ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XX, NR. 2, 2013, ISSN 1453 - 7397

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Examination of Cyclic Plasticity Models Under Uniaxial Loading by Finite Elements Method

One of the main characteristics of the existing plasticity theories is the lack of a theory and specific equations for them. There are various methods with different results for solution of a plasticity problem. In this paper, two cyclic plasticity models of non-linear (Chaboche) and multilinear (Bessel) kinematic hardening are evaluated based on experimental data for 1% Cr-Mo-V steel alloy. Uniaxial loading on the specimen in seven steps is done by control stress method and using Ansys software. In each step, strains of elastic, plastic and then total have been calculated. The values obtained from simulation compared to experimental results is shown a good agreement on the both results, particularly in non-linear solution.

Keywords: Plasticity Models, Cyclic Kinematics, Plastic Strain, Finite Element Method.

1. Introduction.

Practically, many industrial components under loading in the plastic zone entered and a certain amount of energy in the material is stored as residual energy. Failure in those will occur when accumulated energy is equal to the energy needed for fracture. This strain energy from cyclic strain-stress curve of material is calculated by integrating of elastic and plastic components. The strain status in the elastic region can be evaluated using stress situation but plastic deformation depends to the loading history. Different behavior of Plastic strains is due to softening and hardening effects. Therefore, calculation of plastic strains is the most essential step in evaluation of plastic behavior of a structure. For this reason, it is necessary to provide constitutive equations or a model to determine plastic strain incremental during pass from elastic region. Moreover, numerous plasticity models has been proposed so far to estimate the material cyclic deformation[1-3]. But these models are not able to predict material behavior under all loading conditions. Therefore, different models are used for various loading conditions. Two important plasticity models that is used by Ansys software are Bessel[4] and Chaboch[5] models. In the recent years, many researchers have compared performance of the different plasticity models with experimental results[6-8]. In this study, strains calculated from the cyclic plasticity models are evaluated by finite element method for 1% Cr-Mo-V steel alloy. The analyse is carry out using multi-linear (Bessel) and non-linear (Chaboch) kinematic hardening models under similar loading and their results will be compared with experimental data [9, 10].

2. Research Theory

In order to predict material behaviors, calculation of elastic and plastic strains under different loadings is necessary. For calculation of plastic strain when stress field is known (the material is yielded at least at one point), must define the differential relationship between strain and stress in the material. Assuming that loadings history and residual strains impress the current strains, can by using appropriate hypothesis and valid yield functions calculate the values of partial increase of strains due to partial increase of stresses. These values can be added to the previous values to obtain the total strain at the end of loading:

$$\varepsilon = \varepsilon_e + \varepsilon_p \tag{1}$$

In formulating these relations, the hardening property will be introduced in the calculations in linear or non-linear forms. Before providing the relations of the models, the conditions necessary for prediction of the behavior of a hardening material should be provided.

2.1 Hardening Law

When an object is affected by plastic deformation, its resistance to the subsequent deformations will be increased. This phenomenon is called hardening. Physically, hardening is increase of the dislocations density and since dislocations tend to interlock and inhibit the movement of each other, the stresses should increase to develop plastic deformations. Indeed, hardening law shows the change of yield surface with increase of plastic strain. In this situation, yield equation should be satisfied by increasing the plastic strain. The kinematic and isotropic hardening laws are available. Furthermore, for modeling the more complicated behavior of material combine the two above mentioned states is possible. The isotropic hardening does not have the capability of simulation in cyclic loading. For this reason, kinematic hardening models are used.

2.2 Kinematic Hardening

In a kinematic hardening law, it is assumed that the center of yield surface moves like a rigid body in stress space without any change in the initial size of the yield surface. This kind of hardening is generally classified into three groups: Bilinear, multi-linear and non-linear. As mentioned before, in this study, two kinds of plasticity models, namely non-linear and multi-linear hardening, will be evaluated.

2.2.1 Chaboche Non-linear Kinematic Hardening

In this model, a stable hysteresis curve is divided into three critical sections: initial high module at the beginning of yield, transient non-linear segment (knee of the hysteresis curve) and constant module in the range of higher strain. The Chaboche used three analyzed stiffness laws (m=3) to refine the simulation of hysteresis loops. In each step of loading, three analyzed functions are summed and a (X) function is obtained which shows the center of yield surface in that loading. The center of final yield surface or backstress at the chaboche model will be defined by Eq. 2 [5].

$$dX_i = \frac{2}{3} C_i d\varepsilon^p - \gamma_i X_i dp \quad \text{where } i = \mathrm{i} = 1,2,3 \text{ and } dp = \left| d\varepsilon^p \right| \tag{2}$$

Where, dX denotes the tensor of deviational stresses which shows the center of yield surface and γ_i and C_i are material constants that are obtained based on experimental results. *dp* is the plastic cumulative strain and $d\varepsilon^p$ is the plastic strain.

