# CYCLIC BEHAVIOR OF ULTRA HIGH MOLECULAR WEIGHT POLYETHYLENE (UHMWPE) AND MODELING

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**Abstract**

Cyclic stress-strain responses of ultra high molecular weight polyethylene (UHMWPE) are investigated under different load control modes. Uniaxial and biaxial experiments are conducted under strain and stress controlled load reversals. One of the unified state variable models, Viscoplasticity Based Overstress (VBO) model for polymers [1] is used to simulate the recored cyclic responses of UHMWPE. The model does not include any yield surface and loading and unloading conditions. Apart from many existing work in the literature, material parameters for VBO are determined using the genetic algorithm (GA) optimization procedure which is constituted using MATLAB Genetic Algorithm and Direct Search Toolbox.

Thermoplastics like ultra high molecular weight polyethylene (UHMWPE) have been used for a wide variety of applications, such as gears, unlubricated bearing, seals and in the field of biomechanics due to biocompatibility. Accurate prediction of stresses and deformation in service conditions is essential to the designer and finite element analyzer.

## 1. Experiments

For understanding the material behavior of UHMWPE under cyclic loading and evaluating a constitutive model for simulating cyclic responses, a set of material experiments under stress and strain controlled, uniaxial loading cycles are conducted. Tubular, dog-bone shaped specimens are machined from UHMWPE solid rods for conducting these tests. The strain-controlled uniaxial experiments involved monotonic loading up to 40% strain and cyclic loading with various strain-amplitudes. In both cases the prescribed loading rate is kept constant at 0.1%/second. Recorded axial stress-strain response from a cyclic strain-controlled experiment with 3% amplitude cycle is shown in Fig. 1. Stable hysteresis loop response is demonstrated by UHMWPE in this figure. The uniaxial stress-controlled cyclic experiments were conducted by prescribing various stress amplitudes and means, and loading rates. Response from such an experiment with the amplitude stress, 12.5 MPa prescribed at a rate of 0.77 MPa/ second is shown in Fig. 2. As the mean stress prescribed in this experiment is zero, no axial strain ratcheting is obtained. However, after ten such cycles when mean stress is increased to a nonzero value axial strain ratcheting is obtained (not shown).

## 2. Modeling

Cyclic behavior of UHMWPE in different grades and cross-linking has been the object of many researches in the field of biomechanics. Experimental studies have shown that strain softening is observed due to the morphology changes [2]. Even though there are some experimental studies in the literature, there are not many papers dealing with modeling of cyclic behavior of UHMWPE due to the difficulty of simulating viscous effects. In this work, VBO is used for modeling cyclic behavior of UHMWPE. Theory consists of two tensor values state variables, equilibrium and kinematic stress, and a scalar isotropic stress. Flow law is given in Eq.1. Inelastic strain rate is function of overstress which is the difference between Cauchy and equilibrium stresses ($\boldsymbol{o} = \boldsymbol{s} - \boldsymbol{g}$).

$$\dot{e} = \dot{e}^{el} + \dot{e}^{in} = \frac{1+\nu}{CE}\dot{s} + \frac{3}{2}\mathrm{F}\left[\frac{\Gamma}{D}\right]\left(\frac{s-g}{\Gamma}\right) \tag{1}$$

where $s$ and $g$ are the deviatoric part of the Cauchy ($\sigma$) and the equilibrium stress ($G$) tensor, respectively. The equilibrium stress ($G$) is nonlinear, rate-independent and hysteretic. Its evolution equation in deviatoric form is given as:

$$\dot{g} = \Psi\frac{\dot{s}}{\mathrm{E}} + \Psi\,\mathrm{F}\left[\frac{\Gamma}{\mathrm{D}}\right]\left(\frac{s-g}{\Gamma} - \frac{g-k}{\mathrm{A}}\right) + \left(1 - \frac{\Psi}{\mathrm{E}}\right)\dot{k} \tag{2}$$

where $k$ is the deviatoric kinematic stress, which is the repository for the modeling of the Bauschinger effect. $A$ is the isotropic stress, rate independent contribution to the stress, which is responsible for modeling hardening or softening. The evolution equation for the kinematic stress in deviatoric form is,

$$\dot{\mathbf{k}} = \bar{\mathrm{E}}_t \dot{\mathbf{e}}^{in} \tag{3}$$

where $\bar{E}_t = \dfrac{E_t}{1 - \dfrac{E_t}{E}}$ and $E_t$ is the tangent modulus.

For more information about model, see Dusunceli and Colak [3].

## 3. Results

Simulation and experimental results of fully reversed symmetric cyclic loading under strain and stress-control modes is depicted in Fig.1 and 2.

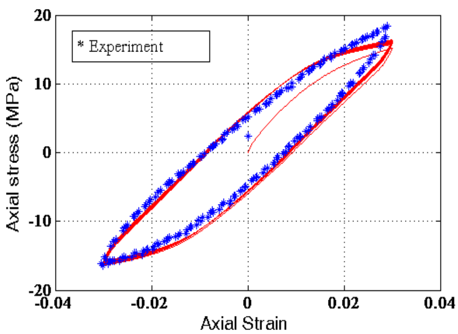


Fig.1 Strain controlled uniaxial loading at the strain rate of 1.E-3 /s.

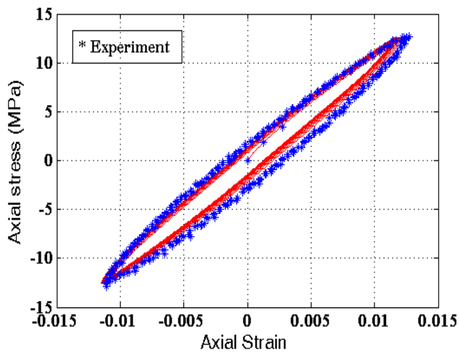


Fig.2 Stress controlled uniaxial loading at the stress rate of 0.77 MPa/s.

## 4. References

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