# DESCRIPTION OF CYCLIC HARDENING OF MATERIAL WITH PLASTICITY INDUCED MARTENSITIC TRANSFORMATION

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## 1. Introduction

The martensitic transformation takes place in the wide group of austenitic steels mainly with high manganese or nickel content and may be caused by various reasons like: temperature, stress or plastic strain. The phase transition process may substantially affect strength properties such as: monotonic and cyclic hardening, corrosion resistance, fatigue life, magnetic sensitivity, etc. The phenomenon of mechanically induced martensite evolution was extensively investigated mostly by Olson and Cohen [1]. They assumed that there are two modes of transformation: *stress-assisted* and *strain-induced martensite*. These modes correspond to different generation of the nucleation sites and to different morphologies of martensite in a form of plate or lathlike structures. The range of temperature variation specifies the area of process of a suitable type.

- *Stress-assisted martensite* – The plates of martensite form at the presence of stress. The process is similar to that occurring spontaneously during cooling at the stress level not exceeding the yield point of the austenite, [2].
- *Strain-induced martensite* – The lathlike martensite [2, 3] forms as a consequence of plastic straining. This process may take place at a higher temperature above $M_s$ level than that occurring during martensite formation in the cooling process (about $200C^o$ higher [2]).


Fig.1. The lathlike martensite – AISI 304 steel [3]

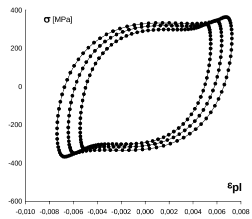



Fig.2. Experimental hysteresis loops [4]

The microscopic picture of the lathlike structure of martensite induced during cyclic deformation is presented in Fig. 1 and the hysteresis loops are shown in Fig.2. The examined cylindrical specimens were made of AISI 304 steel.

The present work aims at description of inelastic material response with plasticity induced martensitic transformation during cyclic deformation. The appearance of martensite changes not only the strength and cyclic properties but also deformation response of material under external load i.e., the form of hysteresis loop, (Fig. 2.). The constitutive equations are required to simulate deformation response of material for complex deformation paths and the related evolution of martensitic phase.

## 2. Material model – main assumptions

Phenomenological constitutive equations are formulated within the framework of irreversible thermodynamics with internal state variables. The volume fraction of martensite ($\xi$) is the most popular macroscopic internal variable specifying the growth of martensitic phase [5] .The evolution equation for this parameter together with suitable model of plastic deformation provides description of the response under monotonic and variable loading. The two-phase material is treated as a thermodynamic system with two coupled irreversible processes namely, plastic deformation and phase transformation. Thus, two conditions of process occurrence must be formulated.

(1) $$F_p = \sqrt{\tfrac{3}{2}(s_{ij} - X_{ij} - f_{ij}(\mathrm{Y},\xi))(s_{ij} - X_{ij} - f_{ij}(\mathrm{Y},\xi)} - R_p \le 0$$ the yield condition.

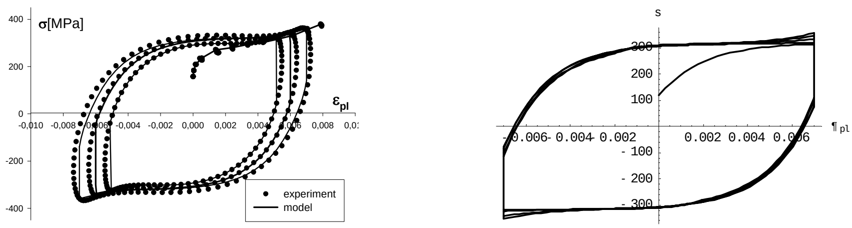
(2) $$F_{tr} = \sqrt{\tfrac{3}{2}(X_{ij} - Y_{ij})(X_{ij} - Y_{ij})} - R_{tr}(\Sigma) \le 0$$ the transformation condition.

Where $s_{ij}$ is the stress deviator. The yield condition (1) takes a familiar Huber-Mises form, but the tensor representing the additional translation of yield surface is specified by the deviatoric tensor $f_{ij}$ related to the back stress $X_{ij}$. Equation (2) represents the transformation condition. The radius of the transformation surface depends on the generalized force $\Sigma$ conjugated to the internal parameter $\xi$. The translation of the yield surface depends on the deviatoric tensor $Y_{ij}$ which represents the center of transformation surface. The proposed model was analyzed assuming the tensor $f_{ij}$ in the form:

(3) $$f_{ij} = a(\xi)\left(\sqrt{\tfrac{3}{2}Y_{kl}Y_{kl}}\right)^n Y_{ij} = a(\xi)\left(Y_e\right)^n Y_{ij}\,.$$

## 3. Identification of model parameters and simulation

The identification of model parameters was carried out for austenitic steel AISI 304, on the basis of experimental data for the steady state of cyclic tension and compression. Next, the simulation for uniaxial and biaxial states was performed taking into account first cycles of loading. Examples of identification and simulation are presented in Fig. 3.




a) b)

Fig. 3. Hysteresis loops: a) the experiment and identification, b) the simulation.

## 4. References

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