2.2.2 Bessel multilinear kinematic Hardening Model

The material behavior is assumed to be composed of various portions(or sub-volumes), all subjected to the same total strain, but each sub-volume having a different yield strength. (For a plane stress analysis, the material can be thought to be made up of a number of different layers, each with a different thickness and yield stress). Each sub-volume has a simple stress-strain response but when combined the model can be represent complex behavior. Each segment has a constant tangential modulus $E_i^t(i = 1,2,\ldots n)$. The stress-strain relation for any one of the linear segments is given by Eq.3 [4]:

$$d\varepsilon_i = d\varepsilon_i^e + d\varepsilon_i^p \qquad (i = 1,2,\ldots n) \tag{3}$$

when,

$$\begin{cases} d\varepsilon_i^e = d\dfrac{\sigma}{E} \\ d\varepsilon_i^p = d\dfrac{\sigma}{E_i^p} \end{cases}$$

where *E* and E^p are the elastic and plastic module, respectively.

Since, elastic modulus *E* remains constant during the deformation, this equation means that the association of the tangential modulus E_i^t to each of the linear segments is equivalent to assigning E_i^p to the Ith segment.

Moreover, the backstress at the Bessel model is obtained by Eq. 4 [4].

$$dX_i = d\mu_i(\sigma_{i+1} - \sigma) \quad (4)$$

where, $d\mu$ is proportionality coefficient.

3. Simulation results and discussion

3.1 Simulation method

Initially, the specimen model was modeled based on ASTM E2207 Standard by Ansys software,as is shown in Fig. 1.

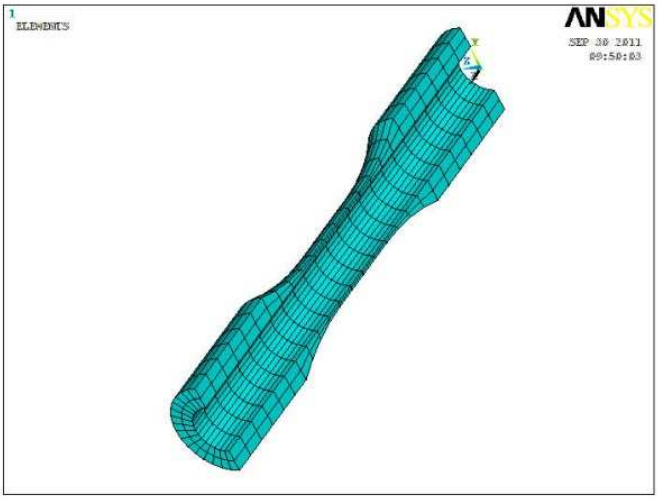

Figure 1. Modeled specimen

The coefficients necessary of software for analysis using non-linear and multilinear kinematic hardening plasticity models are elasticity module and Poisson ratio with amounts 207 Gpa and 0.3, respectively. Specific coefficients needed by software to analyze using Chaboche model are C1, C2 and C3 whose values are obtained as 11235.5, 13267.2 and 13961.8 MPa, by using mentioned theories and applying a computer solution program [11]. Also, in order to analyze using multilinear hardening plasticity model, one should know strain and stress values of plastic part obtained from experimental results and these values should be used with Poisson ratio and elasticity module.

Loading is performed by control stress method and imposing displacement. The displacements are illustrated in Table 1.

Table 1. Displacements at different steps of loading

Loading steps	step 1	step 2	step 3	step 4	step 5	step 6	step 7
Displacement (m)	0.001	0.0012	0.0013	0.0014	0.0016	0.0018	0.002

3.2 Results and discussion

From Fig. 2 can be seen that elastic strains obtained from Bessel multilinear solution are more different than Chaboche non-linear solution in the loading condition. Therefore, it determine strain values in a higher range than to empirical strain. The average difference of results in Bessel and Chaboche are 32% and 58%, respectively.

