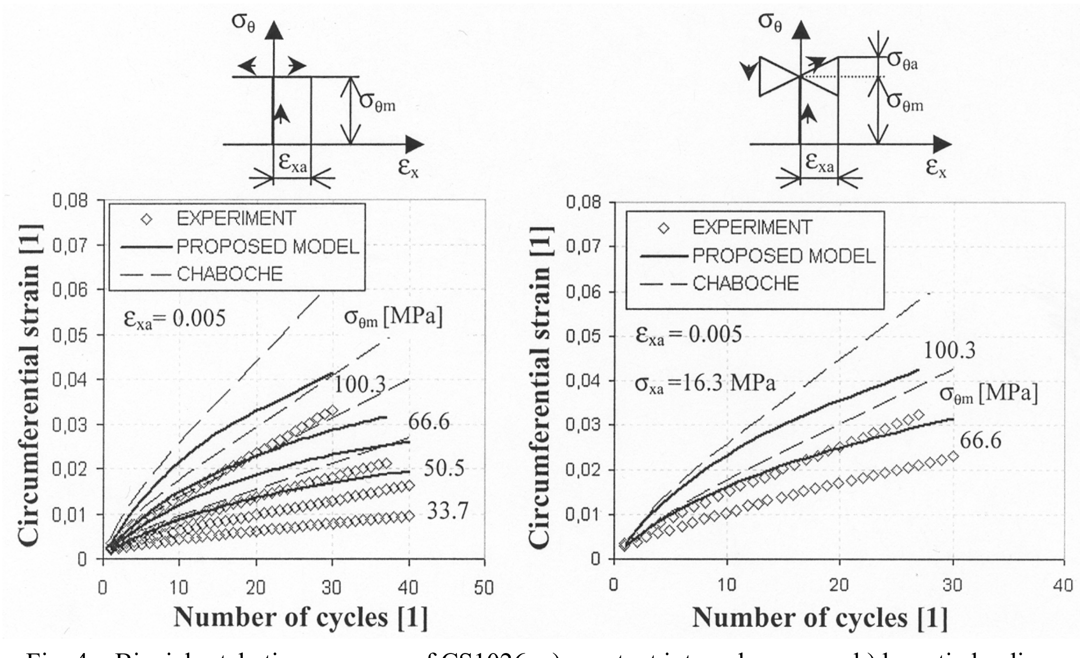

Fig. 4 – Biaxial ratcheting response of CS1026: a) constant internal pressure, b) bow-tie loading (experiments were taken from [6], [7])

The Fig.4 shows biaxial ratcheting of circumferential strain ε_θ from simulations and experiments for chosen cases of constant internal pressure and bow-tie loading histories. It is clear, that transient part of the cyclic strain response is difficult to simulate, but the strain rate at last cycle is predicted very well by the new model (Fig.5).

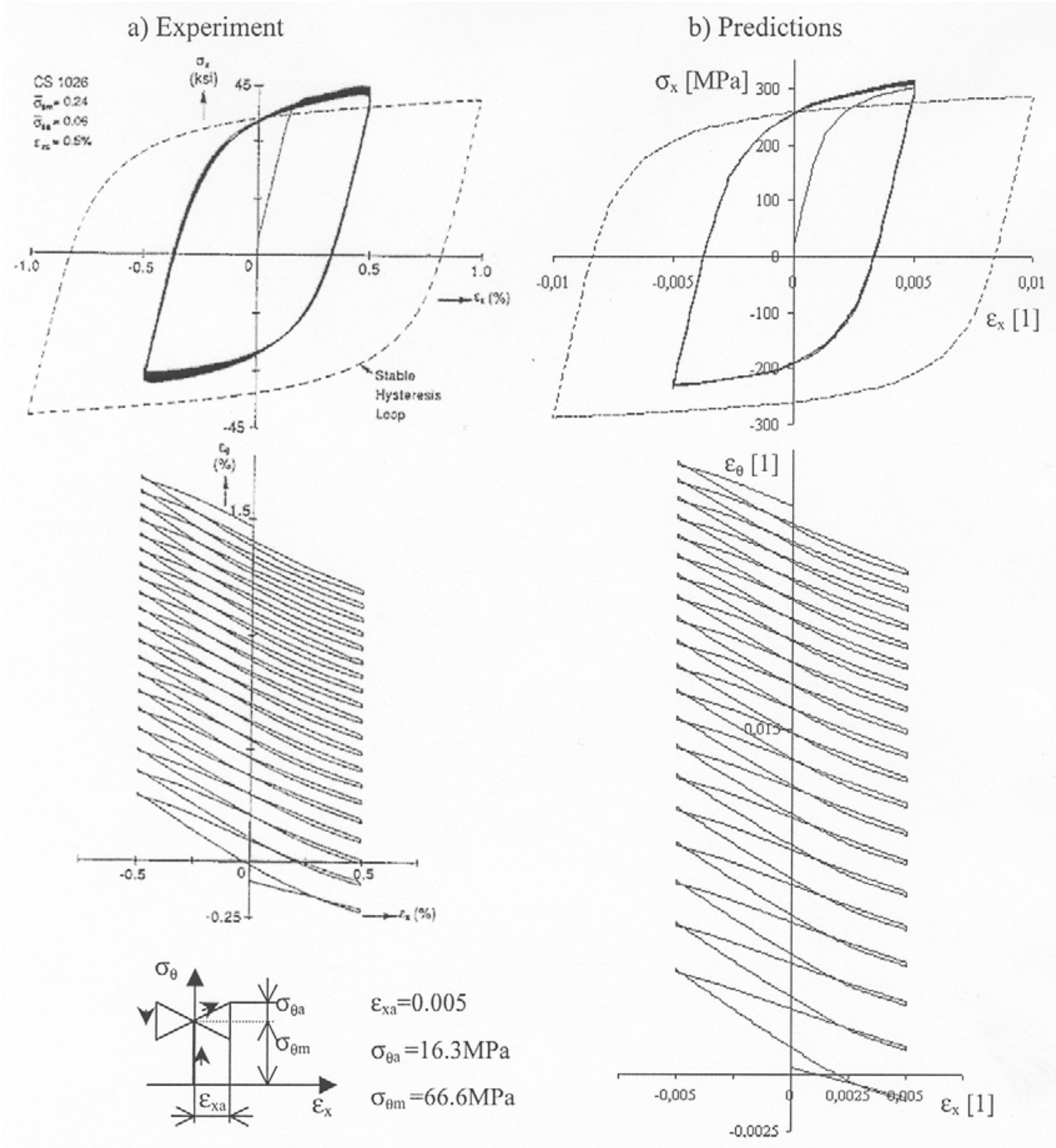

Fig. 5 – Biaxial ratcheting response of CS1026 for bow-tie loading history:
a) experiment (from [6] and [7]), b) predictions

Conclusions

The paper shows some possibilities of the modified cyclic plasticity model of Abdel Karim and Ohno in modelling uniaxial and biaxial ratcheting with various loading histories. For this purpose, the experimental data from Hassan and Kyriakides [5], Hassan et al. [6] and Corona et al. [7] were used. The proposed model was implemented into the FEM software Ansys8.0 [8] and gives much better results than the Chaboche model, included in the SW package. On the other hand, the proposed model needs at least one multiaxial test for the estimation of established nonproportional parameter. The developed model was used also in the repeated rolling and sliding contact analysis with satisfactory results [8]. Consequently, non-isotermal conditions [9], visco-plasticity and other effects could be assumed in future works.

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Recenzent: prof. Ing. Jiří Lenert, CSc.