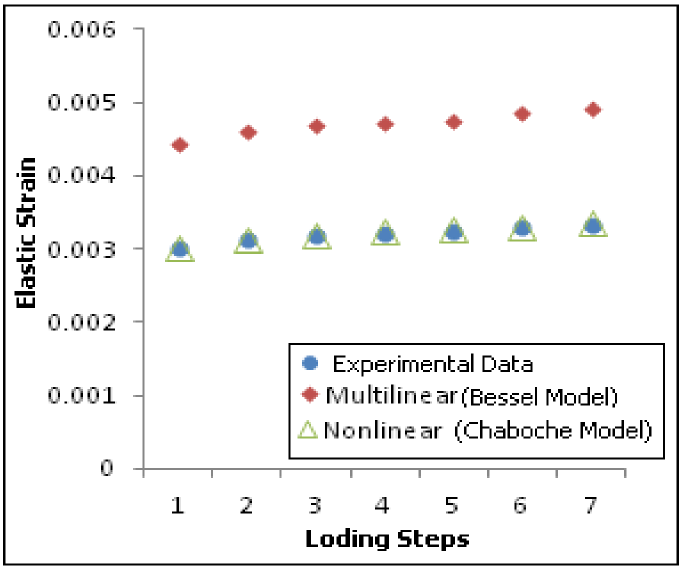

Figure 2. Elastic strains

In the solution of the Chaboche non-linear model, the values of plastic strain are calculated more accurately and with minimum error. However, Bessel multilinear solution is more different from experimental results at lower range (Fig. 3). Amounts calculated for these models show less difference compared to amounts obtained from elastic strain. For Bessel and Chaboche models, the average difference of values compared to experimental results is 15% and 1.7%, respectively.

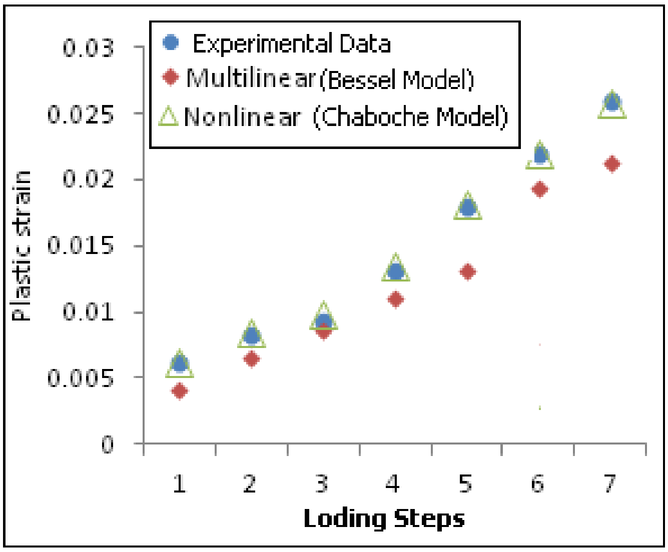

Figure 3. Plastic strains

Fig. 4 shows results of non-linear model solution have more agreement with experimental data than those of multilinear model for total strains. This was also observed in elastic and plastic strain part.

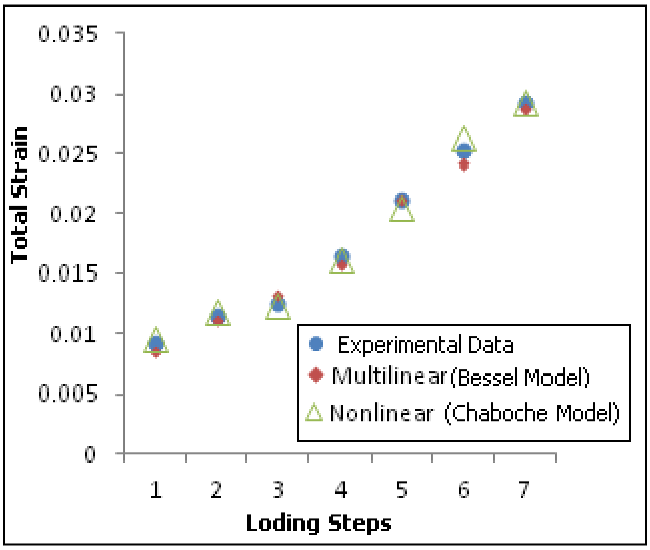

Figure 4. Total strain

The elastic and plastic strains in the Bessel model were located in high and low ranges of experimental curve and for this reason, the total strain resulted from them shows more appropriate results. It can also be observed that maximum and critical strains zone is localized in the non-linear model. While, in the Bessel multilinear model of Von Mises maximum strain zone is more extended because the values of elastic strain are more and effective in plastic zone in every step of loading.

4. Conclusions

Two kinematic plasticity models were used to evaluate of behavior of 1% Cr-Mo-V steel alloy under cyclic tensile loading. From the comparison of the values of elastic, plastic and total strains obtained from the two models with empirical results, it can be concluded that in analyzing problems for this alloy, elastic strain values in the Bessel multilinear model should not be used. The plastic and total strains in both models have shown acceptable results. In general, Chaboche non-linear model provides more accurate responses and is more appropriate for analysis of cyclic loadings in the alloy.

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